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Preparation for Commissioning of Materials Detritiation Facility at Culham Science Centre

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Preparation for Commissioning of Materials Detritiation Facility at Culham Science Centre

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The Materials Detritiation Facility has been designed to thermally treat solid non-combustible radioactive waste produced during operations of the Joint European Torus (JET) that is classified as Intermediate Level Waste in the UK due to its tritium inventory (>12kBq/g). The waste will be thermally treated in a retort furnace at temperatures up to 1000°C under a flowing air atmosphere to reduce its tritium inventory sufficiently to allow its disposal at a lower waste category via existing disposal routes. The gaseous flow from the furnace will be processed via a bubbler system, where released tritium will be trapped in water.

Commissioning of the facility will be divided into two main parts: inactive and active. The main purpose of the inactive commissioning is to verify that all components and safety systems of the facility are installed, tested and operated properly and within their operational limits. Several trials of the furnace with non-radioactive materials will be performed to verify its temperature profile, and to verify operation of the gaseous process line.

During the active commissioning, small amounts of tritium-contaminated material will be introduced into the facility and used for active trials. The tritium inventory in this material has been selected based on the As low as reasonably practicable (ALARP) principle, to ensure that the activity levels are sufficient to fully test the control instrumentation and pose minimal risk to operators during commissioning. Overall, four active trials will be performed with carbon-based and Inconel materials with total tritium inventories of 1MBq, 3GBq, 20GBq and 26GBq. Tritium levels in the bubblers as well as in aerial discharge from the facility will be monitored. Furthermore, all materials used in the active trials will be sampled and analyzed to verify the performance of the process and confirm that a major part of tritium inventory can be removed from materials by the process.

Keywords: Tritiated waste, detritiation, thermal processing, non-combustible waste, commissioning.

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1 Introduction

During operations of the Joint European Torus (JET), radioactive waste has been produced. This waste results from neutron activation and/or from contamination with tritium used as fuel for the fusion reaction. Most of the JET operational solid waste is mainly contaminated with tritium and has well established disposal routes based on the UK Waste Hierarchy principles, e.g. preferring waste management options with the lowest possible environmental impact. However, there is approximately 27 tons of operational solid non-combustible waste at Culham Science Centre (CSC) which is classified as Intermediate Level Waste (ILW) due to its tritium inventory (>12 kBq/g). ILW has no national disposal route currently available until the Geological Deep Disposal Facility is built and commissioned. Therefore, processing options for this waste were sought and onsite thermal treatment was identified as very suitable.

The Materials Detritiation Facility (MDF) will thermally treat this waste in a furnace in order to reduce its tritium inventory below 12 kBq/g enabling its disposal as a lower category of radioactive waste, using existing disposal routes. During the heating cycle, extracted tritium from the waste will leave the furnace in a gaseous flow and will be captured by the bubbler system. The water in the bubblers will then be processed for tritium recovery in Water Detritiation System (WDS), located also at the CSC. The unique combination of the MDF and WDS will demonstrate closure of the fusion fuel cycle by recovering tritium from tritiated waste and using the recovered tritium in future fusion experiments.

This paper is divided into two main parts: the first part describes the MDF and the second part is focused on commissioning of the facility, especially the active trails of the detritiation process line. Commissioning of the MDF is scheduled to start in September 2017.

2 Materials Detritiation Facility

The MDF building is a two-story industrial unit with a footprint of approximately 24x15 meters and with a 14-meter aerial discharge stack sited next to the building. All active ventilation arisings are filtered (via a HEPA filter bank), and discriminately sampled before discharge to the environment.

As the facility will handle radioactive materials, radiological safety principles have been applied during the design of the facility and the following risk-mitigation measures have been used:

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- Using commercial of-the-shelf components
- Employing specialist sub-contractors for specialist tasks, e.g. furnace, ventilation system and building
- Commission sub-systems as early as possible
- Using an actively engaged, multidisciplinary team

The building is weather and leak tight and uses the radiological zoning principle and a pressure cascade safety approach for confining airborne contamination within the building.

As the facility has been designed to process metallic and carbon-based waste contaminated with tritium, additional hazards exist from beta/gamma radiation. However, this beta/gamma radiation will be low due to multiple half-lives since activation and therefore no additional shielding is required. No alpha emitting nuclides will be present in the waste. In addition to the tritium hazard, the waste materials will be contaminated with beryllium on their surfaces.

