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Tritium Inventory Control – the Experience with DT Tokamaks and its Relevance for Future Machines

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ABSTRACT.

At present, the commercial use of tritium is relatively small scale. The main source of supply is as a by-product of heavy water moderated fission reactors and the products are mainly discrete sources or tracers with activity typically in the GBq range. There are in general no restrictions on the use of tritium other than those which would normally apply to the use of radioactive material.

The future use of tritium as intermediate fuel for a fusion power plant series will involve an increase by several orders of magnitude in the industrial use of tritium and may increase concerns relating to safety, transport and waste disposal. In addition, the use of tritium in fusion power will be unable to be satisfied by current sources of supply and tritium production in future fusion power plants will be essential for the operation of the plants as well as for the start of new ones. Power plant studies have however shown that these issues can be satisfactorily addressed. In addition the values for clearance of tritiated materials in a number of countries are consistent with the low environmental impact of disposal of tritiated waste.

There are however many practical operational and regulatory problems which will need to be solved in the context of the experimental programmes.

The current regulations for control and accountancy of tritium inventory, as applied internationally and in specific countries, are reviewed and their influence on the DT fuel cycle considered. The effect of safety case limits on the need for control of tritium inventory in TFTR, JET and ITER is analysed. The sensitivity of the fuel cycle to tritium inventory is considered.

The experience of controlling tritium inventory in TFTR and JET is reviewed and the latest results from JET presented. This takes into account the limits and constraints, the differing requirements for tritium processing, in-vessel retention, the needs for waste management and decommissioning including detritiation, and techniques for measurement. Comparisons with ITER requirements are made and the desirable areas for further development identified.

Issues of tritium inventory control which could influence the viability of the DT fuel cycle are discussed and priorities for action proposed.

1. INTRODUCTION

There are two aspects to tritium inventory control; the first is the minimisation of the tritium inventory of the fuel cycle particularly that of plasma facing components. The second, which this paper concentrates on, is the accountancy of tritium within the cycle to meet both operational and regulatory requirements.

Although it is a component of some nuclear weapons, tritium is not subject to the Non Proliferation Treaties and associated safeguards regimes.

At present, the worldwide use of tritium for commercial applications and fusion research is supplied mainly from heavy water reactors. The amount used in commercial applications is of the order of 100 grams per year [1].

Tritium is also produced in other power producing nuclear reactors and is disposed of as waste. The quantities discharged through this route are of the same order as that used in commercial/fusion applications [2].

The use of tritium in the two magnetic fusion machines, TFTR and JET, and its likely use in ICF research in the next few years is on the same scale as commercial usage i.e. tens of gram quantities.

However ITER will significantly increase the industrial usage to several Kg in one location and the development through DEMO to a power plant series will demand larger amounts than are currently available or foreseeable to be produced using the current commercial routes. Generation or breeding within the fusion power plant series will therefore be essential for the operational needs and for the inventories required during the start up phase of new fusion devices. Tritium will only be the intermediate fuel with the cycle being fuelled by non radioactive lithium and deuterium. Transport of tritium will mainly be an issue for initial fuelling and startup. Only ITER in the absence of a full blanket will require periodic external tritium supplies.

It is an environmentally attractive feature of fusion power that there is no large scale transport of radioactive fuel. The limited tritium inventory within the reactor fuel cycle is also an essential advantage.

However, despite these advantages, the scale of increase in throughput would be such that present regulatory regimes for tritium accountancy may not be applicable.

2. COMMERCIAL USE OF TRITIUM

In the 1980s, the use of tritium for light sources, 'betalights', was seen as a growth industry [3]. A variety of devices were produced such as watches, compasses, telephone dials using small quantities of tritium and larger amounts were used in exit signs and lights. An airfield runway light could typically have a tritium inventory of 0.1g.

With changes in the attitude towards the use of radioactive materials and in particular the principle enshrined in ICRP60 of requiring justification for practices involving the use of radioactivity and concern about waste [4], the production of betalights has declined. The availability of more efficient chemiluminescent materials has allowed alternatives to be used and tritium is now only used in betalights where there is no other practicable option.

The production of bio-medical tracers is now the primary commercial use of tritium and a range of tritium-labelled products such as thymidine are marketed and even custom labelling of specific sites in molecules can be carried out [5]. The amount in individual products is small (typically in the MBq range) but the throughput of the production facilities is relatively large. This arises in part because the production processes such as gas exchange and fermentation are not necessarily efficient in tritium usage and discards to waste are significant (for example environmental discharges of ~4g per year from one plant) [6].

