Fuel circulation system and waste disposal of CFETR

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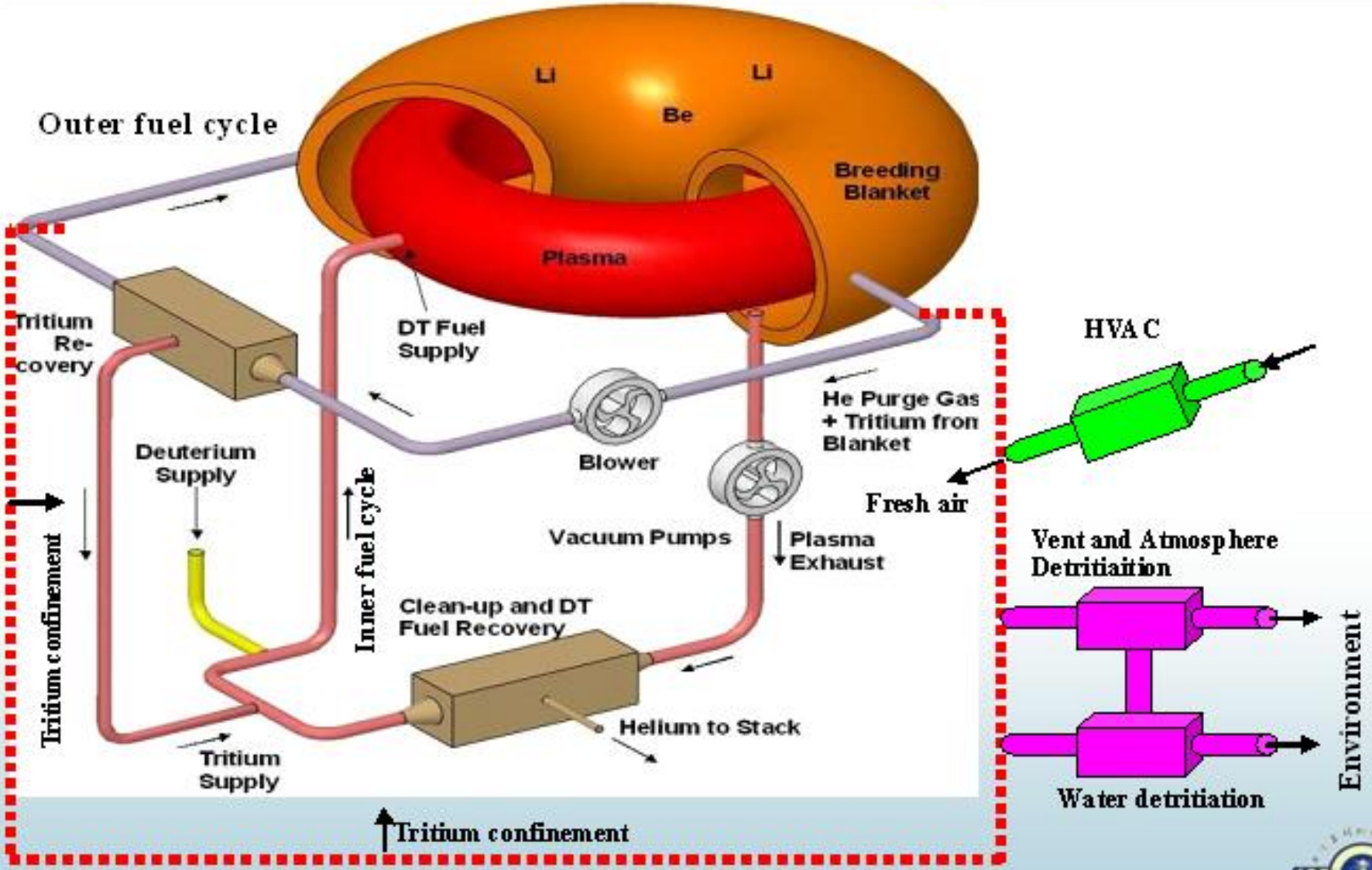
Requirement of fuel recycling

- China has decided to establish its own fusion test reactor (CFETR),and a fuel recycling system must be developed in order that the tritium can be self-preserved
- A set of complete fuel recycling systems must be considered, which include：
  - Inner fuel recycling system functioned as recovery of tritium in the exhaust gases from tokamak plasma and feeding back to the plasma vessel
  - Outer fuel recycling system functioned as tritium breeding and extraction
  - Tritium safety system with tritium confinement and recovery from gases and liquid effusions
  - Tritiated waste disposal system functioned as the treatment of solid or liquid tritiated waste

Preliminary fuel recycling for CFETR



Key processes for fuel recycling

- Tritium storage and delivery system
- Tritium breeding & extraction system
- Tokomak exhaust processing system
- Isotope separation system
- Tritium safety system
- Tritiated waste disposal system
- Tritium analysis and detection system
- …

Fuel requirement for a fusion reactor

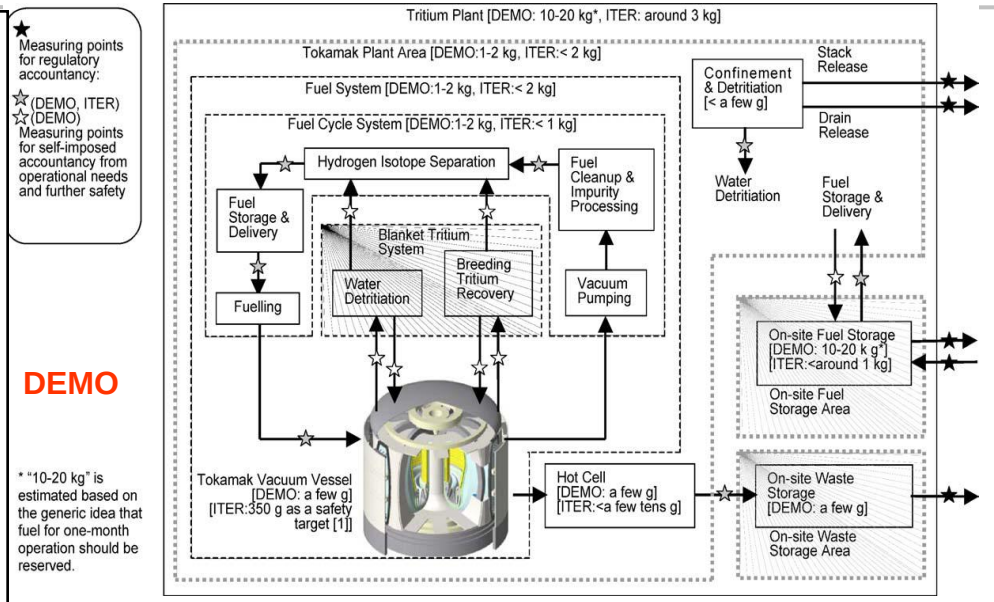
Deuterium is available from natural water (0.016%)

