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JET Experience on Managing Radioactive Waste and Implications for ITER

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The reduced radiotoxicity and half-life of radioactive waste arisings from nuclear fusion reactors as compared to current fission reactors is one of the key benefits of nuclear fusion. As a result of the research programme at the Joint European Torus (JET), significant experience on the management of radioactive waste has been gained which will be of benefit to ITER and the nuclear fusion community.

The successful management of radioactive waste is dependent on accurate and efficient tracking and characterisation of waste streams. To accomplish this all items at JET which are removed from radiological areas are identified and pre-characterised, by recording the radiological history, before being removed from or moved between radiological areas. This system ensures a history of each item is available when it is finally consigned as radioactive waste and also allows detailed forecasting of future arisings. All radioactive waste generated as part of JET operations is transferred to dedicated, on-site, handling facilities for further sorting, sampling and final streaming for off-site disposal. Tritium extraction techniques including leaching, combustion and thermal treatment followed by liquid scintillation counting are used to determine tritium content.

Recent changes to government legislation and Culham specific disposal permit conditions have allowed CCFE to adopt additional disposal routes for fusion wastes requiring new treatment and analysis techniques. Facilities currently under construction include a water de-tritiation facility and a materials de-tritiation facility, both of which are relevant for ITER. The procedures used to manage radioactive waste from generation to off-site disposal have been assessed for relevance to ITER and a number have been shown to be significant. The procedures and de-tritiation factors demonstrated by radioactive waste treatment plants currently under construction will be important to tritium recovery and waste minimisation in ITER and DEMO.

Keywords: *Fusion, Radioactive, Waste Management, Tritium, JET, ITER.*

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** *See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia*

1. Introduction

The reduced radio-toxicity and half-life of radioactive waste arisings from nuclear fusion reactors as compared to current fission reactors is one of the key benefits of nuclear fusion. As a result of the research programme at the Joint European Torus (JET), Culham Centre for Fusion Energy (CCFE), the nuclear fusion research arm of the United Kingdom Atomic Energy Authority (UK AEA), has gained significant experience in the management and disposal of radioactive waste which will be of benefit to ITER, DEMO and the nuclear fusion community, although, it is acknowledged that other devices will have a larger tritium inventory and neutron activation than JET. Activities which form part of JET operations generating radioactive waste include maintenance and upgrade of components and diagnostics which make up the JET machine, maintenance of the Active Gas Handling System (AGHS) and support activities. Generated radioactive waste comprises solid, organic liquid, aqueous and gaseous forms which can be contaminated with tritium, activated by neutron absorption or both. Of the non-radiological hazards associated with the waste, beryllium contamination has the largest impact on waste operations due to the low airborne exposure limits.

When processing radioactive waste for onward disposal, CCFE must comply with the Ionising Radiation Regulations (IRR) 1999 and CCFE's environmental site

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permit issued under the Environmental Permitting Regulations (EPR) 2010. Under this permit radioactive waste is categorised into;

- Out of Scope of Regulation (OSR) defined based on a nuclide specific level, for re-use, recycling or disposal without the need for regulatory control;
- Low Level Waste (LLW) defined as less than 12,000 Bq/g total beta/gamma emitters;
- Intermediate Level Waste (ILW) defined as greater than 12,000 Bq/g and;
- High Level Waste (HLW) defined as heat generating waste.

Each category is generated as part of JET operations with the exception of HLW. Under CCFE's permit there are no restrictions on available disposal routes, the only restriction is that any site receiving waste must be permitted under EPR 2010 to accept the specific type of waste for disposal and ILW can only be transferred to a Nuclear Licensed Site for interim storage. The regulator imposes time, total radioactivity and volume restrictions on the accumulation of radioactive waste stored on the JET site as well as limits to aqueous and gaseous discharges.

