Tritium-related Fusion Technology Programmes under EFDA-JET

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1. Introduction

There is a significant research programme within the EU into fusion as an energy source. The next stage in the programme is to build the International Thermonuclear Experimental Reactor (ITER), which may be sited in Europe. The fuel for the commercial fusion process is a mixture of tritium and deuterium, so inevitably there are many technology issues associated with the use of tritium. Solutions to these issues will need to be ready for ITER, and are already being addressed at JET (the Joint European Torus). The JET machine is unique because it is the largest fusion device in operation, has capabilities for handling beryllium (Be) (which is expected to be used as a cladding material in ITER), can achieve plasma configurations nearest to ITER scenarios, allows the study of the largest variety of heating possibilities, and is best suited to test ITER diagnostics. Its scientific success has been recently summarized [1]. In addition, the JET tokamak was built to handle tritium. Limited and extended campaigns fuelling with a deuterium-tritium mixture were performed in 1991 [2] and 1997 [3], respectively, and remote handling tools have been developed and are used for the replacement of components inside the machine in a Be- and tritium-contaminated environment with a high background radiation.

The exploitation of the JET facilities is managed under the European Fusion Development Agreement (EFDA) by the Associated Leader for JET and the Close Support Unit (CSU) in Culham. Scientific and Technical (S/T) tasks for experiments, enhancements and technology issues are performed in various Task Forces (TF). In the Fusion Technology Task Force (TFFT) mainly S/T tasks with respect to tritium in the tokamak are performed involving the JET Operator (UKAEA) and several EU Laboratories. 26 S/T tasks were performed within TFFT in 2000 to 2002 and 18 new ones are in progress in the 2003 work programme

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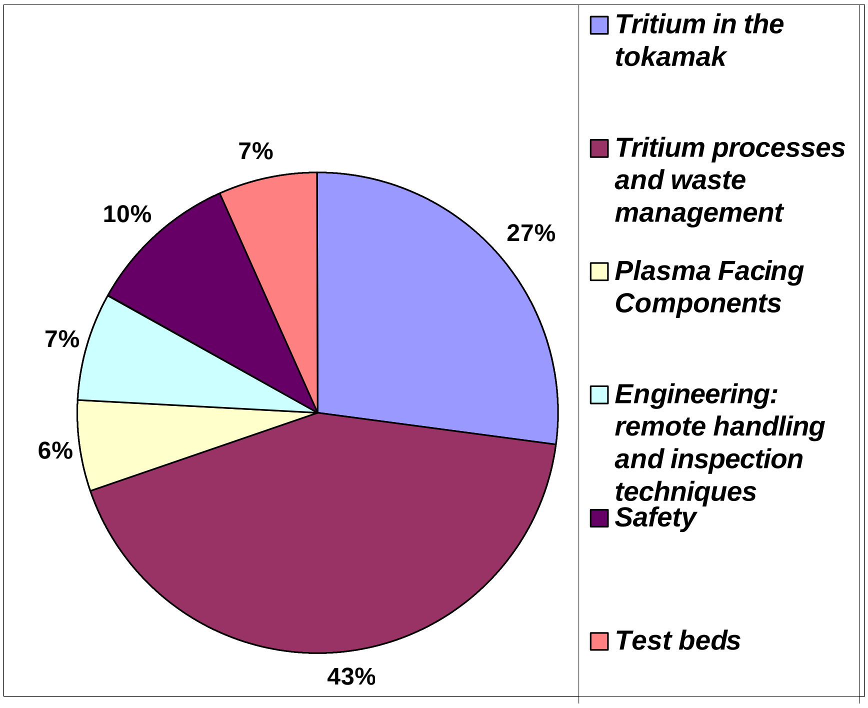
Figure 1: Contributions of the TFFT S/T topics to the research programmes of both JET and ITER during the period 2000-2003.