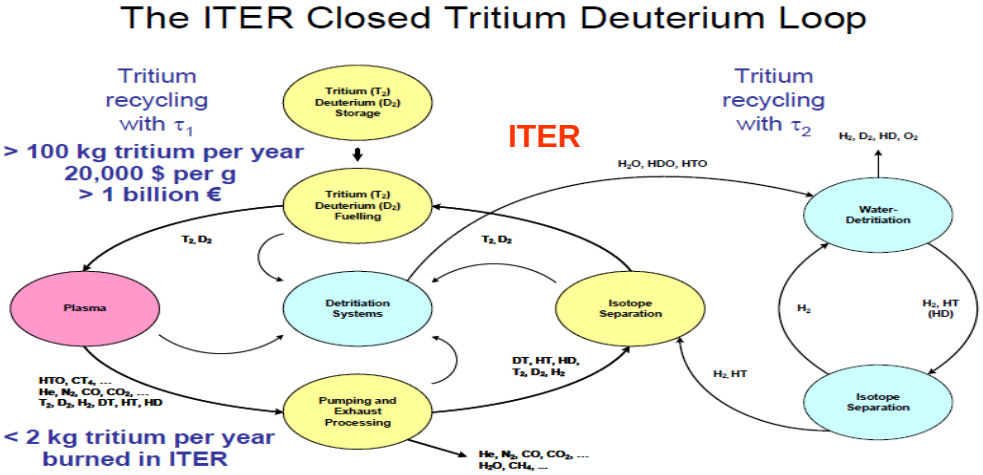
Tritium must be imported (limited) or bred internally from lithium

For a full power supply fusion reactor (like DEMO). tritium requirement is 56kg/y/GW (by M. Glugla)

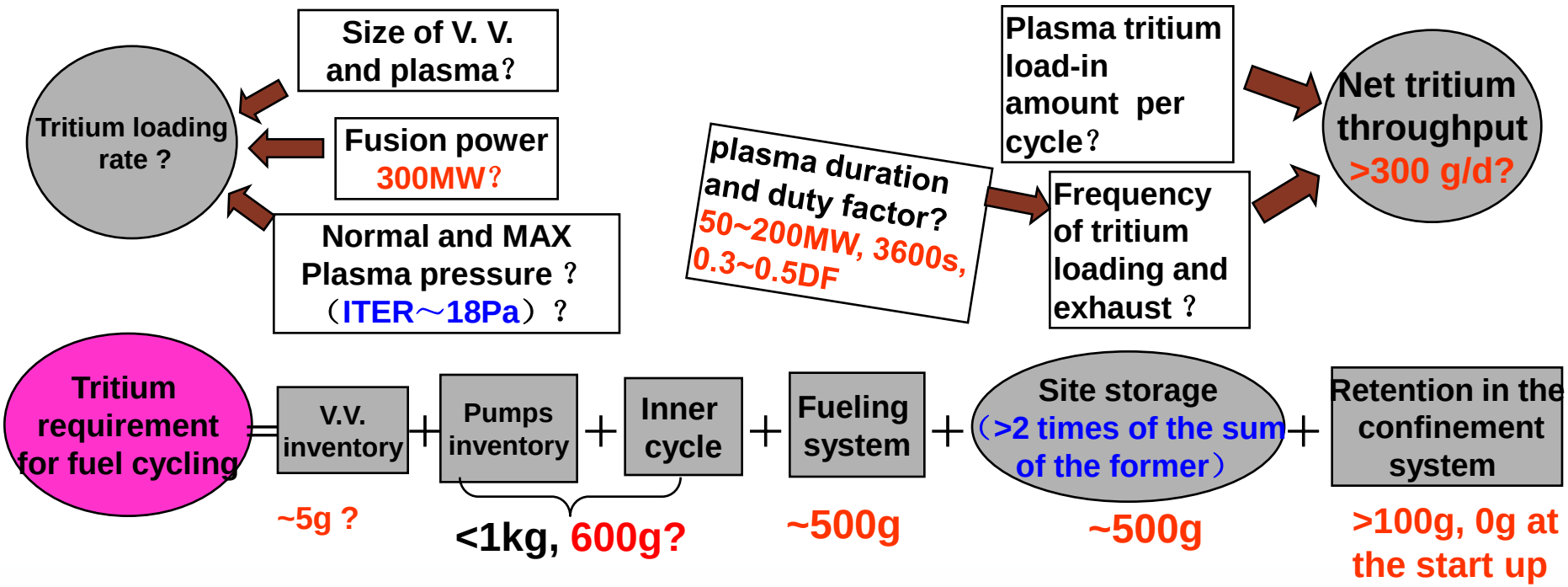
ITER:

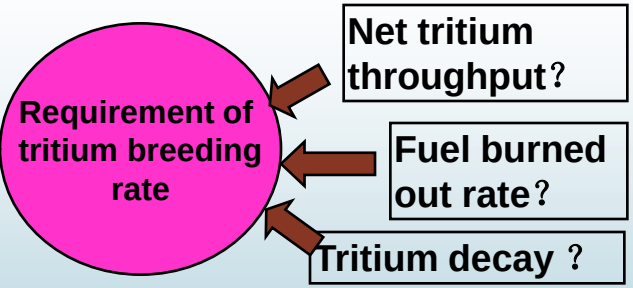
- ✓ **Volume of V.V.: ~1330m^3**
- ✓ **Volume of plasma area: ~837m^3**
- ✓ Scale of tritium operation （by M. Glugla, S. Willms）
  - **Plasma tritium throughput: ~1kg/h**
  - **Plasma tritium inventory: ~0.2g**
  - **Tritium site inventory: <4kg**
  - **Fuel cycle inventory: <2kg**
  - **Tritium burned: <2kg/y**
  - **Imported and being available from Canada**