A number of dedicated waste handling facilities and analysis laboratories have been constructed to allow efficient and cost effective processing; characterisation and disposal of solid and organic liquid radioactive waste generated as part of JET operations. Current waste handling facilities include a generic waste processing facility for processing low-beryllium contaminated drummed waste, a pressurised suit facility for processing high-beryllium and/or tritium contaminated waste and a facility for processing low-beryllium and low-tritium contaminated large items. Analysis laboratories available include a tritium analysis laboratory utilising combustion, a liquid scintillation counting laboratory, a beryllium analysis laboratory utilising fluorescence spectroscopy and a newly developed gamma analysis laboratory. Although there are currently no waste treatment facilities designed to down categorise waste, a Materials Detritiation Facility (MDF) and Water Detritiation System (WDS) are under construction.

Although ITER will be subject to French radioactive waste regulations, and as such will have different disposal routes available, the waste management, procedures and experience will be relevant as these generally apply to all types of radioactive waste regardless of disposal route. As part of the EUROfusion Task JET Work Package 3 [See Section 4.5], CCFE are leading the Waste Production and Characterisation sub-project, a project envisaged to pass on all lessons learnt from the upcoming Tritium and potential Deuterium Tritium Experiments.

This paper will detail each stage in the process of managing of radioactive waste generated as part of JET operations

2. Waste Management of JET Operational Waste

2.1 Site Management

2.1.1 Site Layout

Figure 1 depicts the layout of the buildings on the JET site. As can be seen, the solid waste handling facilities are situated within the JET building boundary but within sufficient space to facilitate expansion.

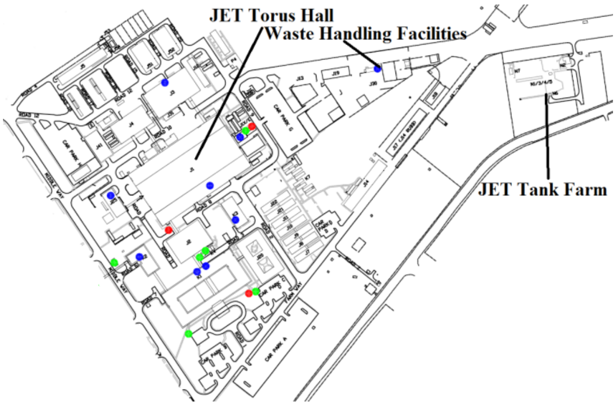

Fig.1. Layout of JET Buildings.

2.1.2 Waste Types

The main waste types generated as a consequence of JET operations include soft waste, suitable for incineration, generally composed of personal protective equipment and hard and metallic waste from equipment and JET configuration changes. Soft waste is typically contaminated with surface and absorbed tritium and is not currently decontaminated due to the availability of suitable disposal routes. Hard waste can be contaminated with surface and bulk tritium with surface treatment techniques potentially available to decontaminate surface contamination.

2.1.3 Waste Processing Facilities

As part of waste processing a number of dedicated processing facilities to handle the specific waste types generated as part of JET operations have been constructed.

The Waste Handling Facility (WHF) was constructed in 1992 and commissioned in 1993 and was the only dedicated waste processing facility for JET operational waste until 2009. The facility processes waste that has been stored in drums, typically 200 litre UN approved steel transport drums, although high density polyethylene containers are also used to store certain wastes. Compactible radioactive waste suitable for incineration is processed in this facility including sacrificial flooring, personal protective equipment and general housekeeping waste. Waste packages are opened in a slit-box, an enclosed waste processing box with forced ventilation, sorted, segregated, sampled and compacted into packages suitable for off-site disposal. This process typically provides an 8:1 volume reduction. The Waste Handling Facility has a hard waste cutting room that can be used to size reduce waste with lower tritium and beryllium contamination, defined by local extract ventilation capacity, which also provides the ability to process and sample organic liquid waste. Current facility throughput is approximately 16,000 kg of radioactive waste per year.

The Bulk Un-suited Facility (BUF) was built in 2009 and was originally designed as a facility to package LLW into third height ISO freight containers. Following the introduction of the Environmental Permitting Regulations in 2010 the facility was re-designated as a facility to process large items with very low levels of tritium, neutron activation and beryllium contamination. Part of the reason for the change was due to the Out of Scope of Regulation (OSR) level for tritium of less than 100 Bq/g which allowed a significant proportion of waste from JET operations to be reclassified as OSR, but was also due to the UK's Low Level Waste Repository (LLWR) imposing stricter waste acceptance criteria for disposal of radioactive waste. The facility is able to handle very large bulky items of waste not suitable for the Waste Handling Facility and processes approximately 20,000 kg of mixed radioactive waste per year.

