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TITLE: ITER FUEL STORAGE SYSTEM CONCEPTUAL DESIGN DESCRIPTION

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ITER FUEL STORAGE SYSTEM
CONCEPTUAL DESIGN DESCRIPTION

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ABSTRACT

Fuel, in the form of hydrogen isotopes Q_2 (where Q is H, D, or T), is required to be stored and assayed in a safe manner at the proposed International Thermonuclear Experimental Reactor (ITER). Two subsystems are proposed for this task: Fuel Storage (FS) and Fuel Management (FM). The combined system, Fuel Storage and Management System (FSMS), will provide fuel storage, tritium inventory, gas analysis, transfer pumping, and flow measurements. Presented is a Conceptual Design Description (CDD) of only the FS portion of the FSMS. The proposed FS system permits tritium and its associated isotopes to be stored within ZrCo storage beds, as a solid metal-hydride, or as a gas stored in tanks.

INTRODUCTION

This design is a contribution of the U.S. to the international ITER effort. The design was produced by personnel of the Tritium Systems Test Assembly (TSTA) at Los Alamos, and incorporates ideas gained from the extensive operating experience at the TSTA. The getter material (ZrCo) used for the storage bed system was preselected as a design requirement.

The general functional requirement provided by FS is the safe storage of all tritiated hydrogen mixtures in the plant for startup, makeup, and shutdown operations under both normal and abnormal conditions. Through FM, this storage mechanism facilitates measurement of the tritium inventory for accountability and segregates different isotopic concentrations without the addition of impurities to the Fuel Cycle process.

For reasons of safety and possible contamination, FS will only be interfaced with other Fuel Cycle systems via FM.

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These Fuel Cycle systems include Fuel Processing, Isotope Separation, Fueling, Plasma Vacuum Pumping, Blanket Tritium Recovery, Neutral Beam Line, Waste Water Processing, Exhaust Gas Detritiation, Solid Waste Recovery, and the Tritium Load In/Out subsystem. The presented FS system satisfies the requirements stated in the Design Information Document Proposed Revisions July 1990¹.

SYSTEM DESCRIPTION

Fuel Storage satisfies four functional requirements: 1) shutdown storage for the fuel cycle inventory following a normal shutdown- capacity to store 2.4 kg of T_2 as purified DT, 10,000 moles of D_2 , and 4,000 moles of purified H_2 ; 2) backup shutdown storage for the fuel cycle inventory following an unscheduled or abnormal shutdown- capacity to store 10,600 moles of nonpurified hydrogen isotopes; 3) in-process surge storage for selected interfaces between Fuel Cycle subsystems requiring specific receive/deliver rates, and 4) makeup storage capacity to store 1 kg of T_2 as DT, 3 kg of D_2 , and 1.5 kg of H_2 .

One of the basic requirements for the tritium handling systems at ITER is that no more than 200 g of T_2 can be exposed to the risk of release from primary containment by a single initiating event. This requirement is met by restricting the storage quantity of the DT storage beds and employing administrative controls.

In this design, DT storage beds are designed for a maximum possible storage capacity of 60 moles of hydrogen isotopes. Global availability of >99 percent is assured by providing 50 percent redundant hydride storage beds for DT, which will also compensate for capacity that might be lost due to bed poisoning by impurities. For gases primarily D_2 and/or H_2 , large, 2000-mole, commercially available hydride beds designed for hydrogen storage will be

used. Hydride beds were chosen over tanks because they offer more compact storage and limit potential energy sources within the facility.

The four required storage modes are discussed in the following paragraphs.

Shutdown storage

Prior to shutdown storage, the inventory of gases in the Fuel Cycle subsystems will be routed through Fuel Processing for purification and then through Isotope Separation for separation. The products requiring storage during the shutdown period will be high-purity hydrogen isotopes. For this requirement 60-mole capacity metal-hydride beds are used to store the 2.4 kg of T_2 as DT and 2000-mole capacity, commercially available metal-hydride beds will store the 10,000 moles of D_2 and 4,000 moles of H_2 . The number of beds required to store this gas are 20, 6, and 3 respectively. The D_2 and H_2 is a high-purity product and will not require secondary containment, but will be located in the Tritium Storage Vault for added protection. The DT hydride beds will be secondarily contained within gloveboxes and located in the Tritium Storage Vault.