The ground floor of the building contains areas for material receipt and processing, analysis laboratory, office and welfare facilities. The waste will be transferred in and out of the facility through an air-lock and will be stored in dedicated areas inside the facility (see Fig. 1.).

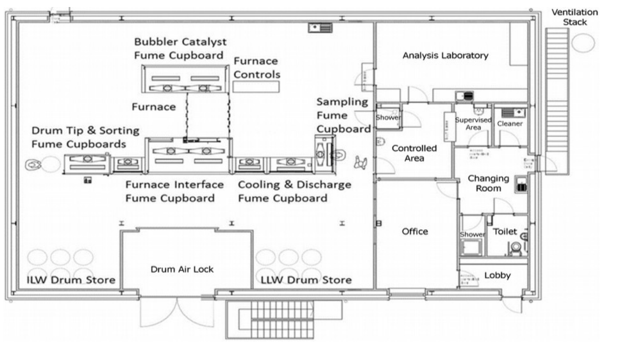

Fig. 1. MDF Ground floor layout

The first floor houses the ventilation plant room and electrical switch room, with a 'clean' storage areas. The ventilation system is composed from the Air Handling Unit (AHU), supplying the fresh air into the building, and two extraction fans (duty and standby). Furthermore, the system is equipped with two heat exchangers (air/liquid and liquid/air) to improve energy efficiency of the building and HEPA filters to remove particulate contamination before discharge to the stack. All fume cupboards installed in the detritiation process line are connected to the ventilation system, as is the air from any of the radiologically designated areas.

The facility is monitored by many systems to ensure safety and to avoid any accidental releases of contamination to the environment. Besides monitoring systems installed in the detritiation process line, the building has installed carbon monoxide (CO) and tritium monitoring systems in the process area, ventilation monitoring system, fire alarm and monitoring systems in the stack for measuring beta and gamma–emitting radionuclides, in addition to tritium, and beryllium.

2.1 Detritiation Process Line

The detritiation process line consists of a series of interconnected fume cupboards, each of them containing specific equipment and having a particular function in the process. The fume cupboards have been designed according to the Design Guide ES_0_1738_Issure 1 [1]. The main purposes of using fume cupboards is to minimize operator dose and beryllium exposure and limit the spread of contamination while maintaining optimal operational conditions, such as internal accessibility and optimal temperature distribution inside the fume cupboards. The furnace and its extraction system are crucial to the process and therefore are built into the process line. The process line will treat up to 110 kg of waste per day and approximately 14 tons per year. The process line has been designed to process waste up to 1 TBq of tritium per furnace load.

Waste processing in the process line (Fig. 3.) will involve the following steps: drum unloading, waste sorting, treating in the furnace, repackaging and post-process sampling. The facility has not been designed for any pre-processing of the waste prior to thermal processing; this will be performed in other JET facilities as required.

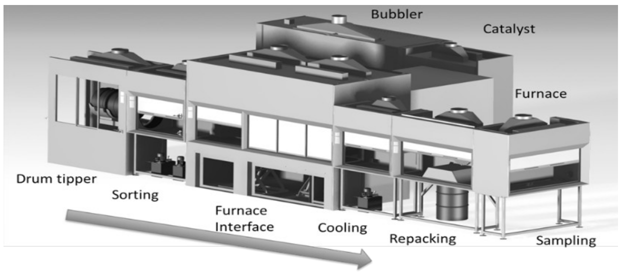

Fig. 3. MDF Detritiation process line

The key parts of the detritiation process line are the furnace and the extraction system of the furnace, mainly the catalyst and the bubblers.

2.1.1 MDF Furnace

The MDF will process waste in a horizontal cylindrical gas-tight chamber furnace with dimensions of the heated chamber approximately 850 mm (diameter) x 1600 mm long. The furnace is electrical with the maximum electrical input power of ~100 kW and with the maximum operating temperature of 1000°C. The hot zone of the furnace is heated with electrical resistance heating elements placed around the furnace retort. The retort is supplied with tempered fresh air from the catalyst fume cupboard and the air is extracted from the retort by the extraction system, located behind the furnace. The furnace must always be operated below the melting point of processed material to mitigate risk of damage. The furnace has been designed to be able to perform one heating cycle per day and will cool overnight.