TFFT supports programmes in the areas of waste management and safety, tritium recovery, tritium analysis and accounting, and testing components under development for ITER at JET. De-tritiation techniques are being developed for a number of waste streams, including water (an important issue also for JET), oils and other organic liquids, getter beds, and soft housekeeping waste. Tritium inventory must be minimised both for safety reasons and because it is a valuable resource, so recovery of tritium from within the torus, and from tiles and flakes is being studied. Among items being tested, or under development, at JET for eventual use on ITER are mass flow meters, a neutronic study of a test blanket, a cryosorption panel, a prototype catalytic exchange unit and optical fibres. Safety-related programmes include collection of JET operating experience on component failure and on occupational radiation exposure to provide reference data for ITER design, as well as assessment of biological damage from tritiated dust, and validation of shutdown dose rate calculations. This paper concentrates on the waste and safety issues: other fields have recently been reviewed elsewhere [4,5]

2. Waste issues

The largest deployment of effort in the waste management area is on water de-tritiation. Figure 2 shows a schematic of a water de-tritiation plant envisaged for JET as a prototype for ITER, and areas of current development work under TFFT are indicated.

(Figure 2 is to be found following the References at the end of this paper)

Responsibility for the overall scheme design is with UKAEA through task FT2.2. Currently about 50 tonnes of tritiated water produced at JET is stored in drums, with tritium activity varying from 0.04 GBq/kg to 204 GBq/kg and a total activity of over 1100 TBq [6]. In order to process water of the highest activity to a level below the discharge limit, the plant is designed to achieve a Decontamination Factor (DF) of 10,000. This should be readily achievable using a **Combined Electrolysis and Catalytic Exchange (CECE)** method. The CECE method proposed here combines an **Electrolyser** to convert tritiated water to gaseous hydrogen with a **Liquid Phase Catalytic Exchange (LPCE)** column where the gaseous hydrogen flows from the column's bottom to the top in counter-current mode to pure (i.e. tritium-free) liquid water. The tritium extracted from the water is in the form of HT gas, and this gas can be enriched in tritium for re-use as a fuelling gas using a **Cryo-distillation (CD)** column (one of which is already in use at JET)

An important part of the process is the catalyst used in the LPCE. Catalysts of different form are under development at SCK-CEN in Belgium, and FZK, Karlsruhe (Germany). Variables such as particle size, the support material/shape and the properties of the packing material at the ends of the exchange unit have been studied. Further studies in progress or planned include longer columns of several exchange modules to increase the DF, and endurance testing of catalysts (e.g. mechanical stability, erosion resistance, resistance to radiative breakdown of catalysts or supports, recovery from degradation due to impurities).

A number of other aspects of a water de-tritiation plant are also being explored within TFFT. The design of a suitable electrolyser as well as a CD with larger capacity for JET are in hand at UKAEA, and FZK are testing solid polymer electrolytes. Since impurities can poison catalysts, attention has also been given to purification of all water and gas feeds to the CECE. For example, tritiated water is a product of the treatment of tritiated organics, and suitable techniques such as actvated carbon, ion exchange beds and micro-filtration for preventing contamination from such feeds have been proposed in the literature. Another possible source of contamination being investigated is spreading of KOH from stripping columns (ionisers).

Tritiated water is just one of the many waste streams from a fusion reactor. Other liquid wastes include oils, organic liquids and scintillation cocktails (from the many hundreds of routine analyses for tritium made every month). Methods to deal with these, together with the ubiquitous, but extremely bulky, soft house-keeping waste are being studied at SCK-CEN, CEA and UKAEA. CEA are also examining the de-tritiation of structural materials such as steels, and, together with FZK and UKAEA have programmes on the de-tritiation of carbon-based in-vessel components from JET.

A technique that is being studied at CEA, Saclay with applications to decontamination is laser ablation/desorption. When a laser beam interacts with a surface there is a transfer of energy. Depending on the power density in the beam and the pulse duration, this energy can be used either to heat the surface to a suitable temperature for desorption of gas (e.g. of tritium and other hydrogen isotopes) from deposited films, or to ablate surface material.