The Bulk Suited Facility (BuS) was constructed in 2013/14 and began processing in October 2014, this is a purpose built facility to allow processing of high tritium and or beryllium contaminated items by utilising pressurised suit operations. It has also been designed to handle ISO container docking and bulk items too large to be processed in the WHF slit-box. Waste is brought into the processing area by either docking an ISO freight container to the facility or by loading wrapped or drummed waste into an airlock. Depending on the form and complexity of waste to be processed the approximate throughput of the facility is 20,000 kg/year.

The Radioactive Drainage System (RDS) links all main low level tritiated water-producing JET areas including the JET Torus Hall and Basement, the Beryllium Handling Facility, the Suit Cleaning Facility and the Health Physics (HP) Laboratories and connects them, using a subterranean pipe network, to the Radioactive and Trade Effluent Tank Farm. Water is discharged under a Waste Management Interface Number [See Section 2.2.2] to ensure acceptability, is then sampled to ensure compliance, and discharged to the Trade Effluent System for onward discharge into a local water course under a Permit issued by the UK Environment Agency. A number of areas on the JET site which do not have an automatic connection to the Radioactive Drainage System use a UN Approved Intermediate Bulk Container (IBC) to collect Radioactive Aqueous waste which is transferred to the Tank Farm using the electronic On-site Radiological / Beryllium Transfer System [See Section 2.3.4] and discharged directly to the Radioactive Drain storage tanks [See Section 2.41].

2.1.4 Management Systems and Corporate Structure

Waste Management Group is part of the Power and Active Operations Department (P&AOD) and is a separate entity from Safety, Health and Environment Group. This structure allows close co-operation between the main producers of radioactive waste, while also ensuring no conflict of interest with the Safety, Health and Environment group.

Health Physics Group have a close working relationship with Waste Management Group and are involved in the protection of personnel working with radioactive waste; from defining personal protective equipment in radiologically controlled areas [See Section 2.2.2] to approving final disposal activity assessments for the transport of off-site disposals. A number of Radioactive Waste Advisors (RWAs) are also members of the Health Physics group and provide specialist advice to the whole JET site.

All site waste procedures are hosted on an internal Management Systems Intranet Portal, this provides instant access to any waste Responsible Officer with computer access, these procedures are interactive and allow a waste producer to follow through the process answering simple questions on waste types to determine the most appropriate actions to be taken to consign waste to Waste Management Group.

2.1.5 Waste Data Systems

The Waste Data Systems currently used are an integral part of the entire life cycle of waste management and link each stage allowing full traceability of item history. The systems currently employed are bespoke Microsoft based systems, developed in-house by embedded staff in Waste Management Group. The use of embedded developers familiar with waste management practices ensures close collaboration on a day to day basis with waste producers, waste processing operators and management to ensure systems are fit for purpose, can adapt quickly to changing user requirements and do not incur significant support and update costs which could result if third party systems were used.

The use of Microsoft based systems ensures users are presented with familiar design and layout, simple integration with other Microsoft Office programs for automated notification emails, standardised Microsoft Word Templates for consignor documentation and data export into Microsoft Excel for data analysis. The added benefit of using Microsoft based systems ensures any future systems development staff require less training before being able to provide support.

2.1.6 Training and Competencies

CCFE employs an appointments system managed by the Learning and Development team to track training and competencies of key staff in the waste management process. All training and appointments for staff external to waste management group are tracked and automatic reminders to refresh training are issued by the Learning and Development system using their in-house developed Course Booking system. There are two specific training packages for radioactive waste producers; Responsible Officers (ROs), who control waste generating tasks and Area Waste Officers (AWOs) who provide specialist guidance to ROs and liaise with Waste Management Group. Within Waste Management and Health Physics Group are a number of Radioactive Waste Advisers, a defined role under the Environmental Permitting Regulations 2010, as radioactive waste experts providing specialist guidance to the JET site. Training, including working experience, within Waste Management Group is tracked using the groups Training Data System; this system links in to the Waste Task Planning System ensuring all waste processing operators selected for a task are competent before being assigned work.