Preliminary evaluation of tritium operation scale for CFETR





$$T \rightarrow {}^{3}He(3\sim 4eV) + \beta^{-} + \bar{\nu} + 18.6keV, \qquad T_{1/2} = 12.33a$$

Compared with ITER，China CFETR

- **Moderate** fusion power：50~200MW ？
- **Moderate** size of plasma and V.V. 500m^3 ?
- Plasma performance parameters：for power supply，beyond ITER (Higher Q, longer plasma duration, …).
- **Tritium breeding blanket** is required for energy output and **tritium supply**（even if TBR<1.2 ？ ）
- Tritium operation scale would not be larger than ITER

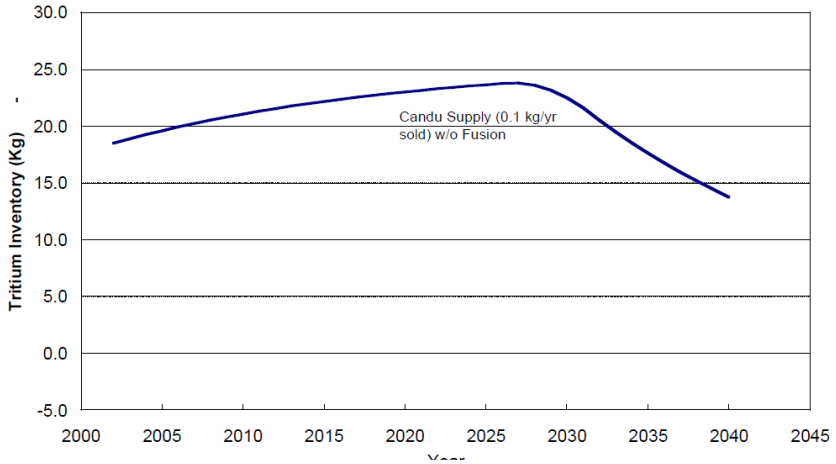
Tritium requirement for start-up of CFETR

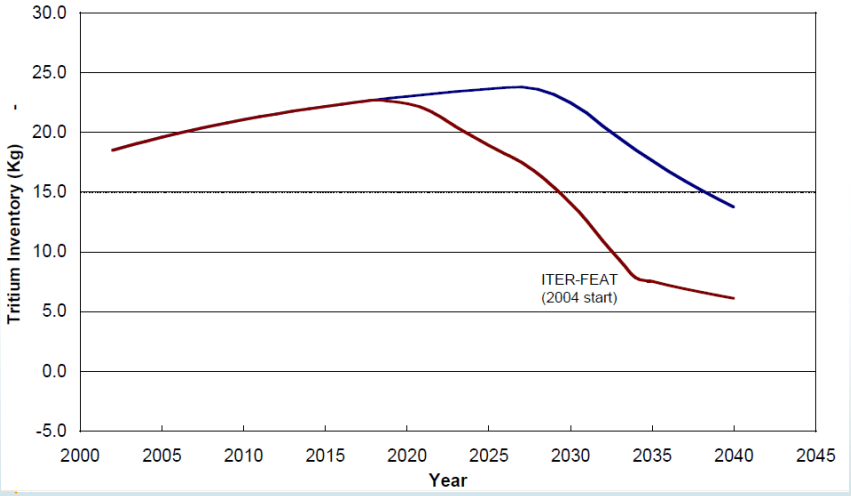
For ITER

- –D-T plasma start is delayed until 2027;
- –Tritium requirement for start-up: ～3kg;
- –Tritium supply : <2kg/y.

For CFETR:

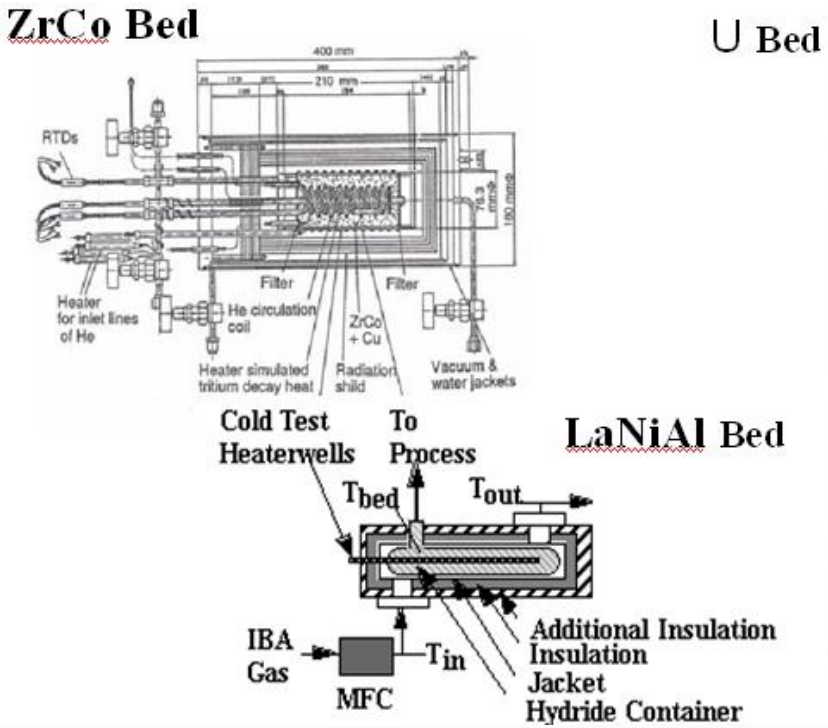
- –Preparation for start-up: 1.6 kg ?
- –Internal bred in CFETR with tritium breeding blanket after start up
- –Outer supply domestically if TBR<1.2 ?
- –Tritium extraction from China CANDU type of fission reactor
  - •Two units are available at present (Qinshan-Ⅲ, ~200g/y/each)
  - •Others ?
- –Other kind of tritium production unit ?