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2.1.2 Extraction System of the Furnace

During the treatment, desorbed tritium will leave the furnace in the gas flow and therefore the flow will need to be appropriately managed. It is expected that the flow will contain tritium in both forms, elemental tritium (HT) and tritiated water vapor (HTO). The HT form will need to be converted into HTO to allow efficient capture in a series of water bubblers. A catalyst has been incorporated in the extraction system of the furnace to ensure HT conversion to HTO. Moreover, the catalyst will allow CO generated during the processing of carbon-based materials to be converted into carbon dioxide (CO_2). The catalyst selected for the MDF is based on noble metals, which have been found to be very effective, promoting oxidation at lower temperature and with good rate kinetics. As the efficiency of the catalyst is dependent on its operational temperature, it will be equipped with an external heating system to ensure optimal operational conditions at all stages of the furnace heating cycle.

After the catalyst, the gaseous flow enters a series of three water bubblers, where oxidized tritium will be trapped. Each bubbler will contain approximately 100 liters of demineralized water, which will be periodically changed as tritium inventory in the water builds up to an optimal level for subsequent processing (~10 GBq/liter). The water from the bubblers will then be transferred to the WDS for further processing.

The airflow in the system will be created by a liquid ring vacuum pump installed after the bubblers and will be controllable in a range between 200 and 500 l/min. Considering water transfer between the bubblers, an optimal airflow rate is expected to be between 200 l/min. and 300 l/min, transferring ~2 liters of water per operational day. Therefore, the first bubbler may require periodical "topping up" to avoid significant mass loss.

After passing through the catalyst and bubblers, the gaseous flow will be discharged into the building ventilation system in the bubbler fume cupboard. Tritium discharges are expected to be low at around 3 GBq/day.

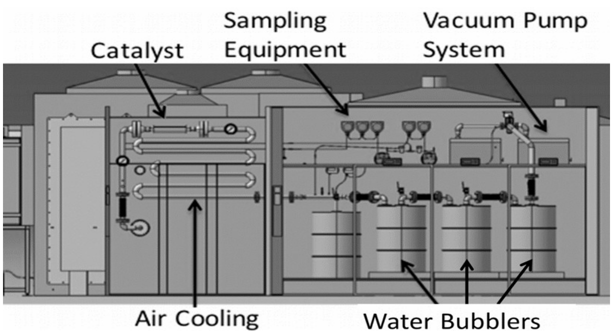

Fig. 4. MDF Extraction system

The extraction system will be equipped with two sets of monitoring systems installed before and after the catalyst. These will monitor process gas parameters, such as a gaseous flow rate and concentrations of CO, O_2, H_2 and T.

2.2 Waste Acceptance Criteria

To ensure safety in the MDF during its operation and to avoid any spread of contamination, the MDF will only accept waste consignments complying with its waste acceptance criteria, limiting, for example, the tritium inventory in the waste, tritium off-gassing rate and acceptable types of packages. Therefore, the waste may require pre-processing, sampling and analyzes, segregation by material type, size reduction, pre-treatment and packaging into ventilated 200-litre drums. This will be performed in other JET facilities as the MDF has only been designed for thermal treatment of the waste.

3 MDF Commissioning

The MDF commissioning will start in September 2017, after the handover of the facility to the UKAEA. The commissioning schedule was defined as a part of a Pre-Commissioning Safety Report (PCmSR) and was subject to approval by the Site Safety Working Party. The commissioning schedule has already been approved and has been divided into two main parts: inactive and active commissioning.

3.1 Inactive Commissioning

The main purpose of the inactive commissioning is to verify that all components and systems of the facility are designed, installed, tested and operated properly and within their operational limits. No radioactive materials will be introduced into the facility during the inactive trials.

The inactive commissioning is divided into the following areas: building fabric, ventilation, furnace, detritiation process line, monitoring instrumentation, electrical and electronic. Each of the areas has defined several tests that will verify functionality of all components and systems, including several inactive trials of the furnace.

3.2 Active Commissioning

The active commissioning will start after successful completion of the inactive commissioning and will be mainly focused on commissioning of the detritiation process line, mainly on the furnace and the extraction system.

3.2.1 Active Trails

Four active trials of the detritiation process line have been defined in the commissioning schedule, using Inconel and Carbon Fiber Composite (CFC) materials contaminated by tritium in the JET Machine.