2.2 Preparation

2.2.1 Waste Management Interface System

At the conception stage of a potentially waste producing task the Responsible Officer completes a Waste Management Interface (WMI) form. This form is used to declare the potential of radioactive waste production to Waste Management Group and allow for specialist guidance to be provided to an RO on applying the waste hierarchy [See Section 2.3.2] within the bounds of available processing and disposal options. Information added to the WMI form includes the physical form of the waste, estimated total arisings, estimated activity and contamination levels, and rate of arisings and is used to allow efficient planning of waste collection and processing campaigns, ensure temporary storage requirements will be suitable and ensure suitable waste transport packages will be provided.

2.2.2 Health Physics Radiologically Controlled Areas

Health Physics Group manages the Radiological and Beryllium Controlled Areas system. Each area involved in JET operations that will produce tritium or beryllium contaminated or neutron activated waste is assigned a unique area reference number and specific local rules dictating emergency procedures, monitoring requirements and personal protective equipment requirements. Each area is also given a designation of high, medium or low for tritium, beryllium and radiation levels expected to be associated with working in the area and any items or waste transferred from the area. The unique area reference number is used to store all details of radiation dose rates, tritium and beryllium smear surveys and tritium in air results during the lifetime of the area. The area reference number is also used for all transfers of equipment or waste entering or leaving the area, information which follows each waste package until off-site disposal. Waste Management Group specifically uses the reference number to group waste into processing campaigns [See Section 2.5.1] of similar waste types and to interrogate historical arisings during review of the WMI form [See section 2.2.4] prior to a waste-generating task being started.

2.2.3 Radioactive Inventory and Spares

Not all items entering or exiting a radiologically controlled area will become waste; depending on the operational value and use, tools and spare components may be required for retention and re-used on other tasks. In this case Waste Management Group use a Radioactive Inventory Management System to track each item and allow a history of use to be built up for each item which will be used to define waste processing, characterisation and disposal practices once the item is declared as radioactive waste. Each item is registered with a unique identification number which is marked on the item or packaging using laser etching or a label. Each electronic transfer record created for the removal or entry of these items must be subject to Waste Management Group approval to ensure items are not needlessly being retained and or duplicated; in addition, all records are continually monitored to ensure items are not being retained unnecessarily.

2.2.4 Waste Management Interface Officer

The Waste Management Interface Officer bridges the gap between Waste Management Group and waste producers on site and is a visible source of expert guidance and support in all waste producing areas.

2.2.5 Waste Acceptance Limits

The Safety Case developed for the waste handling facilities places strict limits on waste operators processing waste to ensure operator safety. These limits have been adopted by Waste Management Group by applying normal waste acceptance criteria [See Table 1]. Any waste falling within these limits is accepted routinely, however, waste that falls outside of the standard acceptance criteria may still be accepted with the completion of a deviation form and additional precautions put in place. This form is completed by the Area Waste Officer and signed by the Waste Acceptance Team and Radioactive Waste Section leader and defines all special requirements for waste storage and processing. The completed form is attached to the Electronic Transfer Certificate associated with the waste and is linked to each package through processing to final disposal.

Table.1. List of Waste Management Groups standard radioactive waste acceptance criteria.

Surface H3 Contamination	1.0 MBq/cm^2
Total Facility H3 Inventory	125 TBq
Package H3 Out-Gassing Rate	<1.5 GBq/day
Be Content	<0.1% by Weight
Be Surface Contamination	<100 μg/m^2
Radiation - Contact	<7.5 μSv/hr
H3 Single Package Limit	<40 GBq
Co60 Single Package Limit	<0.4 GBq
Single Soft Waste Bag Mass	<10 kg
Sharps and jagged items	Packaged to allow safe handling
Chemicals	Deviation Form required
Lead & Asbestos	No Limit
Pressurized vessels or Aerosols	Discharged only
Flammable liquids	Deviation Form required
Dusts and fines	<10 kg
Pyrophoric materials	Deviation Form

	required

2.3 Waste Generation

2.3.1 Monitoring

Once any task has begun the Health Physics technician assigned to the controlled area performs routine monitoring during the entire duration of the task. The level of monitoring is defined in the Health Physics Controlled Area system [See Section 2.2.2], specified in the local rules and is based on the specific tritium, radiation or beryllium designation. Monitoring includes tritium and beryllium smear surveys, tritium in air and gaseous stack discharge measurements.