Tritium available in Canada and the impact of ITER, by S. Willms (2003)

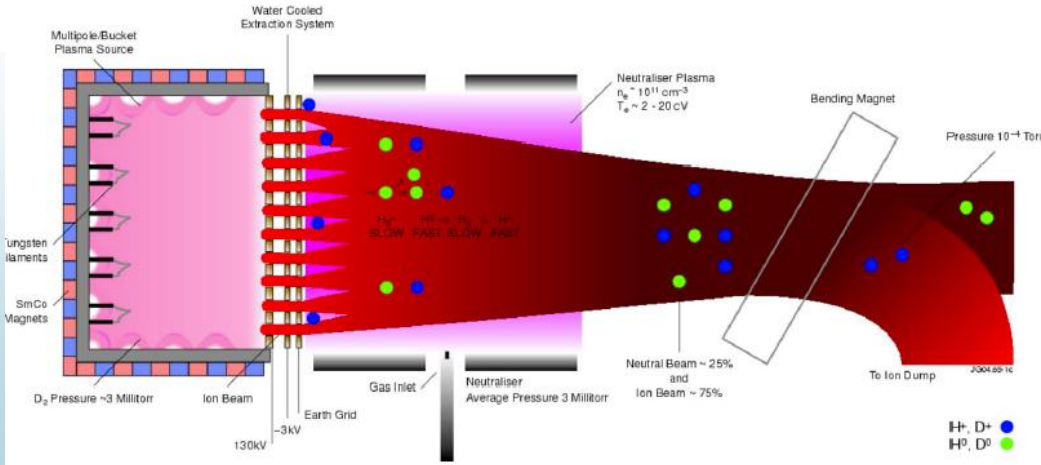
Tritium storage and delivery system



Tritium storage technique is available, but large scale tritium storage is also required:

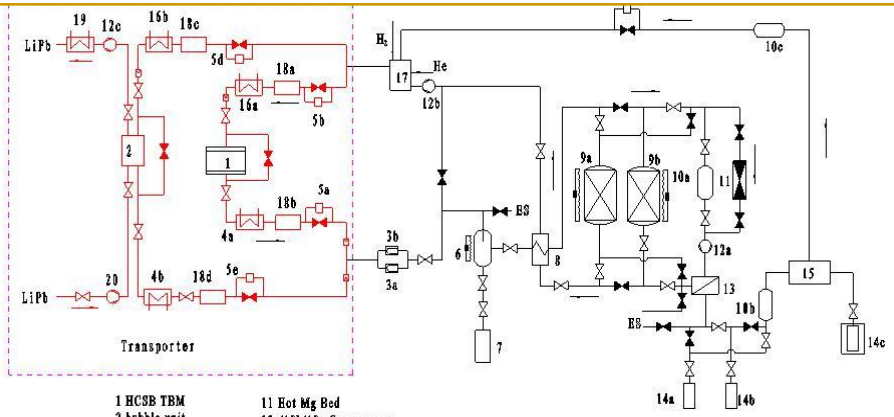
~ 100g of loading capacity for each bed with high reliability, safety and inspectibility.

Delivery technique maybe available, but large scale D-T delivery are also needed to be developed



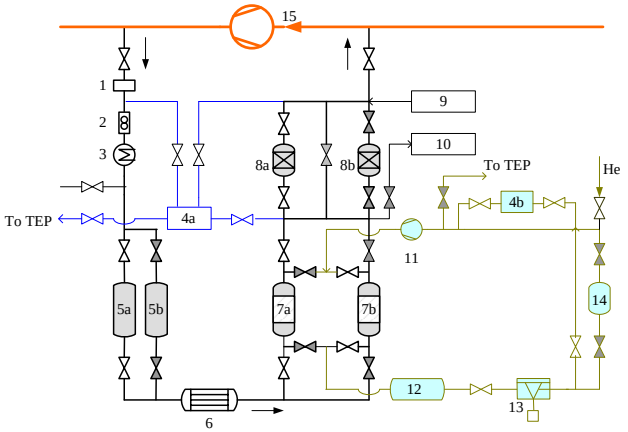
Tritium breeding and extraction system

- **Tritium breeding with solid or liquid breeders is under decision for CFETR**
- **Tritium extraction system from solid/liquid concept of TBM is designed and the technology is being developed, which could be scaled up for a full tritium breeding blanket.**

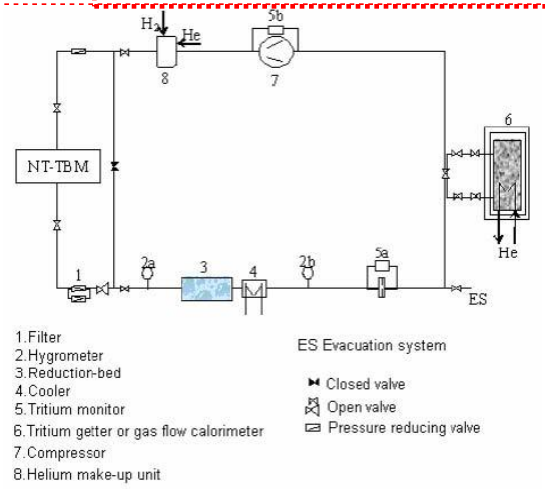


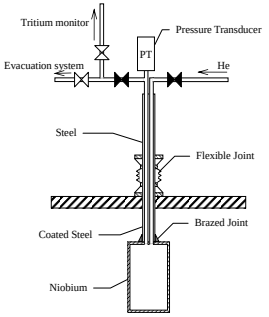
Tritium Extraction System for TBM

Tritium extraction system both for China solid and liquid TBM： Isotopic exchange with hydrogen－adsorption with molecular sieve.