3. TRITIUM IN FUSION RESEARCH

Tritium has been used in facilities for fusion research for a number of years, initially for work on the fuel cycle and materials properties and more recently in tokamaks.

Table I

Facility	*Location*	*Max Inventory*	*Throughput*	*Status*	*Function*
TSTA	Los Alamos USA [7]	100g	>1kg	Decommissioned	Fuel cycle tests
TFTR	Princeton USA	5g	~100g	Decommissioned	Tokamak
JET	Culham UK	20g	~100g	Operational	Tokamak
TPL	Tokai Japan [8]	60g	–	Operational	Fuel cycle tests
TLK	Karlsruhe Germany [9]	40g	160g	Operational	Fuel cycle tests

The inventories and throughputs have generally been in the grams to tens of gram range as shown in Table I.

A significant fraction of the throughput of these facilities was recycled so this is generally much larger than the inventory. In the case of TFTR, most of the tritium was collected on disposable molecular sieve beds (DMSB) as tritium oxide and returned to the Savannah River Station for recovery, or disposed of as waste at the Hanford disposal site in Washington State [10, 11].

The results from some heavy water processing plants at OPG Darlington Canada [12] and ILL Grenoble France [13] with inventories in a similar range have also been relevant to fusion research, as has work in a number of laboratories not specifically dedicated to fusion.

There will be a step change in the use of tritium once ITER is commissioned. The currently envisaged inventory is 2Kg with 500g in the fuel cycle for 3000 s long pulses. Although ITER will have the capability to test breeding, the breeding ratio is less than unity so tritium supply will be needed.

For a power plant series, there is insufficient capability for tritium production to fuel any significant power production (which requires around 170g/GWd [14]) from conventional sources. Tritium will therefore need to be generated as an intermediate fuel within the plant and supplied as start-up inventory to new fusion plants. External fuels are deuterium and lithium.

3.1 REGULATORY CONTROLS ON TRITIUM USAGE

There are no non-proliferation treaty obligations on the use of tritium. It cannot in itself be used to create a thermonuclear device and it is therefore not subject to IAEA or Euratom safeguards.

The primary controls are therefore related to protecting workers and the public and are based on the same criteria as those for other non-safeguardable nuclides. An important consideration is being able to demonstrate control and ensuring that inadvertent exposure of the public does not occur. For example the Basic Safety Standards Directive is used as a basis for establishing national standards within the European Union. This establishes such things as limits for exempting material from regulatory control and clearance levels for recycling. National legislation derived from this may set controls on the accounting for radioactive substances and may require reporting of losses. In the case of the UK releases of more than 1TBq and confirmed losses of more than 10 GBq must be reported. As it is impractical to account for tritium to this precision, the JET arrangements rely on all tritium boundaries being monitored and transfers to waste being measured or assessed .

Additional accountancy controls are applied in some countries because of potential for diversion for weapons use and also in relation to equipment for processing tritium, for example USA [15]. In addition tritium supplied through contracts with Canadian suppliers (to JET and TLK) is subject to a quasi-safeguards accountancy regime.

The absence of formal controls in many countries reflects the relatively small quantities in use and the effects on industry that a more rigorous regime would have.

For JET and TFTR the accountancy depended on there being a 'Material Balance Area' (MBA) consisting of the whole plant with shipments in and out being measured accurately. The balance, after being corrected for transfers to waste, was assumed to be retained. In addition more stringent internal accountancy arrangements were necessary to satisfy process and safety requirements [16, 17].

In the case of future power plants the single MBA concept with the balance being retained cannot be applied as breeding, shipment of tritium as start-up inventory to other power plants and transfer to waste occurs. Even if the breeding recovery cycle inventory is limited to a few days production, the plant inventory will be several kg with an annual throughput of several hundred kg.

3.2 WASTE DISPOSAL

Tritium differs from other nuclides, apart from possibly carbon14, in its propensity to form labelled compounds by isotopic exchange with hydrogen atoms and also like hydrogen, the ease with which it permeates through metals and other materials.

This means that the measurement of tritium in waste is problematical. Absorbed tritium cannot be measured directly except by destructive analysis and surface smear results have limited value.

In addition the ease with which tritium permeates or leaks through valve seats means it can be present in trapped volumes leading to potential exposure during waste processing operations. Both TFTR and JET have experience of this type of occurrence. [18] For power plant systems with throughputs several orders of magnitude higher, the potential for inadvertent transfer to waste of significant i.e gram quantities, clearly exists.