2.3.2 Waste Hierarchy (Symbol)

The Waste Hierarchy adopted for management of radioactive waste generated as part of JET operations is adapted from Article 4 of the EU Waste Framework Directive, transferred into UK legislation in the Waste Regulations 2011 [See Figure 2]. This method must be combined with available and permitted radioactive waste disposal options and balanced with cost and potential environmental impact.

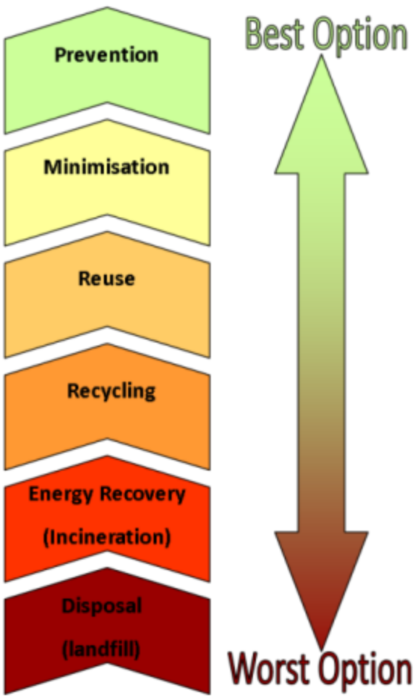

Fig.2. Waste Management Hierarchy applied to radioactive waste generated as part of JET operations (courtesy of www2.LE.ac.uk).

2.3.3 Packaging

Following the completion of the Waste Management Interface form [See Section 2.21] the Responsible Officer or Area Waste officer will contact the Waste Handling Facility Supervisor to request delivery of a suitable transfer package for any anticipated waste to be generated. These uniquely numbered packages are assigned to a Waste Management Interface number, and corresponding Area Waste Officer in Waste Management Groups Container Management System. Tracking all on-site transport packages ensures there is a sufficient stock of packages and, by using an automated emailing system, ensures packages are not kept in controlled areas for longer than 6 months preventing waste accumulation.

2.3.4 On-site Radiological / Beryllium Transfer System

In November 2011 the JET site switched from a paper transfer certificate system to an electronic based system. This system must be used for any movement of items into or removal from a Health Physics Controlled Area and tracks waste, spare equipment and tools. The system is split into four main transfer types: Waste, for any submission or movement of waste items; Holdings (Spare), for any radiologically controlled equipment or tools required for retention or re-use; Free, for any items tracked via another system, for example Radioactive Sources which are tracked via a dedicated register; Beryllium Only, for items moving between non-radiological areas. Every transfer type has a number of standard fields, including details of the transfer locations the item is being moved between, physical properties of the item(s) and a Radiological Activity Assessment. In addition to the standard fields Waste and Holdings (Spare) transfers have a number of specific fields. A Waste Transfer must include the Waste Management Interface Number [See Section 2.2.1] and the Area Waste Officer's name who is identified as an additional approver for the form. For Holdings (Spare) transfers the registered Inventory Number must be added along with the Responsible Officer for the inventory item this data is then transferred automatically to the Radioactive Inventory Management System [See Section 2.2.3] to ensure a history of radiological exposure can be derived for each item while also ensuring the Waste Hierarchy [See Section 2.3.2] is followed.

Each Transfer has three standard approval levels: Health Physics to assess and assign an estimated H3, Co60 and other Beta/Gamma activity, check packaging requirements and confirm compliance with The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009; the Health Physics Technician, who must ensure all transfer packages have been smeared to ensure no transfer of contamination and to confirm specific transfer restrictions; the receiving Responsible Officer who must approve to confirm acceptance. In addition to the standard approval levels, any Waste or Holdings (Spare) transfer must also be approved by Waste Management Group. Although almost entirely electronic, every item moved under the electronic system must have a paper version of the form, only printable once fully approved, to accompany it.