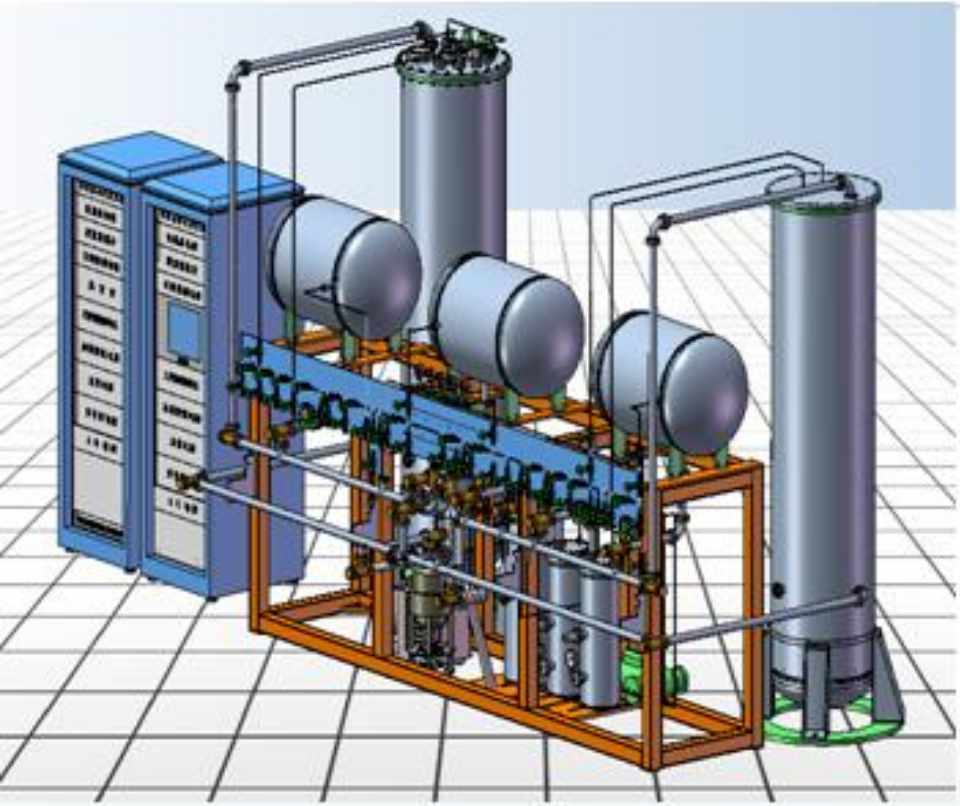
Tritium extraction from helium coolant：Catalytic oxidation －adsorption with molecular sieve.



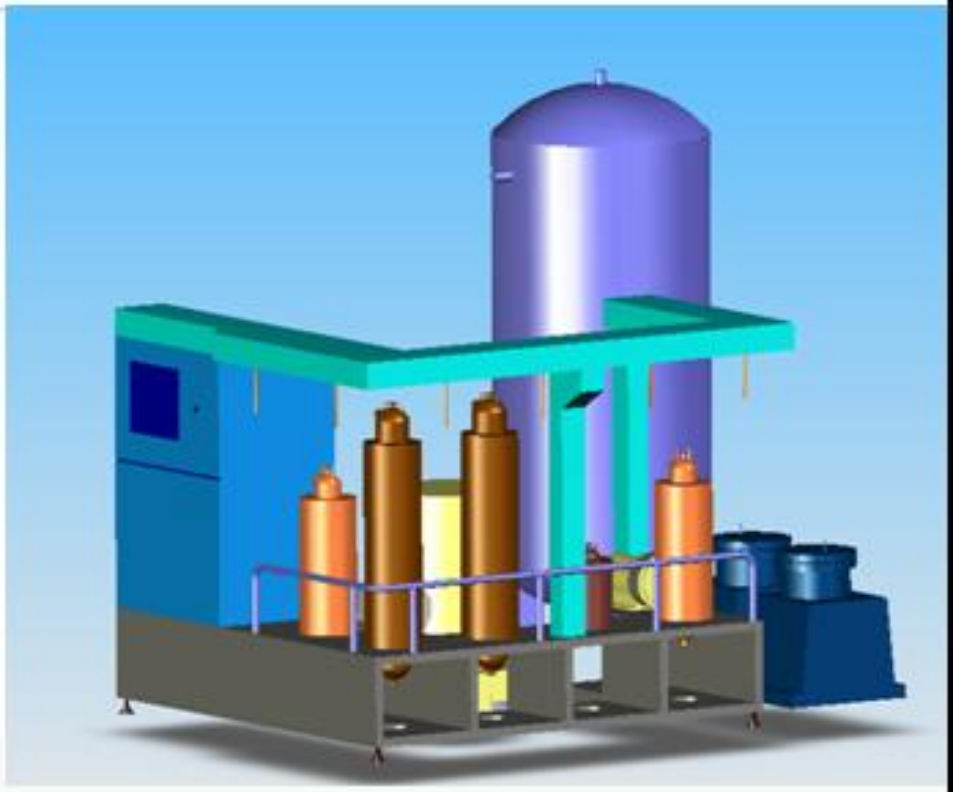


Tritium measurement ： tritium extraction - accountancy

Tritium breeding and extraction system



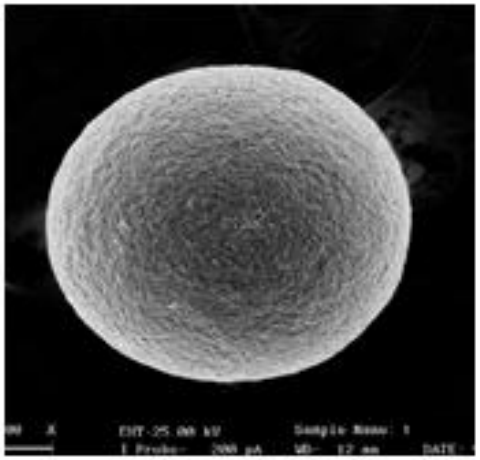
Tritium extraction system for solid breeders: Isotopic exchange with hydrogen—adsorption with molecular sieve.