Backup shutdown storage

Backup shutdown storage is provided for off-normal or emergency shutdown. The backup shutdown storage requirement is met by providing a combination of double-walled storage tanks and 2000-mole capacity, commercially available hydride beds. Total storage of 10,600 moles is required, 9800 moles will be stored in beds and 800 moles in tanks. Specifically, 1992 moles from Isotope Separation, 6075 moles from Neutral Beam Injection, and 1734 moles of propellant gas from Pellet Injection will be stored on eight 2000-mole capacity hydride beds. The 1992 moles from Isotope Separation is made up of the 1660 moles from the first three columns and 332 moles of residuals in the fourth column. The remaining 785 moles of gas will be stored in the double-walled storage tanks.

During normal operations the tanks are maintained in an evacuated standby condition and the beds empty. A total of nine tanks and eight 2000-mole beds are required for backup storage.

In-process surge storage

Fuel Storage is required to provide

in-process surge storage between six Fuel Cycle subsystems. The following double-walled storage tanks are provided: 1) a DT feed tank from the impurity removal stage of Fuel Processing to Isotope Separation; 2) three DT feed or accountability tanks to receive DT Product from Isotope Separation and distribute it to the fueling systems; 3) a H_2 feed tank for the spent propellant coming from Pellet Injection to Fuel Processing; 4) a H_2 feed tank from Blanket Tritium Recovery to Isotope Separation; 5) a D_2 feed tank from the torus-side cryopumps of the Neutral Beam Injection Modules to Isotope Separation, and 6) a feed tank to collect the various gases that will be routed to Exhaust Gas Detritiation for final purification prior to atmospheric release.

Tank sizes are first based on limiting the tritium inventory to less than 200 grams, and second, to provide capacity for two hours of operation at normal flowrates.

Fuel makeup storage

This requirement is met by providing a combination of double-walled storage tanks and 60-mole metal-hydride storage beds. A total of 10 hydride beds will be provided to store the 1 kg of T_2 as DT and three tanks to store the 3 kg of D_2 and 1.5 kg of H_2 . During Fuel Cycle operations only one of these tanks will be required. The other two will provide short term buffer storage for checking hydride bed tritium accountability measurements by conventional PVT and mass spectrometer techniques.

All of the hydride beds for fuel makeup storage will be secondarily contained within gloveboxes and located in the Tritium Storage Vault. Table 1 shows the design parameters and the storage bed specifications. Table 2 is a summary of the hydride beds used within Fuel Storage. Figure 1 shows the Fuel Storage flow diagram.

Bed configuration and design

Storage beds, associated plumbing, and instrumentation are contained within inert-atmosphere gloveboxes. Fuel Storage 60-mole bed gloveboxes are divided into two sections. The upper section contains the necessary process valves, piping, vacuum equipment, and instrumentation. The lower section contains the secondary containers, water-cooling lines, and the secondary container lifting/lowering jacks shown in Figure 2. Gloveboxes can also function

as a fume hood, if needed, during storage bed maintenance operations.

DESIGN PARAMETERS		ZrCo + 1.40, = ZrCoO ₂
Grams of ZrCo/mol =		150.15
Density ZrCo, g/cc =		7.63
Design density ZrCoT ₂ , g/cc =		2.00
Floor area of each glovebox, m ² =		10.00
Volume of each glovebox, m ³ =		25.00
Storage beds per glovebox (60-mole) =		8.00
Storage beds per glovebox (2000-mole) =		2.00
STORAGE BEDS		
	60-MOLE	2000-MOLE
Amount of gas to be stored, mol =	1,134.00	23,801.00
Capacity per bed, mol =	60.00	2,000.00
System capacity factor =	1.50	1.50
System capacity, mol =	1,701.00	35,701.50
ZrCo required per bed, Kg =	6.44	214.50
Number of beds required =	28	18
Total ZrCo required, Kg =	182.43	3,828.99
Primary container volume, liters =	3.22	107.25
Number of gloveboxes required =	4	9
Floor area of gloveboxes, m ² =	35.44	89.25
Volume of gloveboxes, m ³ =	88.59	223.13