3.3 SAFETY CASE ISSUES

Tritium is one of the main source terms in accident scenarios for all DT magnetic fusion and ICF devices. To meet some of the key requirements for limitation of worker and public dose in accidents limits need to be placed on the tritium inventory. This may be a global limit or limits in individual components, dependent on the ease of mobilisation.

In TFTR there was an overall limit of 2.5g of releasable tritium. This was set by the public dose at the site boundary. The releasable inventory was assumed to be 100% in the oxide form and applied to the complete fuel cycle. This limit led to the design of a low inventory isotope separation system for tritium purification and re-use.

At JET there are a number of separate limits for different parts of the plant. There is a limit of 30g in the tritium recycling plant, 20g retained in the torus, and 10g on cryopumps. These limits are

derived from the different accident scenarios which were analysed before the DTE1 series of experiments and reflected the potential for mobilisation. It was assumed that 10% of the retained tritium could be mobilised whereas all the tritium trapped on the cryopumps would be released in an up-to-air accident. The higher value in the AGHS arose because of the greater number of barriers to release and differing assumptions about conversion rate to HTO.

In ITER the limit of 450g of mobilisable tritium (330g in plasma facing components and 120g in the cryo-pumps) is set primarily by the 'no-evacuation' criterion. Steps have been taken to minimise the free inventory in the fuel cycle such as limiting the capacity of the storage beds and reservoirs to below 100g per component, of the isotope separation system (ISS) to below 220g and optimising the regeneration cycle of the cryopumps. [19]

In power plants also, it is likely that the 'no-evacuation' criterion will apply and that similar steps will be needed to control the tritium inventory.

An important issue is that in cases where there is effectively only an administrative control on tritium inventory, compliance with safety case limits may be difficult to demonstrate.

3.4 MEASUREMENT TECHNIQUES

There are two separate requirements for measurement. The first is that of tritium inventory determination, either statically or in process flows where tritium is at a relatively high concentration; and the second is that of surface or bulk contamination measurement such as in waste or for personnel protection.

The primary methods of measuring tritium rely on the radioactive properties, in particular ionisation chambers and liquid scintillation counting. Other techniques include solid (plastic) beta scintillators, which can be used for tritium in water measurements, and PIN diodes.

For process flow/inventory measurements, parameters such as mass flow or PVT must also be measured and physical properties can be measured to determine the concentration of tritium. These include, in addition to ionisation chambers, mass spectrometry, gas chromatography and Raman spectroscopy. In this range the main difficulty is cross contamination and memory effects and was the main reason for the poor performance of the JET on-line torus exhaust measurements discussed later.

Calorimetry is a technique which can be used successfully with tritium and high accuracy can be obtained in static measurements. It does not suffer from memory effects. Direct measurement of tritium in storage beds has been developed and although the accuracy is relatively low, it is likely to be sufficient for process measurement [20]. With improvements in the sensitivity of calorimetry, the possibility of developing pseudo-static on-line measurements exists.

Also in magnetic fusion devices, certain plasma diagnostics can be used to give an indication of tritium content and flows.

Although surface contamination measurements are relatively straightforward, these cannot be used for bulk determination which usually involves destructive measurements. In the case of limited permeation of for example stainless steel, techniques such as bremsstrahlung analysis may be usable

[21] and for well characterised waste materials, outgassing may be able to be correlated with tritium content. At relatively high contamination levels, in the range > 10kBq/g, calorimetry may be capable of being developed as a usable tool.

3.5 ACCOUNTANCY AT TFTR DURING DT OPERATIONS

Initially the cycle at TFTR was once through with tritium being delivered in transport vessels and removed from site in Disposable Molecular Sieve Beds (DSMB). Part way through the campaign, the cryodistillation system for isotope separation was commissioned and approximately 8g was eventually recycled. [22]

The requirements for tritium accountancy were set by the need both to comply with the safety limits and with the USDOE tritium accountancy requirements. The primary measurements were made in the two Gas Holding Tanks and the Plasma Exhaust Tank. [23] Accounts were kept of the inventory of these, the cleanup system beds and in waste as summarised in Figure 2. The balance 'Material-in-Process' was assumed to be the amount in the torus or the unregenerated cryopanels.