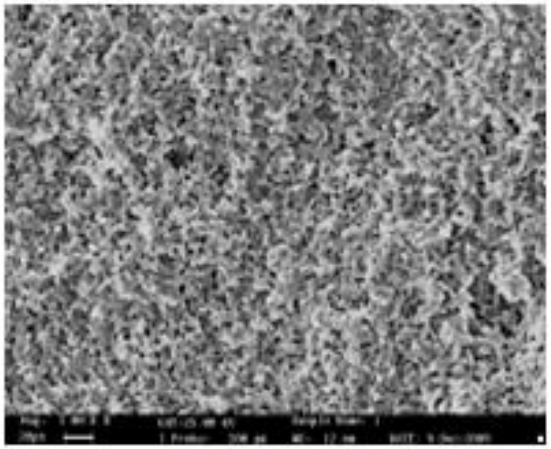


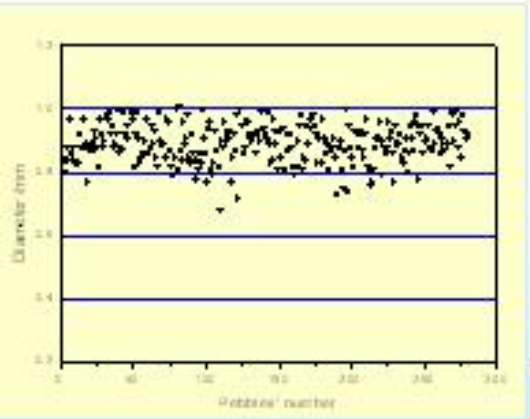
Tritium extraction system for helium coolant: Catalytic oxidation—adsorption with molecular sieve.

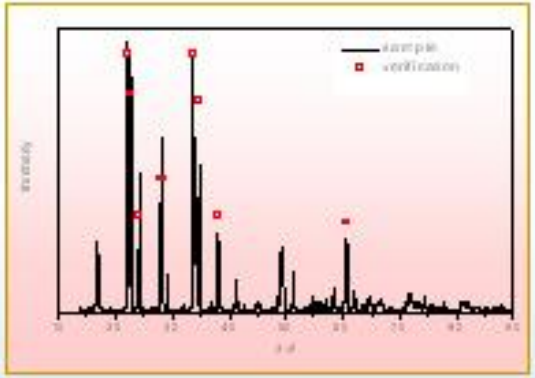
- Test systems for tritium extraction from breeders and coolant are being set up.
- They will be available by July, 2012.

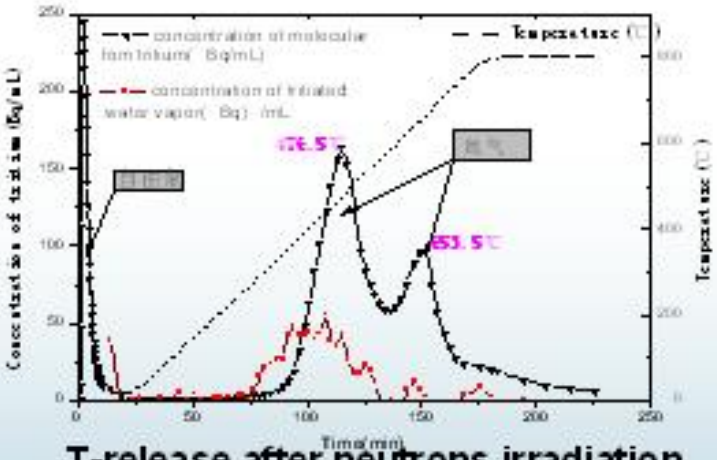
Tritium breeding and extraction system







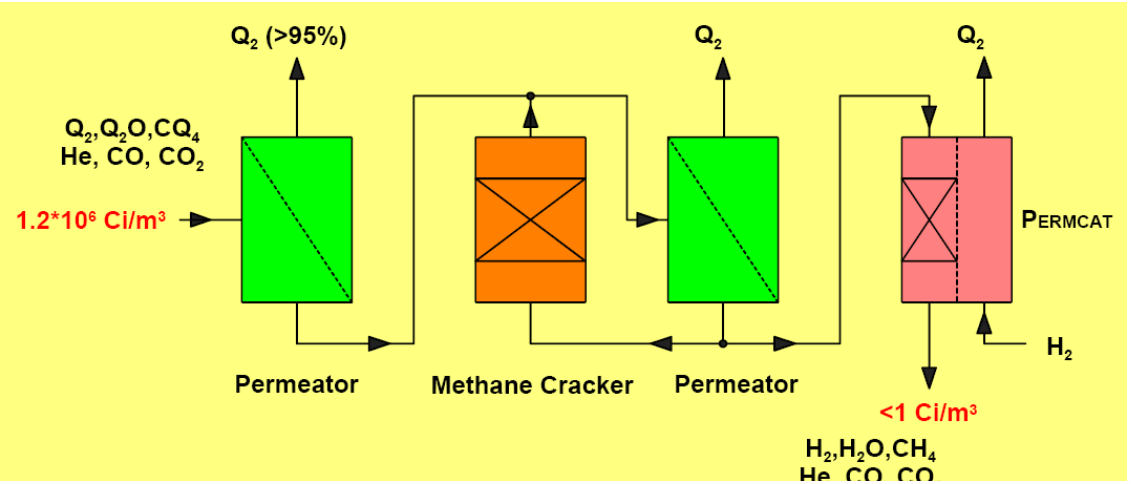


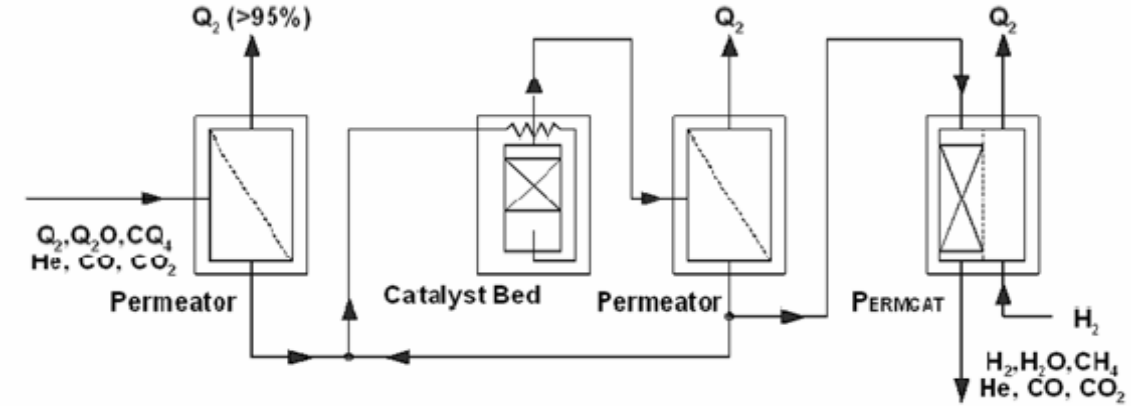


Preparation of Li_4SiO_4 pebbles by "wet" method

T-release after neutrons irradiation

Tokomak exhaust processing system





Chemistry of the 2nd step: (Q = H, D, T)

