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Performance of the Improved Tritium Decanting Facility in support of JET tritium operations

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Abstract

A Tritium fuel cycle must have the capability to import tritium inventory from transport storage containers to enable initial inventory stockpiling and future refresh of the inventory. The Joint European Torus (JET) Active Gas Handling System (AGHS) previously imported tritium inventory from Amersham Uranium beds (U-beds) via a decanting system housed in the Analytical Make-Up box secondary containment. Due to significant operational challenges with this decanting system, a new system, the Tritium Decanting Facility (TDF) was designed and built, to enable import of tritium inventory from Amersham U-Beds for the JET Deuterium-Tritium Experiment 2 (DTE2). The TDF process design incorporated several changes, including a tertiary containment with independent purge system, process services supply including argon, and direct connection to the AGHS Intermediate Storage (IS) system. These changes resulted in significant improvements to the decanting process, including a significant reduction in contamination effects from off-gassing, reduced decanting time, and reduced risk of exposure to the operators. The key features of the TDF design and their subsequent impact on the operation of the AGHS are discussed in detail.

Keywords: Deuterium Tritium Experiment 2, Tritium Decanting Facility, Active Gas Handling System, Fuel Cycle, Amersham Uranium Bed

1. Introduction

The Active Gas Handling System (AGHS) is the tritium fuel recycling plant for the Joint European Torus (JET). Its function and operation have been previously described by Lässer et al. (1).

In order to fulfil its fuel cycle function, the AGHS requires input of tritium into the process. Tritium is supplied by Ontario Power Generation (OPG) in Amersham transport Uranium beds (U-beds). Previously this function was fulfilled using a combination of the Analytical Laboratory (AN) Make-up glovebox, and the Product Storage (PS) subsystem(1)(3).

During the early stages of recommissioning for the Deuterium-Tritium Experiment 2 (DTE2) campaign(2), it became apparent that both the AN and PS subsystems would not be available in the necessary timeframe to allow fuelling of the facility, as both systems were undergoing their own upgrade and commissioning activities. To address this, a new Tritium Decanting Facility was designed and built to enable tritium import for the DTE2 experimental campaign.

2. Decanting process and Challenges

2.1 Decanting Process Outline

All historic AGHS decanting operations with the original system followed the same process: (1) on admission to the AGHS, each Amersham's tritium content was assessed via precision calorimetry(4) to confirm the supplier inventory figures. Once assessed, an Amersham U-Bed was connected to the AGHS process in the AN Make-up box and the connection leak tested by means of a pressure rise test. Only one Amersham container was permitted in the decanting glovebox at a time to prevent accidental mixing of transfer package components.

Once a leak-tight connection was established, each Amersham was gradually heated to 450 °C and the desorbed tritium was batch-transferred via a tank to enable Pressure-Volume-Temperature (PVT) measurements to the PS-T_2 storage U-beds. PVT measurements were performed for accountancy purposes, and required static gas volumes for measurement followed by absorption and ^{3}He removal, further delaying the transfer. During these PVT/absorption cycles, the Amersham U-Bed was held at an elevated temperature.

Following the tritium transfer, the Amersham was allowed to cool to ambient temperature and then was filled with blanketing argon gas as a protective atmosphere, disconnected from the primary process, and reassessed by precision calorimetry(4) to determine the small residual tritium heel left in the U-bed. The assessed Amersham U-Bed was then repackaged under argon and removed to the AGHS U-bed safe storage area.

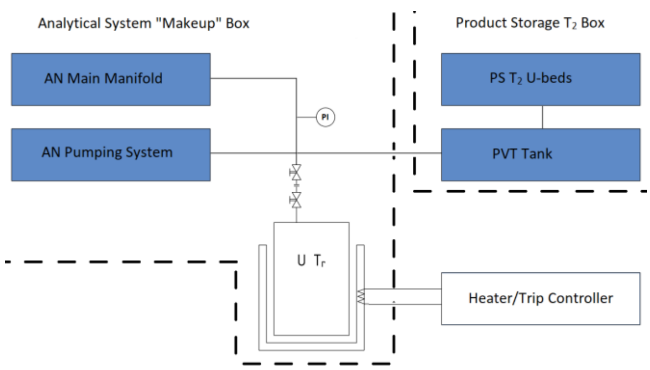

Figure 1: Simplified diagram of the AN "Makeup" Box decanting system

2.2 Decanting Process Challenges

The AN decanting system had several significant challenges associated with its operation. The available fleet of Amersham U-beds have been thermally cycled many times with varying tritium loads during their lifetime, as such their steel casings have absorbed a significant amount of tritium, thus off-gassing of tritium into the surrounding atmosphere is very high during heating. The AGHS safety management limits specify a maximum glovebox activity level of 4 GBq/m^3 for decanting operations. In the first Amersham transfer in 2015, activity levels began to rise early in the heating process, with the 4 GBq/m3 limit being reached only shortly after the 450°C temperature plateau was achieved.