To permit the inventories to be calculated, measurement parameters were defined and specific calculation procedures were prepared for transfers. These were based on PVT measurements in the tanks with composition determined by quadrupole mass spectrometer and activity by an ionisation chamber in a separate loop corrected for pressure, specific gas species and concentration. On several occasions the in-line tritium monitors employed for accountancy in the tritium recovery part of the system (post GHTs) gave erroneous data due to the formation of acid on the monitor electronics. This was caused by SF6 leaks into the vacuum vessel originating from the NBIs. In addition several instances when moisture and organics (oil blow down from pumps) migrated to the GHTs the detectors needed to be taken off-line for clean-out and in some instances repair. Although in-line filters provided some level of protection from these contaminants there were instances when contaminants accumulated in the in-line (ion chamber) causing invalid data. The in-line detectors were calibrated with various gas mixtures and curves were generated which detailed the appropriate coefficients to be used when correcting in-line monitor readouts for the type of gas and percentages in the GHTs and PET. The precision was of the order of several percent. Backup instrumentation was available and several times grab samples were collected and analysed off-line.

In addition to the key measurement volumes, the capacity of 50 or so other volumes within the fuel cycle were known so that transfers between them could also be calculated. Once the Tritium Purification System (TPS) was placed on line at TFTR additional points became available to measure tritium for accountancy purposes. This included the use of hydride transport vessels (HTV) which were portable U-beds. These were used to return tritium to SRS for introduction back into the US inventory. When the HTV was received at SRS a confirmatory measurement was taken which typically was within 1% of what was measured at PPPL.

The regime at TFTR was generally effective in satisfying the regulatory needs although significant effort was required to operate the system.

3.6 ACCOUNTANCY AT JET DURING DT OPERATIONS

The Active Gas Handling System (AGHS) is used to recycle tritium. [24] As with TFTR, all the process volumes in the AGHS were accurately measured and a tritium transfer operation procedure put in place with precalculated transfer algorithms. Instead of using the IC/QMS system, JET used an analytical gas chromatograph for composition analysis.

Although there are many similarities between the two systems, there are a number of differences which have a significant effect on tritium accountancy:

The JET fuel cycle was designed for recycling with a single MBA. Special accountancy tanks were therefore installed only at the receipt point. The gases from the torus are cryopumped and there is no direct way of carrying out accountancy in the way that was done for TFTR using the PET or GHTs. The gas amounts released during regenerations of the cryo-pumps to 77K in the torus and neutral beam injection systems were measured. These PVT-c measurements required a knowledge of the large (~200m^3) torus and NIB volumes and effective temperatures reflecting the variation from 77K cryopump, 300C torus and ambient temperature transfer lines. The tritium content was determined by ionisation chambers. Afterwards the gases were cryo-pumped in the Active Gas Handling System. Due to the large volumes, the uncertainty in effective temperatures and the low pressures achieved during DTE1 when the cryo-pumps were regenerated daily to reduce the tritium inventory on the pumps, the accuracy of these measurements was very limited.

Table II shows the tritium concentration of the same batches of gas using three different instruments; the AGHS analytical gas chromatograph, an off-line ionisation chamber capable of being purged, and an on-line ionisation chamber. The contamination and memory effects in the ICs can clearly be seen.

Tritium was in general stored on uranium beds. Although these beds were not specifically designed for calorimetry, arrangements for in-bed calorimetry were tested. However calorimetry could not be used during operations because of the time taken to stabilise and the limited precision. [25]

The JET machine operated at over 300ºC in comparison with TFTR at room temperature. This led to significant permeation into the baking loop of the vessel and collection on molecular sieve beds.

The arrangements at JET during DT operations when tritium was being supplied to the machine involved a daily meeting to reconcile the accountancy figures and to confirm that the safety case limits were not being exceeded with in the limits of measurement. At one point the torus inventory reached 11.5g.

Because of the low accuracy of the tritium amounts received by the AGHS, a batch accountancy exercise was carried out almost once per week. No plasma operations took place during the three days of accountancy in order to start the following week with an accurate

Table II

Batch	*GC*	*Off-line IC*	*In-line IC*
1	7.6%	8.6%	26.5%
2	1.8%	3.4%	9.4%
3	2.3%	2.8%	8.4%

accountancy figure. This operation restricted the JET operational campaign and could lead to 3 days of delays in DT plasma operation but was unavoidable.

The batch wise tritium accountancy within AGHS involved the tritium recovery from impurities, transfer of all protium and deuterium diluted tritium to the isotope separation system for enrichment to nearly 100%, collection of all tritium enriched gases in one U-bed with subsequent full desorption, accurate (PVT-c) determination in a special volume and full transfer to another U-bed.

The tritium content of tritiated water obtained by regeneration of the Exhaust Detritiation System was significant as a result of ventilation operations carried out during repair of one of the neutral beam systems.