The tritium inventory in the materials will be gradually increased for the trials and the total tritium inventories will be approximately 1 MBq, 3 GBq, 20 GBq and 26 GBq respectively (the MDF process line tritium limit is 1 TBq). The inventories have relatively low tritium contamination in comparison with the JET ILW feedstock (up to ~29 MBq/g) as they have been selected based on the ALARP principle such that the activity is sufficient to fully test the control & instrumentation and pose minimal risk to operators during the commissioning. The highest

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tritium activity used in the trials has been set to ~1.05 MBq/g, corresponding to the average tritium activity in the JET carbon-based waste.

Materials for the active trials will be prepared from the MKIIa divertor tiles and carriers[1]. Divertor components will be sampled before and after the trials by taking core samples from the tiles and slow cutting 10 g samples from the carriers, to avoid any heating of the samples. The samples will be analyzed in a pyrolizer to investigate their tritium content and determine the detritiation efficiency of the system.

The divertor components are also expected to be beryllium contaminated hence operators will be required to wear Personal Protective Equipment (PPE), Respiratory Protective Equipment (RPE) and a Personal Air Sampler (PAS).

[1] *The divertor was used in the JET machine during the DTE1 campaign in 1997.*

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Table 1. MDF Active trials

	Trail 1	Trail 2	Trail 3	Trail 4
Mass	5 g	2.9 kg	100 kg	100 kg
Material	Inconel	CFC	Inconel	Inconel + CFC
Tritium specific activity	0.2 MBq/g	1.05 MBq/g	0.2 MBq/g	0.2 MBq/g (Inconel) 1.05 MBq/g (CFC)
Total tritium inventory	1 MBq	3 GBq	20 GBq	26 GBq

Note: The tritium specific activity corresponds to the average activity calculated from all post-disassembling tritium analysis of the MKIIa divertor.

3.2.2 Test Programme for the Furnace

As the active trials will involve heating of the materials in the furnace, a test programme for the furnace was defined. Although the efficiency of tritium removal from materials processed is crucial for the detritiation process, the active trials will be mainly focused on successful commissioning of the facility and specific detritiation programmes for each material types processed will be defined and optimized after the commissioning phase using data gathered during the commissioning.

3.2.2.1 Operational Conditions

Operational conditions of the furnace will mainly depend on the materials selected for the trials.

Materials used in the trials will consist of Inconel and carbon with melting points of 1,336°C and more than 3,000°C respectively. As the maximum operational temperature in the hot zone of the furnace is 1,000°C, it is not feasible to melt these materials during the trials even if the furnace is operated at its maximum temperature.

The airflow through the detritiation process can be easily measured by flow meters installed on the inlet to the furnace and in the extraction system. To ensure a sufficient air change rate in the furnace and thus avoid depletion of oxygen while processing carbon-based materials and build-up of tritium in the furnace, the airflow during the trials will be set to 300 l/min.

Lab-scale experiments performed at CSC showed that most of tritium is removed in the first few hours (~2 hours) of the thermal processing, however, to ensure that tritium has sufficient time to migrate from the materials to the air atmosphere, the length of detritiation will be extended up to 6 hours (soak time) and will be followed by cooling of the furnace overnight (~14 hours). The length of detritiation is a parameter that can be easily optimized based on experience gained during the commissioning.

The amount of material in the furnace will be changed during the active commissioning and will be gradually increased up to 100 kg.

Table 2. MDF Furnace - Operational conditions

Temperature	1000°C
Air flow rate	300 liters/min.
Initial heating ramp-up	~5°C/min.
Soak time	6 hours
Cooling phase	14 hours

3.2.2.2 Performance of the Process Line

Performance of the process line will depend on efficiency of several components, the main components have been identified as the furnace, catalyst and water bubblers. A simplified schematic of the MDF process has been used to assess the overall performance of the process (see Fig. 5).

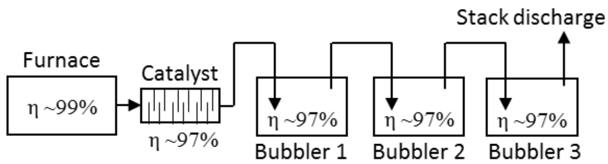

Fig. 5. Efficiency of the MDF Process Line

The detritiation efficiency of the furnace was considered approximately 99%, based on laboratory-scale experiments performed at the CSC. The form of extracted tritium (HT/HTO) will also have impact on efficiency of the process line, however, this ratio will be calculated from data collected during the trials and therefore a more conservative approach considering all extracted tritium in the form of HT has been chosen.