2.4 Waste Transfer

2.4.1 Transfer and Storage

Following the completion of a task in a radiologically controlled area, or during if a package has been filled, the Responsible Officer will complete the electronic on-site transfer form [See Section 2.3.4] to inform Waste Management Group of the request for collection. At this stage, depending on the results of any Health Physics monitoring [See Section 2.3.1], the Responsible Officer may request clearance from radiological control by completing a Health Physics Clearance certificate. This clearance, if granted, will allow the waste to be defined as Out of Scope of Regulation (OSR) and be consigned as controlled or hazardous waste as opposed to radioactive waste. The limit for OSR clearance in the UK, as defined in the Environmental and Permitting Regulations 2010 uses a nuclide specific summation rule; each quantified radionuclide must be fractioned to the OSR limit and the sum of fractions must be less than 1. Limits for nuclides currently encountered in waste generated as part of JET operations includes 100 Bq/g tritium, 0.1 Bq/g Co60, 100 Bq/g Fe55 and 100 Bq/g Ni63. As a safety margin Health Physics will only grant a clearance certificate for waste items if there is no history of neutron exposure and tritium levels are <10 Bq/g. All other waste must be consigned to Waste Management Group as radioactive waste; full characterisation is then undertaken to justify OSR classification

Once the electronic transfer form has been approved by all parties and accepted by the receiving officer the data is transferred to Waste Management Groups waste collection team via a mobile electronic tablet. The tablet contains all information associated with the waste and includes copies of emergency and normal operating procedures for reference, is used to record the temporary pre-processing storage location of the waste and transfers all data to the main Radioactive Waste Database.

2.4.2 Forecasting and Process Facilities

CCFE has, in collaboration with the JET Exploitation Unit, developed a detailed forecasting platform, linked into all Waste Management Groups radioactive waste tracking systems to forecast future waste arisings, processing and disposals, using long term JET operational campaign plans. Having accurate forecasts on radioactive waste production ensures suitable facilities and processes are in place prior to generation helping to reduce secondary waste arisings.

2.5 Waste Processing

2.5.1 Processing Plan and Target Lists

Before waste that has been stored following collection can be processed in the assigned waste processing facility the waste data is added to the Waste Management Groups Life Time Plan and Processing Management System, part of the Radioactive Waste Database. This system allows the Radioactive Waste Section Leader and each processing facility supervisor to group waste material types, with similar neutron, tritium and beryllium exposure to ensure sampling and analysis is consistent for each processing campaign and also to align with the off-site disposal plan and contracts.

2.5.2 Packing List System

Once waste has been identified on a processing campaign it is automatically added to the Packing List System part of the Radioactive Waste Database. This system is displayed on data entry terminals within the processing areas and allows waste operators to input data relating to the waste during processing. All data entry is reviewed by the facility senior operator or supervisor before becoming live data.

2.5.3 Waste Sorting and Segregation

As mixed waste packages are processed in all facilities the Packing List System enables operators to split original waste packages containing different material types into separate final disposal packages. The separation of material types minimises the error when sampling for tritium and performing gamma spectroscopy due to material variations in tritium permeability and neutron activation cross sections.

2.5.4 Sampling and Smearing

During waste processing all waste is sampled for tritium and beryllium contamination if applicable. For incinerable waste, a leach process is applied to determine tritium content, this process involves taking random pieces of material packed into a final disposal package to produce an initial sample of approximately 300 g. This sample is soaked in de-mineralised water for 4 weeks and periodically shaken to assist tritium liberation before liquid scintillation counting is performed on the water to determine the estimated tritium content, to allow for on or off-site transfer. Historical data suggests that the percentage of contained tritium leached is 25% [1] and as such a factor of 4 is applied to the sample to estimate total tritium content in the case of off-site transfer. Following drying of the leach sample, a 10 g sub-sample is taken of the remaining solid and combustion, tritium capture and liquid scintillation counting is performed on the sample in the Tritium Analysis Laboratory. This result is added to the leach result to determine final tritium specific activity of the final disposal package. CCFE is in the process of publishing a paper on this process including historical data. For other solid waste, not suitable for water soak, including metals, a representative sample is obtained using cold cutting techniques to minimise tritium release, and is either combusted or thermally treated to release tritium followed by liquid scintillation counting of captured tritium.