The AN Make-up box is equipped with a forced-purging system similar to other containments in the AGHS. This was used during transfers to reduce the contamination level in the box. However, in practice the off-gassing rate was greater than the purge rate of tritium removal from the box atmosphere. This often led to premature halts in the heating operations and pauses of several days while the glovebox activity level was reduced.

For later transfers, a temporary modification of the glovebox purge system was implemented in order to increase the rate of atmosphere changes in the Make-up Box, and the 4 GBq/m^3 management limit was increased to 8 GBq/m^3, subject to additional separate external safety controls. Despite these improvements, multiple decanting sessions were still required to transfer the contents of each Amersham U-Bed, because the management limit was reached very quickly. This meant that the amount of time spent on preparation (including the associated overheads of set up time), heating, and purging, greatly exceeded the time spent transferring tritium, with purging often taking several days.

The transfer of tritium in batches via the PVT tank introduced an inefficiency to the transfers. Whilst it allowed for inventory monitoring during the transfer, it significantly increased the time the Amersham would remain at high temperature and therefore prolonged off-gassing from the steel vessel.

The location of the decanting system inside the AN Make-up box made the ergonomics of the operation difficult. Space inside the box is limited and the height and position of the glovebox and the gloveports required the operator to work in cramped conditions, with some manually operated valves and components in difficult to reach positions.

When originally designed, provision of a dedicated supply of argon for blanketing was not included. This meant that a cylinder would have to be temporarily connected to the glovebox each time a fill was required. Connection of a gas cylinder to the system required a breach of the primary process pipework, with the associated exposure hazards. Careful operation was required to avoid contamination of the gas cylinder.

3. Tritium Decanting Facility

The Tritium Decanting Facility (TDF) replicates the functionality of the earlier AN Make-up box system, whilst also incorporating several improvements.

The system is housed in a glovebox in the AGHS main process area; this glovebox was repurposed from a previous experimental system that was no longer in use. The original pumping chain, pressure control and tritium monitoring capabilities from that system were retained, with most of the upper compartment's legacy contents being removed to make space for the TDF. All other process equipment was designed, installed, and commissioned prior to DTE2.

3.1 Process Design

The TDF system was designed to perform tritium decanting from Amersham U-Beds directly to fixed storage U-Beds, whilst reducing the contamination effects of off-gassing.

Primarily, this was achieved by design and installation of an intermediate containment with an argon purge system. The intermediate containment, colloquially known as a 'Bell Jar' due to its shape, was designed to sit over the Amersham bed and heater apparatus to create a smaller volume containment around it than that provided by a glovebox. When lowered into position, the Bell Jar rested on a static platform through which the system services such as process pipes, power, and instrumentation, were connected. An ethylene propylene diene monomer (EPDM) O-ring, chosen for its resistance to damage when exposed to tritium(5), and a raised bevel were incorporated into the platform surface to create a good seal and prevent sideways movement of the Bell Jar. The platform height was specified to provide the glovebox operator with maximum access to equipment and improve manual handling aspects.

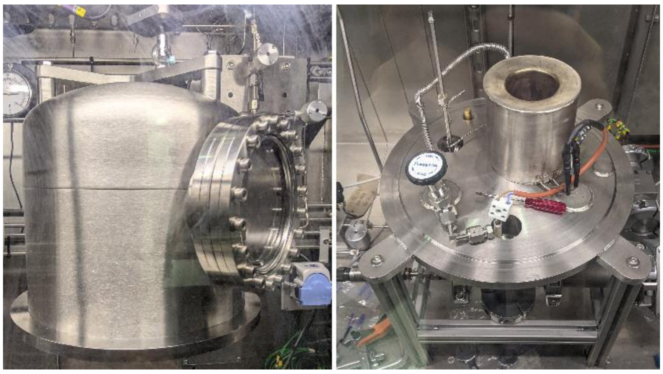

Figure 2: The "Bell Jar" suspended from its lifting arm (left) and the base plate (right), on which the Amersham heater jacket is mounted.

The argon purge system was designed to supply argon purge gas to the Bell Jar containment during heating operations, whilst also continuously pumping this gas to an AGHS Buffer Tank. This aimed to reduce the activity permeated through to the main glovebox atmosphere, and in doing so prolong the time taken before the 4GBq/m^3 was reached, allowing for longer transfer periods before stopping to purge the glovebox. The design also ensured that the Bell Jar containment was maintained at a slight depression relative to the glovebox atmosphere, which further reduced the risk of high activity in the glovebox in the event of a leak from the primary process lines.