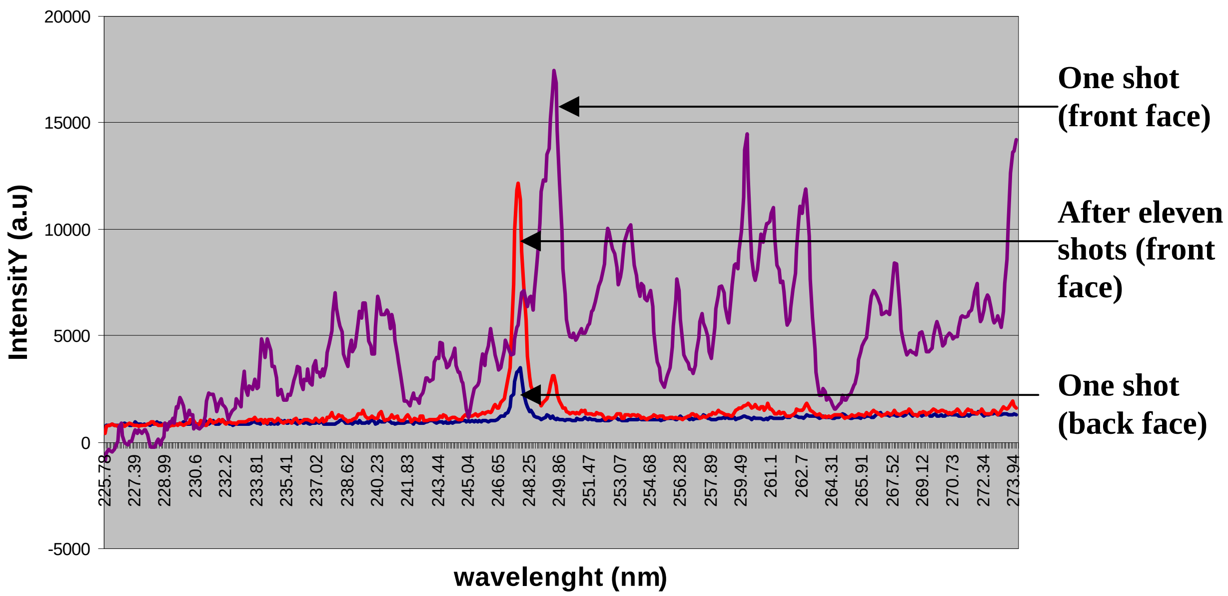


Figure 3: Optical Emission Spectroscopy of a carbon tile from Tore Supra before and after scanning with a laser to remove the co-deposited layer.

Among the surfaces treated have been stainless steel coated with Mo and Zr, and carbon tiles from within the Tore Supra tokamak covered with co-deposited films. With the laser in the ablation mode, the cleaning process can be followed by viewing the ablated species spectroscopically, and cleaning is successful when the spectrum from the surface impurities disappear and are replaced by that of the substrate. Two techniques in use at CEA are Luminescent Discharge Spectroscopy (LDS) and Optical Emission Spectroscopy (OES), and an example of the use of the latter is given in Figure 3. Material ablated from the first laser pulse gives a spectrum characteristic of the deposited layer, whilst after eleven shots the spectrum has almost reverted to that ablated by a pulse on the (clean) back surface of the tile.

3. Safety-related programmes

Some of the safety-related issues being investigated on behalf of future fusion facilities such as ITER through TFFT include evaluation of operating experience at JET and studies of tritium spreading and inhalation effects. JET has operated with tritium for more that a decade, and has comprehensive records of dose rates to staff, and operating experience with tritium handling equipment and vacuum and plasma heating plant. It is important to record and learn lessons from this experience.

The approach to predicting occupational exposure in ITER adopted by TFFT is three-pronged. Firstly, an **Occupational Radiation Exposure (ORE)** data-base is collected from JET experience; secondly, develop computational models of exposure rates based on activation and dose rate calculations on JET; thirdly, compare and validate the models against the ORE data-base, and then extend to ITER. The ORE database is being collected by ENEA in collaboration with the JET Health Physics department, firstly using data from Neutral Beam Injection system maintenance activities as a test case. The ORE assessment requires knowledge of the sources, the time for each intervention, the number of people involved, the number of planned maintenance activities, and the frequency of unexpected (unplanned) events resulting from failure of components.

Two different Monte Carlo computational schemes are being applied to model dose rates at selected points interior and exterior to the JET machine. The **Rigorous 2-step (R2S)** system with automated interfaces is being developed at FZK, and the **Direct 1-step (D1S)** Monte Carlo method is used by ENEA. For each model, it is necessary to use the output of the

Monte Carlo N-Particle (MCNP) transport code developed at Los Alamos [7] for activation of the JET components and full drawings provided by UKAEA. It is planned to make a first comparison of the results from these codes with experimental data within the next few months.