As well as the tritium retained in the torus and machine components, the balance included the following AGHS components:

- The getters used to pump the secondary containments of the uranium beds. The containments of the uranium beds were pumped by two sets of getters as shown in figure. The pump on the inner volume had been added as a modification to avoid excessive tritium permeation into the HISA volume and had no regeneration capability. Tritium was eventually removed from these by isotopic swamping and pumping leaving a residual inventory of a few mg.
- The 'heel' of hydrogen isotopes which could not be released from uranium beds at the maximum regeneration temperature of 480ºC. This was also estimated and reduced by isotopic swamping leaving a residual inventory of less than 1mg.
- The tritium removed as water vapour from the vessel He baking loop by molecular sieves was assessed by measurement of the difference between ionisation chamber values before and after the primary sieve bed. This gave an inventory of 0.1g. [26] This value has yet to be confirmed by the planned regeneration of the beds and recovery of the tritium using the AGHS IP system.

The differences between the on-line and batch accountancy figures were both positive and negative, depending on which sets of instruments were used and were typically in the range 5 to 10% of the torus inventory. For example, for the batch values shown in Table III, the equivalent value for torus inventory measured by on-line instruments was 7.9g.

3.7 POST DTE1 ACCOUNTANCY AT JET

Since DTE1, there has been a periodic inspection by Euratom to verify the amount of tritium stored in the AGHS with the balance between this and the calculated total inventory being declared as Material in Process.

After DTE1, there was a shutdown (RTE) to reconfigure the JET divertor by remote handling. During this time a significant amount of tritium was recovered by outgassing, an operation was performed to remove by vacuum cleaning co-deposited dust and flakes from the divertor surfaces

Table III

Component	*Quantity of Gas (barl)*	*Tritium Purity (%)*	*Tritium (g)*
T storage Ubed	41.66	99.86	10.31
IP Ubed	5.53	2.30	0.03
Remainder of IP	1.74	81.0	0.35
GC Ubed	14.38	11.4	0.41
Remainder of GC	480	0.014	0.02
Cryodistillation	~2000	–	0.21
Tritiated water	–	–	0.14
Waste discharges	–	–	0.005
Balance (MIP)			8.4

and the divertor tiles used in DTE1, (the MKIIA) were put in storage. At the end of this shutdown a significant amount of the tritium retained at the end of DTE1 was therefore no longer in the torus.

A number of measurements of tritium activity and depth profile on tile samples have led to an assessment of the inventory of the MKIIA as 0.1g.

About 150g of flakes and dust was removed with the specific activity of 1.2 TBq per g measured by calorimetry in a special facility. [27] The material which was accessible for vacuum cleaning during the RTE was only a fraction of the total amount of co-deposited material produced. Subsequent examination of the machine using an endoscope showed that a significant amount of material had spalled off the divertor tiles and louvres and was lying below the divertor.

A further amount of flake material was removed from the sub-divertor region of octant 5 during the 2001 shutdown. This was assessed to be approximately 4% of the flakes in the entire vessel, and is expected to weigh about 40g.Its tritium content will shortly be measured by calorimetry. Assuming activity corrected for decay and outgassing is the same as that previously collected, this gives current total inventory distribution within the JET MBA in August 2002 as shown below:

Tritium gas in AGHS	10.674g
Tritiated water in plant	0.023g
Tritiated water in drums	0.113g
Tritiated flakes	0.419g
Site Inventory	12.714g
MIP	1.485g

The MIP was estimated to be made up of:

MKIIA divertor	0.1g
Baking loop mol sieves	0.1g
Dust and flakes	1.2g
Balance in machine	0.1g

This is about 10% of the site inventory.

The experience at JET and in particular the issues related to the content of tritium in dust shows that unless steps are taken at an early stage to account for tritium, it can be extremely problematical and time consuming to do it retrospectively.

3.8 PROPOSED ITER ACCOUNTANCY ARRANGEMENTS

The arrangements currently foreseen for ITER are to have two MBAs, one for long term storage and the other consisting of all the other tritium systems including the tokamak. The second is analogous to the JET MBA. As with JET, tritium received will be measured by calorimetry and cross-checked by PVT-c on transfer into the plant with the concentration determined by gas chromatography.

Transfers between the two MBAs will be measured by PVT-c with an accuracy of a few percent. Tritium will be transferred to long term storage to store tritium recovered from the plasma facing components.

Within the tritium plant, inventory measurements are foreseen to be carried out by in-bed calorimetry on the delivery system ZrCo beds. These will be required to have a fast response time to enable to provide usable inventory measurements during the process cycle.

Measurement of tritium supplied to the user systems is carried out by mass flow meters and calibrated reservoirs with composition known from ionisation chambers or GC measurements.