Table 1. Design parameters and storage bed specifications

A major feature of the 60-mole bed design is the rapid in situ method for tritium assays. This is accomplished by utilizing the tritium decay heat and measuring the steady-state temperature of each vacuum-insulated bed. Bed calibration is accomplished by measuring the primary container steady-state temperature at several measured heater input-power settings. Steady-state bed temperature calibrations will be performed periodically to correct for any changes in container emissivity. Vacuum was chosen over blanket-insulation because of the rapid bed-heating/cooling response times that are possible with secondary-container water-cooling combined with primary container convective cooling. By utilizing nitrogen-convective-cooling, cooling water adjacent to the hot primary getter beds can be eliminated thus eliminating tritium permeation into the cooling water.

PURPOSE	Tritium Grams	Total Moles	Cap. Moles	Number Req.
Shutdown Storage	2400	400	40	20
Backup Shutdown Storage				
ISS Backup	105	1992	2000	2
Neut. Beam Int.	10	6075	2000	4
PI Propellant Gas	105	1734	2000	2
Fuel Makeup Storage				
Fuel Makeup H2	1000	334	66	9
Fuel Makeup D2	<1	10,000	2000	6
Fuel Makeup H2	<1	4,000	2000	3

Table 2. Summary of the hydride beds used within Fuel Storage

Figure 1. Fuel storage flow diagram.

Two types of the large 2000-mole commercially available capacity beds are utilized, the flow-through and dead-ended types. The dead-ended types are used to scavenge most of the hydrogen isotopes while the flow-through types are used to remove the residual hydrogen isotopes from the process stream by the addition of helium gas. These beds are constructed from 54 mm stainless steel tubing with an effective length of approximately 65 meters. For glovebox applications the beds would be reconfigured to 0.5 m diameter by 1.3 m long units. Delivery rates of 400 moles/hr and heating rates of 200°C/hr are also achievable.² Due to the low tritium inventory of these beds, vacuum jackets would not be required.

Figure 2. Typical ITER fuel storage glovebox showing two 60-mole beds.

At the present, calorimetric assay is not planned for the 2000-mole beds due to the small amount of tritium they will contain. However, calorimetric assay can be accomplished by the same technique described above or by measuring the change in temperature, during the equilibrium states of the bed, of a circulation gas loop that could serve as a heat transfer medium to an external heat exchanger.

Storage tanks

These are stand-alone, double-walled tanks. Pressures within the DT tanks are limited to 0.9 bar while other low concentration tritium storage tanks are limited to 20 bar. The amount of gas in each tank is controlled by computer-actuated inlet and outlet valves located within the gloveboxes. Continuous inner tank integrity is verified by monitoring the outer portion of the tanks for tritium. The Fuel Storage computer will track the inventory of each tank by employing gas analysis, temperature, volume, and pressure data.

CONTROL PHILOSOPHY

Computer control is absolutely essential for the integration of this system with the other ITER subsystems. During on-line torus operations the main facility computer will initiate and monitor the required functions of the FSMS by communicating with the FSMS computer.

The FSMS computer will control bed heating and cooling, accountability, flow rates, gas composition by in situ Raman Spectroscopy, flow paths, and will monitor the temperatures, pressures, flows, valve positions, bed inventories, tank inventories, glovebox radiation levels, and the storage tank secondary containment radiation levels.

For good responsive bed heating rates (200°C/hr) power is not limited by the normal operating temperatures of the beds. Fuel Storage systems that limit the power to the bed heaters -- to protect against over heating the primary beds--are very slow to heat, typically four to six hours, and are prone to shutdown due to heater maintenance. The over temperature protection incorporated into this system is such that over temperature excursions have a very low probability.

KEY DESIGN ASSUMPTIONS

The Japanese and Germans have shown that

ZrCo is a good substitute for uranium.^{4,5,6,7,8} This material is currently being used at the Tritium Process Laboratory (TPL) at the Japan Atomic Energy Research Institute (JAERI) and being tested at TSTA. Pressure-composition isotherms for this material are shown in Figure 3. The logarithmic pressure and the reciprocal temperature is shown in Figure 4 to have a linear relationship. These data show that hydrogen can be recovered to a residual partial pressure of less than 10^{-4} torr at room temperature and has a dissociation pressure at 400°C of approximately 500 torr.