$CQ_4 \leftrightarrow C + 2\,Q_2$

$C + CO_2 \leftrightarrow 2\,CO$

$CO + Q_2O \leftrightarrow CO_2 + Q_2$

$CO + 3\,Q_2 \leftrightarrow CQ_4 + Q_2O$

Chemistry of the PERMCAT:

$H_2 + CQ_4 \leftrightarrow CH_4 + Q_2$

$H_2 + Q_2O \leftrightarrow H_2O + Q_2$

- Some kinds of catalysts, such as Pt-PTFE、Pt-SDB、Pt-C-PTFE,Ni-Cu-SiO_2,etc. have been developed
- Some Pd based membrane have been applied in the development of Tokomak exhaust processing system
- But the technique is under going

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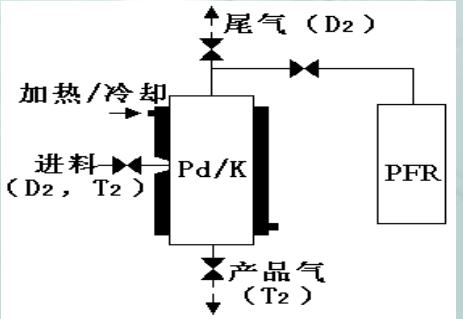
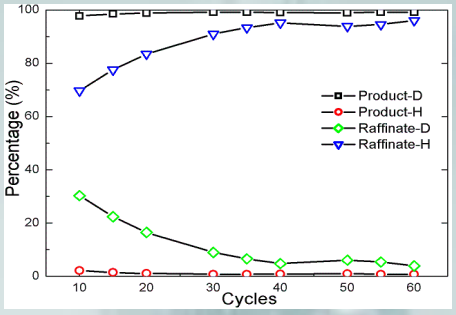
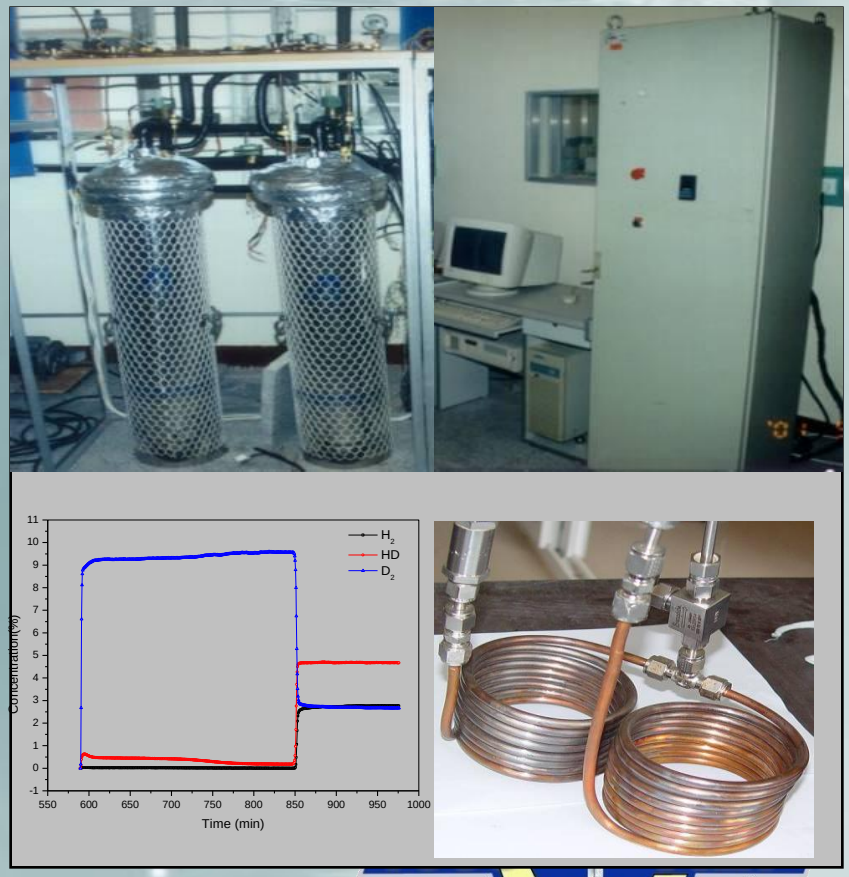
Isotopic separation system

- Besides cryogenic distillation (CD), some gas chromatographic separation techniques has been developed in China
  - Thermo displacement GC
  - Low temperature GC (~100m^3/d)
  - TCAP (thermo cycling adsorption process) with high efficiency
  - …
- They are left to be scaled up for CFETR





TCAP, suitable for obtaining tritium of high purity



Low temperature GC for tritium enrichment Low temperature GC for tritium enrichment