All samples collected have an associated time-limited spare sample collected concurrently, and stored in a manner which minimises degradation, to allow auditing or re-analysis if required.

2.5.5 Completing Packages

Once a final disposal package has been completed and all samples collected the package is physically closed and marked as such on the Radioactive Waste Database. Appropriate labels are generated from the database, applied to the top and side of each package and the package is stored pending off-site consignment. All spare samples are stored in a freezer until destruction certificates have been provided by the disposal contractor.

2.5.6 Gamma Spectroscopy

For final disposal of drums and containers containing items with suspected neutron radiation exposure a Gamma Spectroscopy campaign is completed following receipt of all other sampling analysis. This campaign is carried out by a specialist contractor on-site to determine final package dose rate and gamma emitting nuclide content.

2.6 Off-site Waste Disposal

2.6.1 Analysis and Analysis Tracking

Tritium and beryllium analysis samples, when sent for analysis, are grouped into batches related to processing campaigns, which can take up to four weeks for results to be received. As such, the Radioactive Waste Database has a specific sub-system to track all samples to ensure they are sent for analysis in the order they are created thus minimising storage time and ensuring off-site disposal consignments are completed in time to meet consignment contracts.

2.62 Consignment Selection

The off-site radioactive waste consignment process is managed using specific contracts with UK disposal sites able to accept radioactive waste. Each disposal package, prior to being selected for inclusion in a consignment is subject to a peer review process to check and confirm all data related to each item packed into the disposal package. This includes all data from each system including the Waste Management Interface form and the final packing list generated during waste processing. Consignments are typically grouped by material type, although, due to current limitations in acceptance criteria of available UK disposal contractors, total radioactivity is the limiting factor.

2.6.3 Documentation

All consignment documentation, including the disposal contractor's specific requirements are generated using standard templates and populated automatically using the Radioactive Waste Database data, this ensures accuracy by minimising data entry.

2.6.4 Selection and Consignment

Depending on the specific disposal route each package may be re-labelled using labels generated from the Radioactive Waste Database prior to package selection and disposal off site. Following receipt of the final disposal or destruction certificate the consignment is marked as disposed in the Radioactive Waste database and the final recipient and disposal or destruction date is added to the disposal package record. At this point any spare samples associated with disposed waste are themselves packed into a disposal drum.

2.7 Post Disposal Management

2.7.1 Record Management

Each disposal package record contained within the radioactive waste database, following final disposal or destruction certification, is locked to prevent any changes to data. Records are currently kept indefinitely, and data is backed up according to the UK Atomic Energy Authority's server policy, this includes on and off site electronic and physical tape backups.

2.7.2 Data / Trend Analysis

The Radioactive Waste Database is linked to all stages of the waste management process, and having data stored indefinitely allows data analysis on all radioactive waste generated since JET began operating in 1983. This data is especially useful to ITER to forecast tritium and beryllium content of anticipated waste to be generated as part of ITER operations. Due to the experimental nature of JET, operating schedules can change from year to year, including the forecast closure of JET. The data generated during waste processing allows evaluation of cost and environmental impacts due to amendments to the JET operating schedule and enables different scenarios to be modelled prior to agreement.

3. Key Lessons from JET for ITER

3.1 Early Involvement

During the lifetime of JET operations the attitude towards waste management within the nuclear industry and other industrial settings has changed significantly. Whereas in the past waste may have been stored for long periods before processing it is now key part of planning any project. As an example, in the latest JET Operating Contract, waste liability reduction has been given equal priority to JET plasma operations. The most important lesson from JET is the early involvement of waste management staff and advisors in any project likely to produce waste; this should be in place at conception stage to ensure that the waste hierarchy [See Section 2.3.2] is successfully applied, allow a project to be properly costed and thus inform project initiation decisions and ensure suitable pre-characterisation and provenance data can be collected which reduces final characterisation time and costs.