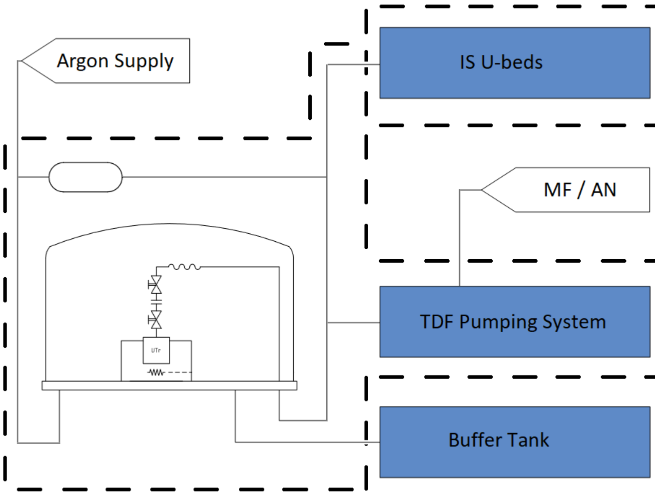

Figure 3: Simplified diagram of the Tritium Decanting Facility

Instead of connecting to Product Storage, The TDF was designed to connect directly to the AGHS Intermediate Storage and Transfer (IS&T) subsystem (3), which has an array of U-Beds, PVT vessels and a vacuum pumping system. A new primary process line was designed and installed between the subsystems to achieve this. This line was held in secondary containment, with the atmosphere of the secondary containment linked to the TDF glovebox atmosphere to allow for Over Under Pressure Protection System (OUPPS) nitrogen purging and use of the OUPPS tritium monitoring. This allows the decanted tritium to be stored until the PS-T_2 storage U-beds and their associated PVT tank are available. Instead, PVT accountancy measurements were completed after the transfer of inventory was complete. This allowed for fewer PVT

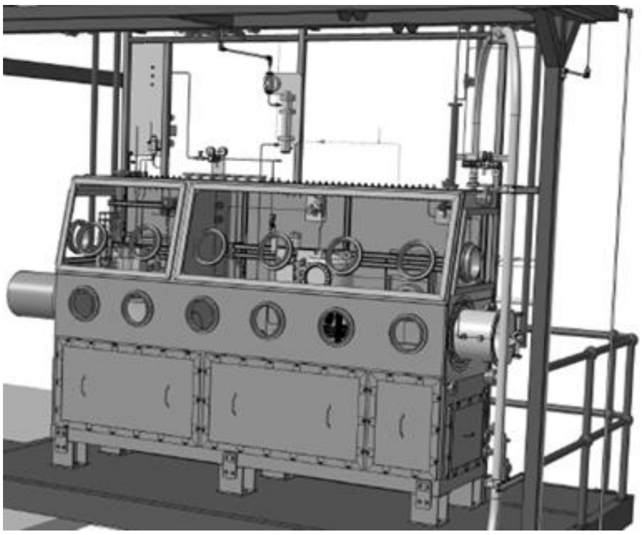

Figure 4: 3D render of the TDF glovebox, the bell is visible in the "closed" position in the main box

measurements overall and reduced the hazards of the operation. As above, this aimed to reduce the activity levels in the glovebox atmosphere by reducing the amount of time that the Amersham spent at high temperature, off-gassing.

Another feature of the TDF that was incorporated at process design was the argon blanketing functionality. A small tank, placed in-line on an argon supply to the Amersham U-bed, allowed for argon blanketing of the empty U-Bed, after the decanting operation was completed. The tank was sized such that when the tank contents was expanded to the empty U-bed, it would be filled to the required blanket pressure. The Amersham U-bed could then be isolated and disconnected from the primary process line. The batch expansion mode of this operation also prevented back-diffusion of tritium occurring, from the contaminated process pipework to the argon supply.

4. Tritium Decanting Facility Performance

During operations prior to DTE2, five Amersham containers were decanted in six sessions, over the course of which 51.2 g of tritium was transferred to the IS subsystem. Significant improvements in performance and operability over the previous system were observed across several different metrics.

4.1 Operational performance

During the decanting operation, the glovebox ion chamber detected no rise in glovebox tritium activity, indicating that the Intermediate containment purge system reduced the leak rate into the glovebox to below detectable levels. This removed the need for repeated heating and purging cycles to fully decant the inventory of one Amersham U-Bed, since it was possible to fully decant the inventory of an Amersham in one heating cycle without exceeding the safety management limit for activity within the glovebox containment. For comparison, the previous system required nine sessions to transfer three Amersham containers.