ENEA have been at the forefront of data collection on single component malfunctions and failures. Information has been gathered on the Vacuum and Tritium Gas Handling plants at JET and on the facilities at the Tritium Laboratory, Karlsruhe. The procedure is to collect the information useful to evaluate probabilistic values for failures, to estimate reliability parameters (with standard errors and confidence intervals) and point out practical information from the operating experience.

The number of generic faults in the JET Advanced Gas Handling System from 1995 to January 2002 has been evaluated, and 21 different items that had failed were listed, with frequencies varying from once to 61 times within the period. Valves failing to respond to commands were the most numerous faults. A similar exhaustive survey has been completed on the JET vacuum system; 616 vacuum leaks were recorded from 1983 (the first year of JET operation) to 2002 (inclusive): data are presented in Figures 4 and 5.

Compone nt	Qty on Vacuum	Operating Hours	N° of Installatio
Bellow	243	18,122,328	421
Burst Disk	2	189,648	4
Butt	686	42,077,976	1084
ComFit	236	14,690,760	432
DNnnn	462	26,479,320	719
F/T Cryo	4	379,296	8
F/T El	143	9,158,256	221
F/T Gas	19	1,118,832	33
F/T Lq	72	3,482,688	106
Fillet	806	53,084,424	1321
GaugeP	95	6,320,208	159
Insulator	1	50,256	2
Lip	542	30,882,624	841
RHnnn	254	16,888,344	411
VacPump	42	2,866,152	71
Valve	153	9,393,960	245
Window	252	15,578,736	393
	4012	#########	6471

Figure 4: Statistics on a number of identifiable types of vacuum system components, their quantity and cumulative operating time, in the JET vacuum system.