Figure 3. The pressure-composition isotherms for the ZrCo-H system.

An important safety concern for all getter materials is the pyrophoricity of the material.³ Neither ZrCo powder nor ZrCo hydride powder burns in air at room temperature⁴; however, they are pyrophoric at temperatures above 280°C. ZrCo has some attractive advantages over uranium: 1) it is of comparatively low pyrophoricity and its reactivity towards impurities characteristic of the fusion fuel cycle is low; 2) it is of non-nuclear character; 3) it shows a small volume expansion upon hydride formation, and 4) tritium gettering by ZrCo can be

released at relatively low temperatures. The main drawbacks of ZrCo are seen in the somewhat higher hydrogen dissociation pressure of ZrCo hydride at room temperatures and in the more stringent conditions needed to recover quantitatively the gettered tritium.⁵ It is also less fully tested than uranium at this point.

Figure 4. Temperature dependence of the equilibrium hydrogen pressure of hydriding $\text{ZrCoH}_{0.8}$.

Another advantage of ZrCo is the dissociation of ZrCo in hydrogen at pressures above 1 atmosphere at temperatures above 500°C . The reaction forms ZrO_2 and ZrCo_2 . It was observed that this reaction can be reversed if heated to 500°C under vacuum.⁵ After repeated hydriding both uranium and ZrCo become a fine powder, however, it has been observed that ZrCo does this to a much less of a degree.

A major concern for all tritium storage systems is tritium assay. This design incorporates calorimetric assay of each of the 60-mole beds by utilizing the tritium decay-heat and measuring the equilibrium temperature of the primary container. The average response in the temperature range studied is 3.9°K for every 1055 joules or 3.9°K for each gram of tritium on the bed. Assuming that calibrated thermocouples with an accuracy of $\pm 0.14^\circ\text{K}$ are available, the

potential sensitivity when used for inventory determination is ± 0.035 grams.

Valves, transducers, flowmeters, and other needed components will be all-metal components only. No elastomers, organics, or fluorocarbons will be exposed to tritium. The only exception to no-organics is that the valve stems may be made of polyimide.¹⁰ Process piping will be fabricated from 300-series stainless steel or from annealed deoxidized high-phosphorus (DHP) copper tubing with brazed tube fittings of the zero-clearance, coined-gasket type.

CONFINEMENT/CONTAINMENT

Gloveboxes are fabricated from aluminum or stainless steel to a required helium leak tightness of $< 1 \times 10^{-7}$ std cc atm/sec. Each glovebox is inerted with nitrogen. The radiation and oxygen is measured and maintained at low levels by nitrogen purging to the Exhaust Gas Detritation system (EGD). All gloveboxes have independent pressure control systems that are activated by the FSMS computer if a high tritium concentration exists. Local instrumentation is activated to reduce excessive glovebox pressure. Passive ethylene glycol pressure-relief bubblers are connected directly to the EGD system to protect each glovebox from high pressure excursions.

Storage tanks associated with FS have three levels of containment: 1) the outer secondary containment tank wall, 2) the Tritium Storage Vault, and 3) the FS room. Tank integrity is verified by continuous tritium monitoring of the outer secondary containment wall. These data are monitored by the FSMS computer.

COST ESTIMATES

The cost estimate for the Fuel Storage system in calendar year 1990 is shown in Table 3.

Component	Cost/item (K\$)	#Required	Cost (K\$)
ZrCo material (kg)	25	4011	1002.7
60-mole beds	15.00	2	30.00
Gloveboxes	25.00	4	100.00
Vac sys per glovebox	60.00	4	240.00
2000-mole beds	20.00	19	380.00
Gloveboxes	25.00	9	225.00
Storage Tanks	20.00	19	380.00
Valves (6/bed)	0.50	174	87.00
Valves (6/tank)	0.50	202	101.00
Flowmeters (3/bed)	0.90	144	129.60
Flowmeters (2/tank)	0.90	38	34.20
Press. Transducers	0.70	40	28.00
Computer	20.00	1	20.00
Sub Total			1617.7
Design and installation			1500.0
Total			3117.7

Table 3. Fuel storage system cost in calendar year 1990 dollars.

SUMMARY

The design of a fuel storage system suitable for ITER is described.

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