The employment of direct Amersham to IS U-bed transfers also provided an increase in transfer efficiency, because it removed the need for pauses in the process for tank to receiving U-Bed transfers and ^{3}He recovery, reducing the time spent at high temperature. A reduction in the overall time spent at high temperature brought about by this improvement, reduced the amount of tritium off-gassed from the Amersham U-bed structure.

A direct connection to the building argon supply for the post-decanting argon blanketing of the Amersham U-bed was added to allow this to occur with the U-bed inside the glovebox, meaning the U-bed could be fully sealed into its secondary container before its removal from the glovebox. The previous method required an argon bottle to be brought into the small room where the decanting had taken place, and breach of pipework to introduce the argon into the glovebox, with resultant radiological and asphyxiation hazard. This also required implementation of paperwork and a scheme of works. The argon blanket fill system reduced what had previously been an operation that could take half a day, to an activity taking less than 5 minutes as part of a standard operating instruction.

The Amersham U-bed and heater assembly was positioned on a raised platform within the glovebox within easier reach of the gloves. This meant that the first manual connection of the U-bed to the TDF inlet, operation of manual valves and sealing of the bell jar could be undertaken more easily by the operator compared to the lower position within the AN make up box.

A larger glovebox was used, independent of other plant systems meaning more space was available to remove the U-bed from its secondary containment, improving access to the equipment and reducing probability of losing bolts and seals within the box which had been an issue with the previous system.

For a more direct comparison of the two systems, it is notable that the first AN transfer in 2015 and the first TDF transfer in 2020 were both performed using the same Amersham container, 0035/4018. A comparison of their performance across several metrics is presented in Table 1. Despite the fact that the 2020 decanting operation was for higher inventory, the total heating time was less than half that of 2015. This led/contributed to a significantly faster transfer rate. The most notable difference is the time that the Amersham U-bed spent in the glovebox containment, in 2015 the total operation took 89 days whereas only 6 days were required in 2020. The 2015 operation took significantly longer because the inventory limit of the glovebox was consistently exceeded (peak activity observed in 2015 was 3.85 GBq/m3 whereas it remained below detectable limits in 2020) and several days for purging and reducing activity levels were required in between heating operations.

	AN-Glovebox Transfer 2015	Tritium Decanting Facility 2020
Inventory (g T)	7.74	9.79
Total Heating Time (hh:mm)	11:12	4:45
Transfer Rate* (g/h)	0.94	2.23
Number of heating cycles?	4	1
Time spent in glovebox (days)	89	6
Peak activity detected in glovebox during transfer (GBq/m3).	3.85	< LOD
*Expressed as time from first observed pressure rise after heating, to end of heating, in each session.		

Table 1: Comparison of transfers of Amersham 0035/4018 using both decanting systems at the JET AGHS.

4.2 Room for Improvement

A number of opportunities for improvement were found during the operation of the system, which are being considered for future tritium decanting facilities at Culham.

The upgraded TDF was installed in a pre-existing glovebox situated on the second floor of the facility. No lift was available so this required two flights of stairs to be climbed for access. The U-beds must be moved when they are inside their secondary and tertiary containments. These are approx 21 kg in weight and a total package size of approx 0.33 m diameter and 0.4 m height, resulting in a cumbersome manual handling process. Future planned tritium decanting facilities at Culham are planned to be accessible by lift.

Due to time constraints, not all instrumentation had been implemented in the control system software, meaning that some measurements were required to be taken manually by operators directly from the local indicators. This was a burden on operators, as well as introducing risk of misrecording. It also meant that operators had to remain local to the operation, rather than operating from the control room.

The bell jar did not sufficiently seal under its own weight as was assumed it would in design; this resulted in the addition of clamps to hold the bell jar in place onto the platform. Due to this being a commissioning addition, it was not possible to design in such a way as to make the process ergonomic for the operators, resulting in difficulty in fitting the clamps before every decanting operation.

5. Conclusions

A new Tritium Decanting System was designed and built for the JET AGHS. 51.2g of tritium was successfully transferred to the AGHS for use in the DTE2 experimental campaign. Incorporation of a separate purging enclosure around the around the transport U-bed resulted in major improvements in both operational efficiency and process safety.

Purging away off-gassed tritium from the transport bed reduced the spread of contamination and allowed longer decanting sessions to be performed, overal drastically reducing the amount of operational time required. This also reduced operator “in-glove” exposure to tritium from repeat startup/shut-down and glovebox purging operations. The reduction in spread of contamination through the glovebox also increases operator safety when the U-bed is removed from the containment.

The outcome of this activity highlights the need for the consideration of purging systems in design of fuelling facilities for future fusion fuel cycles such STEP, ITER or DEMO. It is expected that kilogram-scale tritium inventories will be needed for these facilities, with corresponding challenges in the safe design of processes and hardware for meeting this requirement.

Acknowledgements

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