Measurement of the tritium exhausted from the tokamak is not foreseen. This means that the inventory of the tokamak and the remainder of the MBA are not separately known. In particular the amount of tritium trapped in the tokamak can only be deduced by difference when there is a periodic full inventory assessment of the tritium plant. This requires temporary cessation of plasma operation.

4. DISCUSSION

It appears that item accounting, measurement of waste discharges and an appropriate level of process accountancy are acceptable for the quantities of tritium used in fission reactors, light source manufacture, and the radiochemical industry. This also applies to CANDU reactors where the tritium production rates are well defined, moderator levels can be determined, and the tritium removal plant operates in a stable way. These regimes were also the basis of what was applied to TFTR and JET.

However the two issues which are distinct for fusion are tritium retention and breeding and the challenge is to ensure that these do not prompt regulators to demand a more onerous accountancy regime for fusion power plants.

Tritium retention is already being addressed and the choice of PFC materials and development of detritiation techniques will reduce the scale of the problems which occurred in JET and to a lesser extent TFTR. Assay of tritium will remain an area requiring development.

Tritium generation in fusion blankets, in which the tritium throughput is higher than any other previous source, additionally has the potential to dilute the perceived environmental advantages of fusion if not properly addressed.

Both TFTR and JET have had some difficulties in meeting the limited accountancy regimes specified for their operations. Lack of diversity in instrumentation, the different time constants

required for the different accountancy measuring devices and, particularly in the case of JET, lack of an appropriate method of measuring the tritium pumped from the machine led to discrepancies and restriction of the programme.

Even with the periodic inventory measurement in JET the knowledge of tritium distribution was inadequate and still remains so at present. For any future significant DT campaign at JET improvements in the measurement of tritium exhausted from the machine are desirable in order to avoid long delays in plasma operation to perform full accountancy within AGHS.

Technical difficulties experienced included significant problems with contamination of ionisation chambers and sample cross contamination. Further work on non-invasive forms of concentration measurement such as laser Raman spectroscopy would improve this aspect considerably, but would require the use of special windows or fibre optics.

The regime proposed for ITER is very similar to JET, apart from ITER having the capability for in-bed calorimetry. As with JET, it is likely that a full shutdown of ITER tritium processing will be necessary to perform periodic inventory measurements. An improvement in the information on the dynamics of tritium retention could be achieved by the installation of additional accountancy volumes for measurement of the tokamak exhaust because the ITER Tritium plant uses mechanical pumps instead of cryo-pumps as in the JET AGHS. Although systematic errors between measurements in different parts of the cycle would accumulate and still require a periodic overall inventory assessment to reconcile them, this would be much less frequent.

ITER is similar to TFTR and JET in that virtually all of the tritium will be transported to site. The amount of tritium bred is a very small part of the throughput. Modelling and/or measurement will be needed to enable this to be accounted for.

For power producing plants, tritium flows will be dominated by tritium generation in the blankets and there will need to be adequate means to account for it in the cycle from an operational and safety point of view. Of particular concern could be inadvertent transfers to waste during maintenance. In view of the scale of use a robust assessment of possible accountancy regimes and techniques is necessary to ensure that appropriate provisions are made. For example, as the tritium recovery from the blanket streams will be done in special tritium removal systems, this could be considered as a further special MBA. The techniques used for measurement within this MBA could be developed and tested in JET. ITER, TLK and other laboratories.

However it is important for licensing that proposals to regulators on tritium accountancy for power plants are realistic and can be met.

CONCLUSIONS

1. Tritium inventory measurement at JET and TFTR was not straightforward and required significant effort and operational time to resolve.
2. The use of carbon tiles as a first wall material in these machines further complicated tritium accountability due to co-deposition issues

3. Improved exhaust gas monitoring should be considered for any future significant DT campaign in JET.
4. Further development should be carried out on non-invasive methods of tritium measurement
5. It would be advantageous for ITER to improve the accountancy capability in the fuel cycle. In addition the ITER fuel cycle needs to be configured in a fashion to avoid accountancy choke points.
6. Earlier attention should be given to the regime of accountancy for power plants and appropriate development work initiated.
7. Existing facilities and ITER should be used to demonstrate the viability of any accountancy regime.