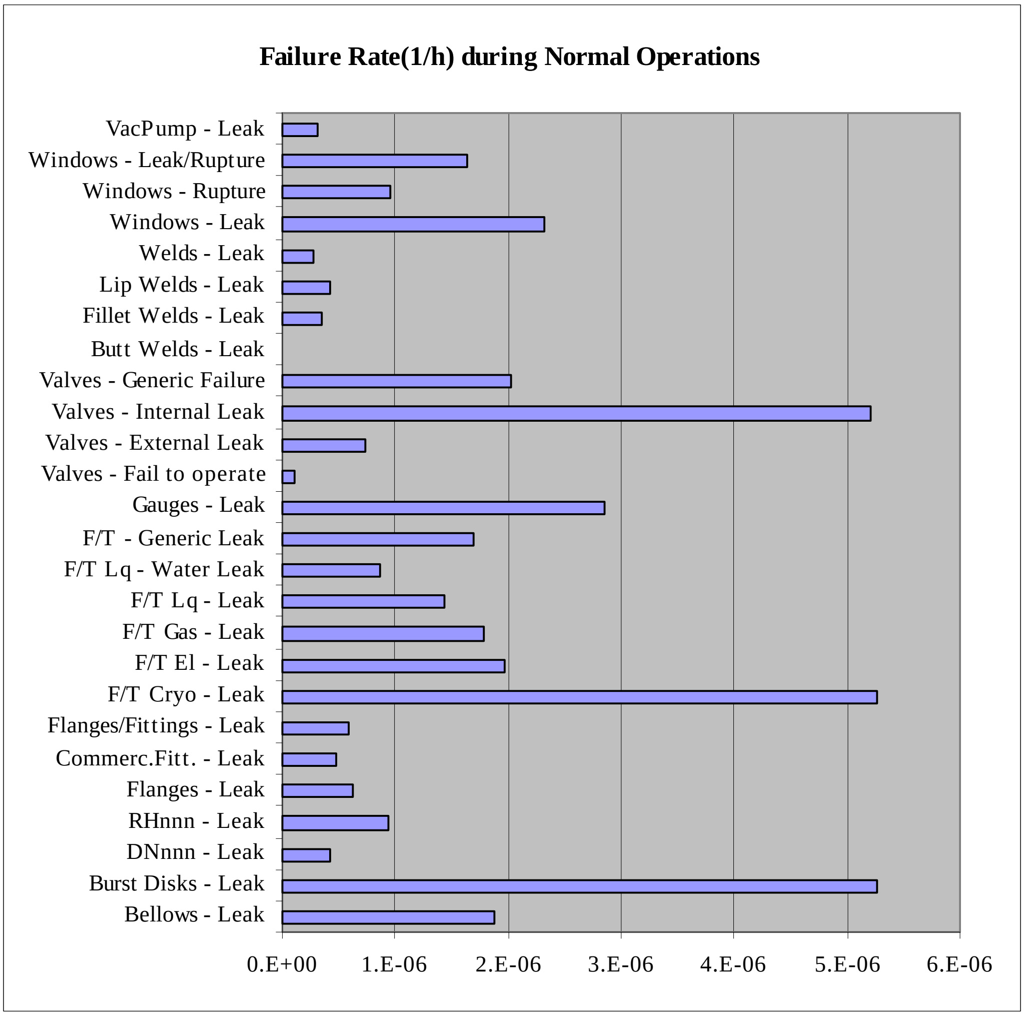


Figure 5: Failure rate (per hour of operation time) for each failure mode identified for the JET vacuum system.

Whilst all conceivable steps are taken to ensure the integrity of plant handling tritium, and JET has an exemplary record in this connection, Planning Authorities expect a full analysis of the effect of failures, however unlikely. Should a breech occur in a system containing tritium, some idea of the possible spread of the tritium gas is required, and of possible air-borne dust and flakes. Associated with this is a study on the effects of the inhalation of tritiated particles.

The simulation of tritium spreading in controlled areas being undertaken by FZK aims to calculate the activity inventories and shutdown dose rates following DD and DT operation at JET. The work is performed using the **GASFLOW** code (finite volume method). The numerical model is being modified in order to take into account absorption and desorption phenomena on the walls and the ventilation of the volume being modelled (the “caisson”). The model can be developed and applied to more complicated structures representing rooms containing large items of plant. Results are validated by comparison with experimental data in conjunction with the Japanese Tritium Laboratory.

Tritium gas, even if inhaled, has relatively short-term effects. Potentially more serious are air-borne particles such as carbon dust that may be highly tritiated and can lodge in the respiratory tract and lungs. So far under TFFT a literature search has been completed by ENEA, and an assessment of the aerodynamic properties of dust from JET collected in the 1999 shutdown. The Intake of T as a particulate can yield a dose quite different to intake of the same quantity as HTO. The amount of T exchanged into body fluids and hence the dose delivered will depend on the deposition of particulate in the respiratory tract and lungs, as shown in Figure 6. This in turn depends on the particle composition, the particle aerodynamic diameter, and the particle motion and lung air-flow pattern which is governed by breathing rate and route of intake. The amount exchanged also depends on the rate of clearance, the dissolution rate of T from the material and the activity present. The next phases of the TFFT programme will be in-vitro tests on the interaction of tritiated dust from JET with body fluids, and then possibly to proceed to in-vivo tests.

Conclusions

The Fusion Technology Task Force (TFFT) has a wide-ranging series of programmes in the areas of waste management and safety, tritium recovery, tritium analysis and accounting, and testing components under development for ITER at JET. Examples have been presented here in the fields of waste management and safety.

In waste management, the largest effort is currently on water de-tritiation, which is considered to be the most urgent and important topic affecting JET operations, and plant design is also required for ITER. It is also the most technically challenging of the waste de-tritiation issues. A complete design for a water de-tritiation plant for JET (a prototype for ITER), including optimised and tested catalysts, is expected within the next 2 years.

TFFT safety programmes support the on-going work on safety in preparation for ITER, including tritium spreading and dust inhalation effects for worse-case accident scenarios. Effort is also going into documenting the operational experience of the JET machine with respect to reliability of mechanical components within the tritium boundary and radiation exposure, and inferring what lessons should be learnt for ITER.