The efficiency of the catalyst at a temperature of 500°C is approximately 97%.

A gaseous flow from the catalyst will pass through a series of water bubblers that will capture tritium in the form of tritiated water vapor. Efficiency of each of the bubblers is approximately 97% hence the first drum in the series is expected to capture most of the tritium.

The schematic in Fig. 5 does not consider tritium retention on inner surfaces of the process line components, such as the furnace, the catalyst or the pipework. It is expected that tritium carryover will be low when taking into consideration the temperature of the furnace and gasses present. Moreover, amounts of tritium captured in the bubblers and discharged through the stack will be directly linked to the initial tritium inventories in the materials and therefore accurate analysis of initial tritium contents is crucial for assessment of the performance of the process line.

Tritium contents in the water bubblers have been calculated based on the scheme shown in Fig. 5. Results of the calculations are listed in Table 3.

As water in the bubblers will not be changed between the trials, levels of tritium in the bubblers in Table 3. correspond to tritium captured during all previous trials.

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The water in each bubbler will be sampled after each trial to investigate evolution of retained tritium inventories.

Efficiency of tritium capturing in the bubbler system is calculated from the initial tritium inventories and the amounts of tritium captured in the bubblers.

Table 3. MDF Active trials – Efficiency of the process line

	Initial Tritium Inventory in Material (GBq)	Residual Tritium Inventory in Material (GBq)	Total Tritium Inventory (GBq)			Aerial Discharge (GBq)	Efficiency of Tritium Capturing (%)
			Bubbler 1	Bubbler 2	Bubbler 3		
Trial 1	1E-3	1E-5	9.3E-04	2.8E-05	8.4E-07	2.6E-08	96.03
Trial 2	3	0.03	2.8	0.08	2.5E-03	7.8E-05	96.03
Trial 3	20	0.2	21.4	0.64	1.9E-02	5.2E-04	96.03
Trial 4	26	0.26	45.6	1.37	4.1E-02	6.7E-04	96.03
Total	49	0.49	45.6	1.37	41.9E-03	1.3E-03	96.03

3.2.3 Discussion

The furnace will undergo several inactive trials before the active commissioning to ensure that it is fully prepared for the active trials and the residual risk for the active commissioning is ALARP. The inactive trials will also involve heating of inactive carbon to verify functionality of the extraction system and investigate carbon monoxide generation. The test programme for the furnace has been created based on properties of the materials used in the trials, parameters of the furnace and laboratory-scale experiments performed at the CSC. Although this is not the case for Inconel and CFC, the temperature limitation will be relevant when processing materials such as aluminium.

Given the high efficiency of the bubblers (~97% each), the first bubbler is expected to contain most of the tritium (~46 GBq after the fourth trial). Results on tritium inventories in the bubblers listed in Table 3 will be verified by analysis of water from the bubblers after each trial. Differences in the results could be caused by tritium retention in the extraction system or by evaporative losses of the water from the bubblers, as this has not been considered in the calculation.

The total efficiency of tritium removal from the gaseous flow was calculated at approximately 96% of the initial tritium inventories, considering all extracted tritium is in the form of HT, which is a conservative approach. Calculations assuming different fractions of HT/HTO were performed and showed that the efficiency could rise above 99%. However, the efficiency will need to be verified based on data gathered during the commissioning.

The total aerial discharge was calculated at 1.27 MBq, which is well below the facility discharge limit.

Although the active commissioning is mainly intended to prepare the facility for full operation, the trials will provide the first results on efficiency of the detritiation process and useful data for process optimization.

4 Conclusion

This paper has presented the MDF, which is currently under construction at CSC. The facility has been designed to thermally process legacy JET tritiated ILW while allowing the extracted tritium to be captured in the series of water bubblers. The water from the bubblers will be further processed for tritium recovery in the WDS. This makes the MDF a unique facility allowing the tritium fuel cycle to be closed, making tritium available for next fusion experiments.

The commissioning is scheduled to start in September 2017 and will be composed of two phases – inactive and active. The paper is mainly focused on the active commissioning, which will consist of four active trials of the process line. Parameters of the materials used in the trials, operational conditions of the furnace and assessment of the performance of the process are presented in the paper.

Acknowledgments

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[1] ES_0_1738_1_Issue 1 – Ventilation Systems for Radioactive Facilities Design Guide – 26 May 2015.

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