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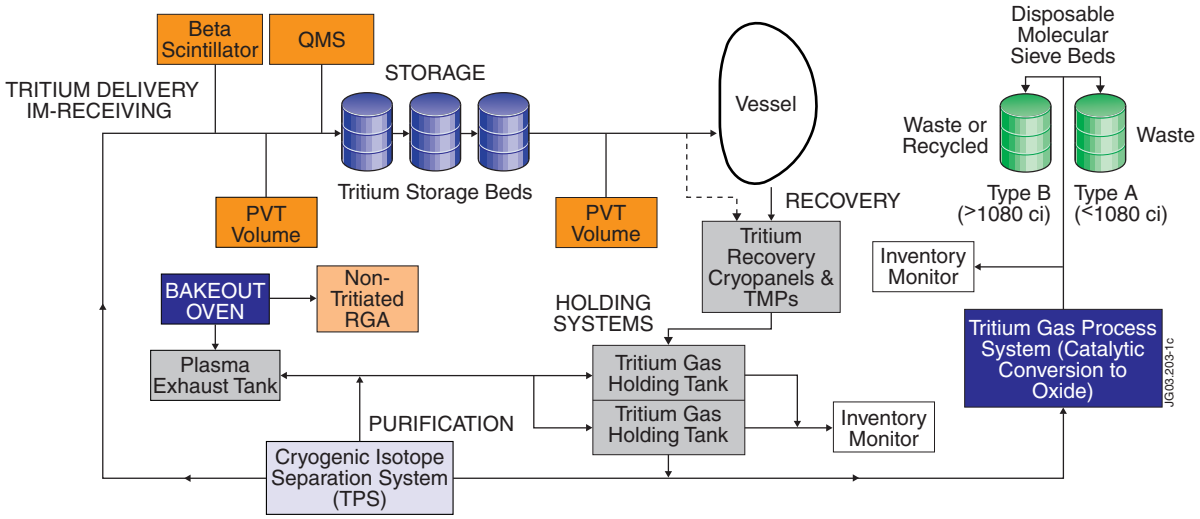

Figure 1: TFTR Fuel Cycle.