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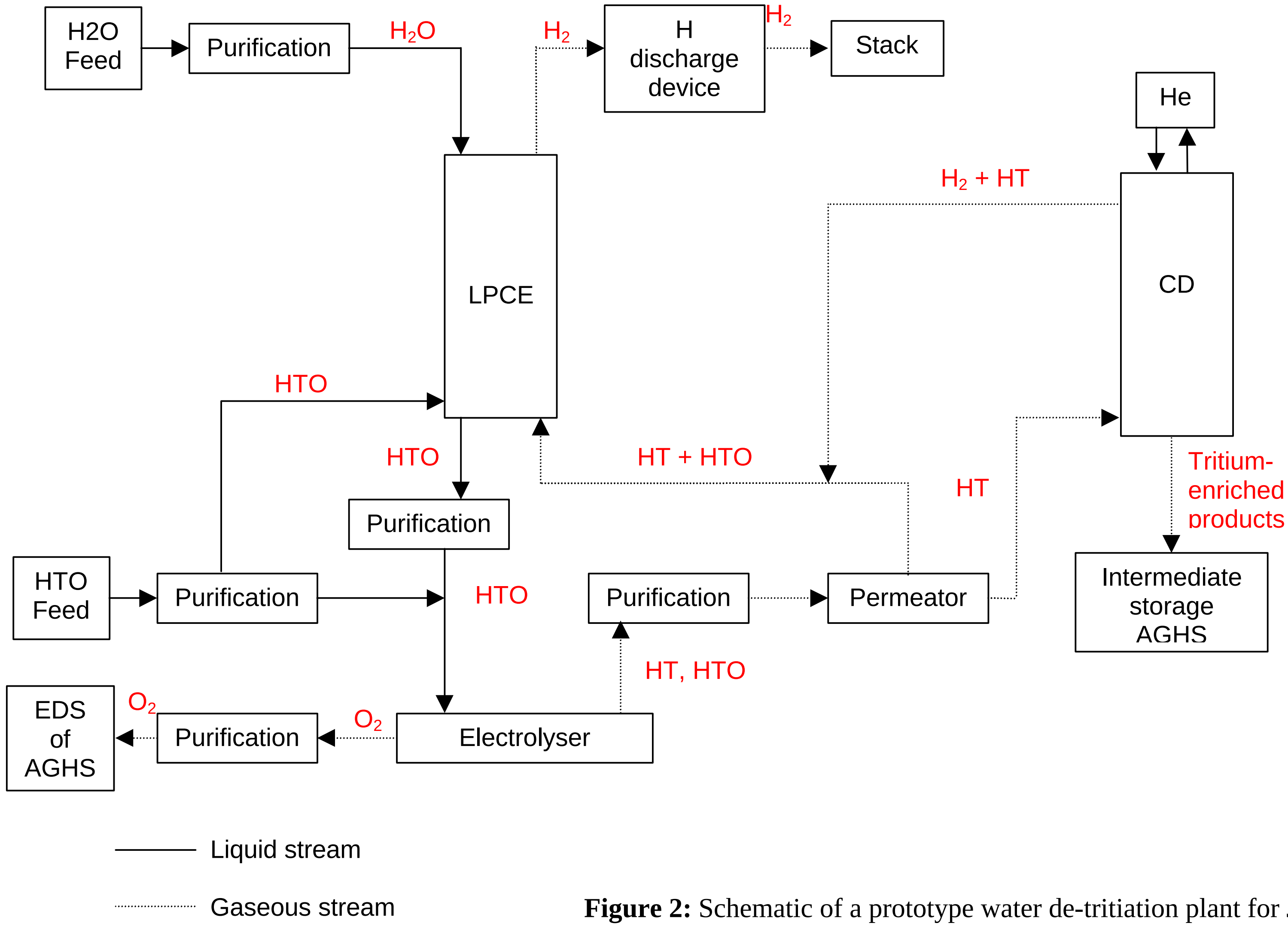
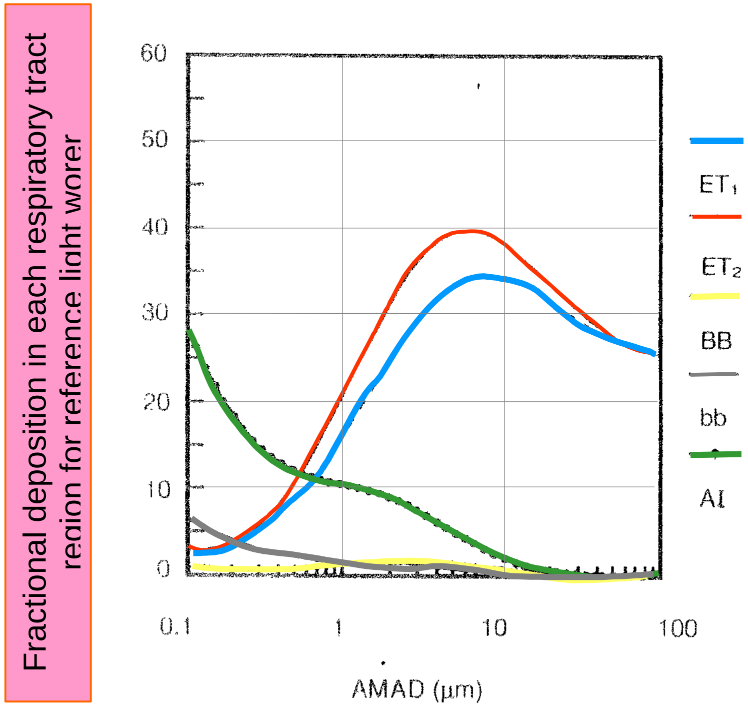
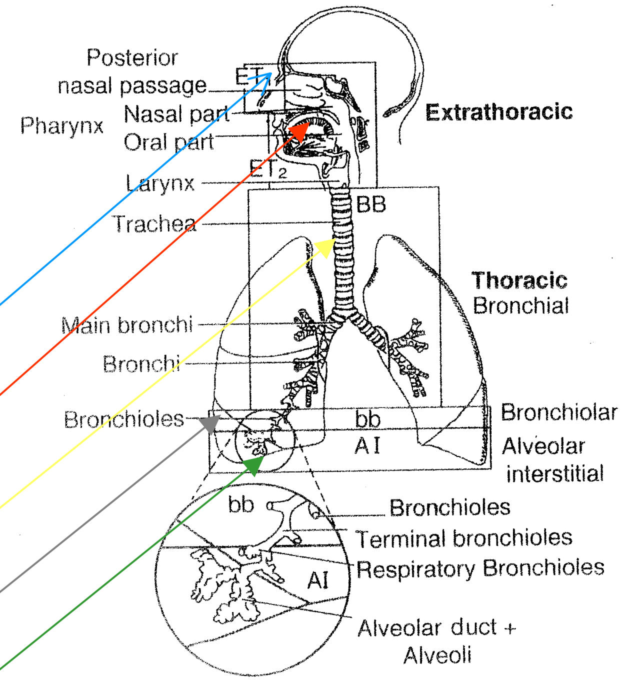
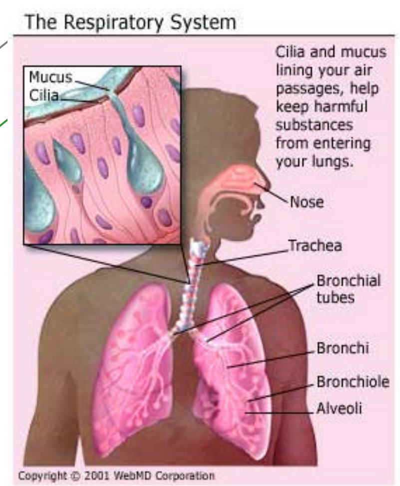


Figure 2: Schematic of a prototype water de-tritiation plant for JET, indicating areas of current development work under TFFT.

- Measurements of dust collected during JET 1999 shut-down showed a mean diameter (AMAD) of 4 µm
- This value is in the range of the respirable aerosols (<10 µm). The deposition in the different parts of the human respiratory system depends on the particle aerodynamic diameter.
- According to predictions by the new ICRP Model for the Human Respiratory Model (HRTM), the fractional deposition of dust versus AMAD is shown in the figure below.







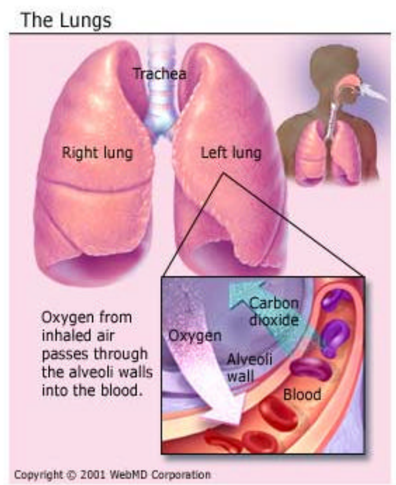


Figure 6: Tritiated dust inhalation and uptake mechanisms in the human body.