3.2 Regulators and Key Stakeholders

Early involvement and close collaboration with regulators and available disposal contractors is also an important lesson to be taken from experience gained during the management of JET operational waste. Radioactive waste from JET is significantly different from fission generated radioactive waste and as such may not be routinely accepted by nuclear disposal contractors without further justifications and agreement with regulators. This process can take a significant amount of time to complete and to prevent waste storage on site the earlier this process is begun the better.

3.3 Tracking and Approval

The waste management process needs to be as simple and efficient as possible for responsible officers, utilising automated tools and reminders where possible. During radioactive waste and Holding (Spare) inventory reviews it has been noted that for perceived difficult items, often responsible officers tend to retain waste as a spare rather than declaring as waste due to the difficulty in consigning. Since the introduction of the electronic on-site transfer system [See section 2.3.4] this practice has reduced significantly.

3.4 Review and External/Internal Auditing

Due to the experimental nature of JET there are many unique pieces of equipment used for specific operational campaigns. Historically it has been found that often responsible officers will declare items as spares to be retained for potential re-use; subsequent changes to the JET configuration then makes the equipment redundant. A regular review of all spare equipment should be undertaken to confirm continuing retention status and to account for orphan equipment due to responsible officers retiring or leaving the organisation.

3.5 Waste Quantities and Types

Historically, there has been a tendency to underestimate quantities of waste arisings generated as part of JET operations. This has, in part, been due to the significant secondary waste generated during waste processing itself; although this should be considered alongside the volume reduction achieved during processing of soft compactible waste. An engineered solution to achieve volume reduction and eliminate secondary waste arisings would be the ideal solution as available storage space for waste from JET operations would be insufficient without the current volume reduction achieved in the waste processing facilities. Separate processes for handling the differing waste types from fusion experiments should also be considered to minimise cross contamination, increase operator safety and potentially exploit different disposal routes including recycling.

4. Further work and development

4.1 Water Detritiation System

To further enhance successful implementation of the waste hierarchy a new tritium recovery system is currently under construction for tritiated condensate generated as part of JET operations. Historically this condensate was not considered waste due to its inherent value and was shipped abroad to recover tritium. The process will involve de-ionisation of the condensate followed by hydrogen isotope separation to recover tritium for re-use in JET experiments. As the system is still under construction no data is currently available to be included although data will be provided to ITER via the JET Work Package 3 EUROfusion sub-project.

4.2 Materials Detritiation Facility

Following upgrade of the JET tokamak to the ITER Like Wall configuration, a previous configuration of plasma facing tiles and components became waste. Currently this, and other highly tritiated waste, from JET operations is not acceptable for disposal in any UK disposal facility. To enable off-site disposal there is currently under construction a Materials Detritiation Facility designed to thermally treat solid materials, recover the thermally liberated tritium for re-use and down categorise the waste. Data on de-tritiation factors obtained using real fusion materials will be provided to ITER as part of the EUROfusion JET Work package 3 project.

4.3 Waste Characterisation Techniques

Work is currently in progress to improve the waste characterisation techniques used for radioactive waste generated as part of JET operations. This includes a review of the tritium leach process used to estimate the specific activity of soft incinerable radioactive waste, an on-site gamma spectroscopy process for analysing small samples, approximately 10g and the use of a hyperbaric oxidiser to perform combustion of larger samples, approximately 50g, followed by standard tritium capture and liquid scintillation counting.

4. Summary

This paper has introduced and described the current waste management structure and processes in place for managing radioactive waste generated as part of JET operations. A description of the site management structure, waste processing facilities and processes and procedures used to process, characterise and dispose of radioactive waste has been included. The key lessons to be learnt for future nuclear fusion experiments, and specifically ITER, are the early involvement of specialist waste management advisors and representatives of local regulators and the implementation of a complete integrated electronic waste tracking system which is simple to implement, and use, for all staff. Further data, to be generated as part of new waste treatment facilities under construction, will be of benefit to ITER in demonstrating achievable detritiation factors for radioactive waste in an industrial setting and will be provided as part of the JET Work Package 3 EUROfusion sub-project and published papers.

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