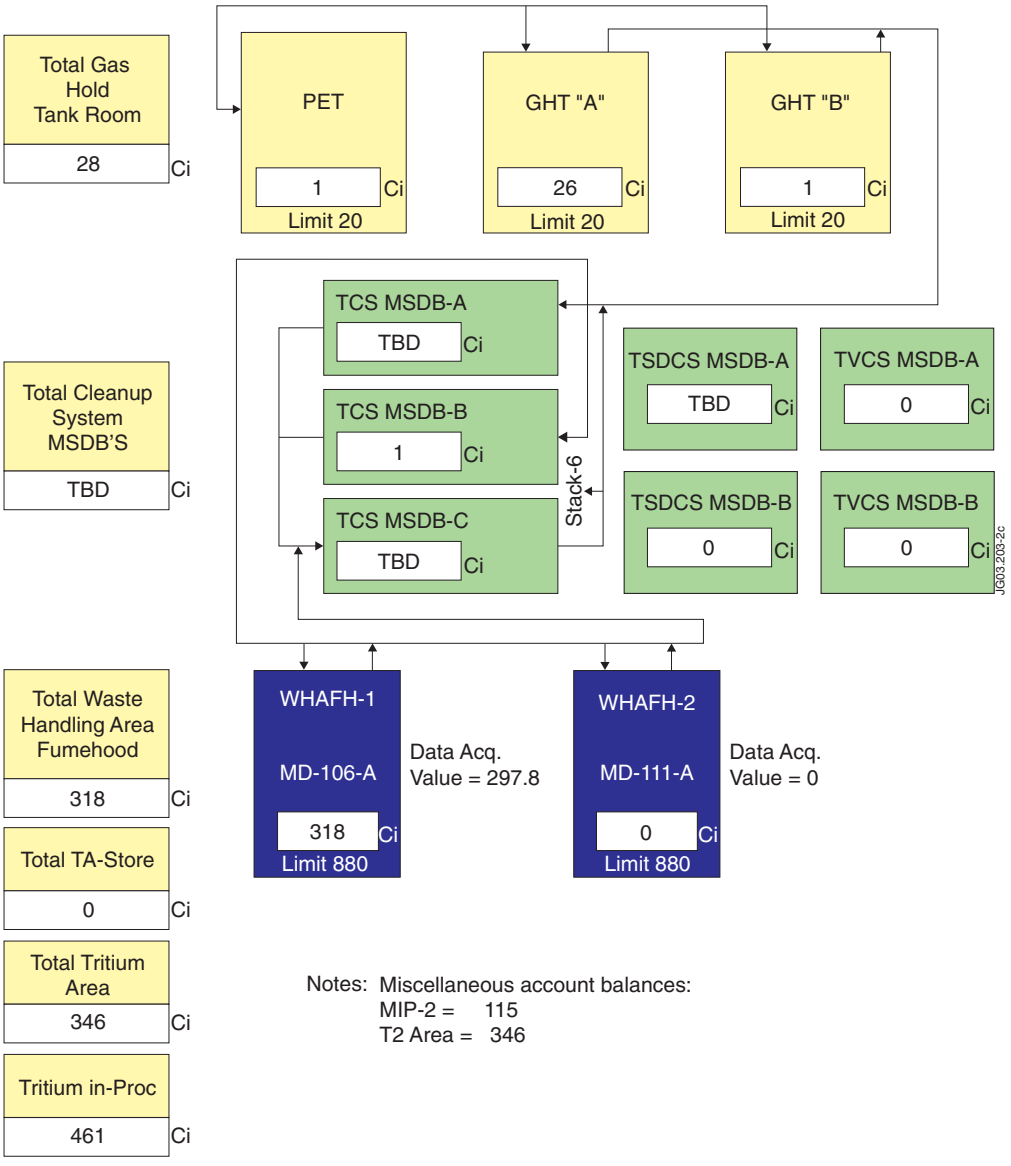

Figure 2: TFTR Accountancy.

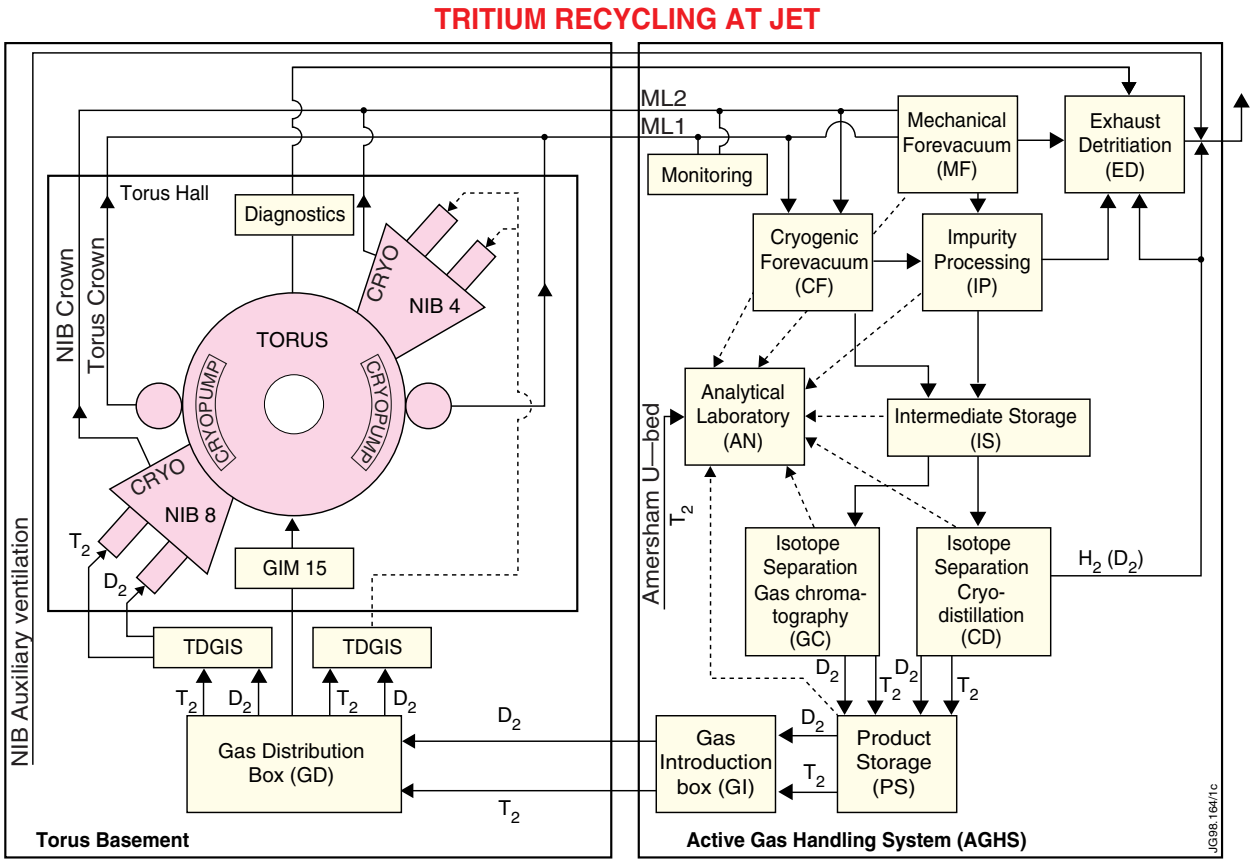

Figure 3: JET Fuel Cycle.