Present scale: 100m^3/d

GC for tritium enrichment

0.3m³/d GC System

Separation System

Control System

0.7m³/d GC System

Separation System

Control System

8m³/d GC System

Separation System

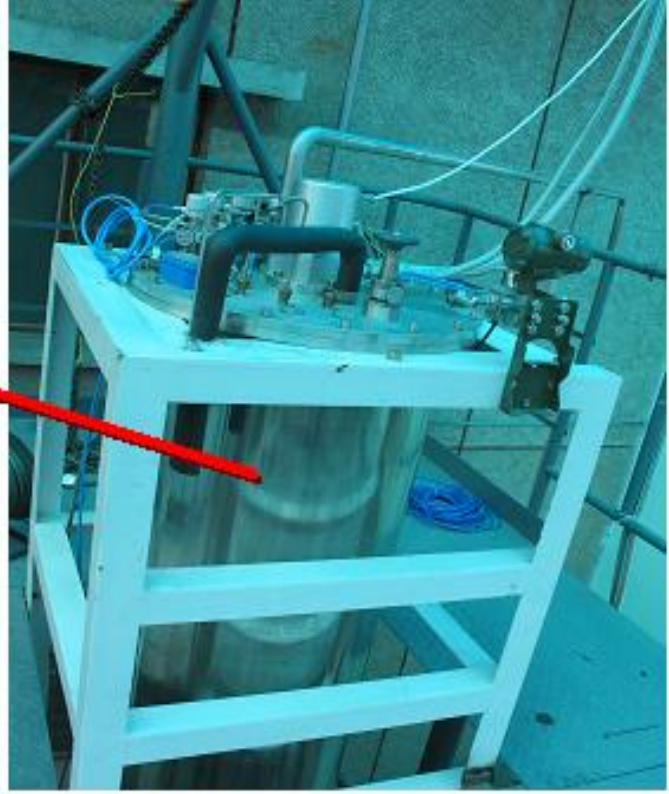
Control System

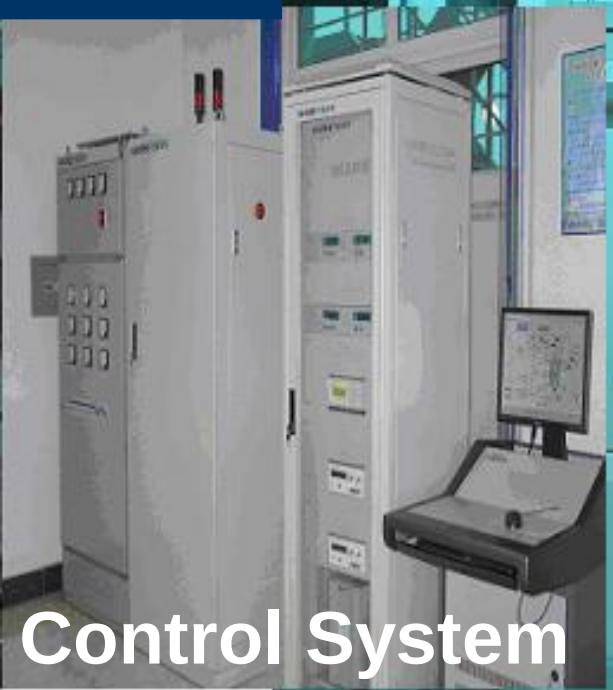
50m³/d GC System

Separation System

Control System

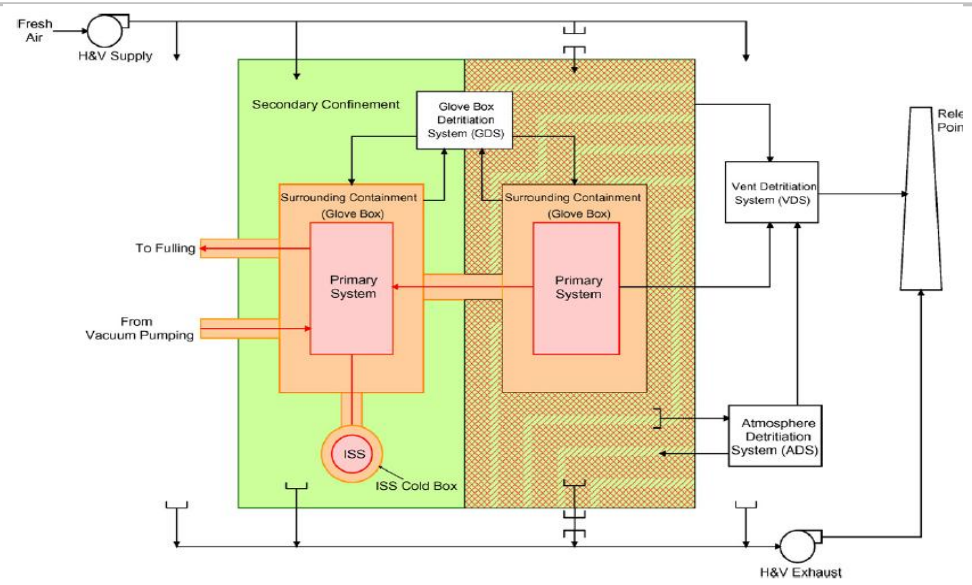
CD

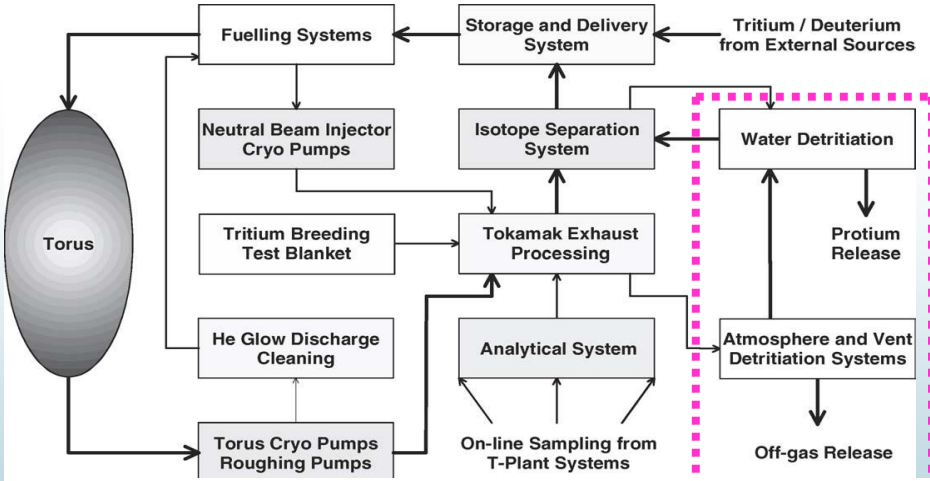




Tritium safety system

- **Include：**
  - Tritium confinement
  - Tritium monitoring system
  - Detritiation system：VDS, ADS/GDS, WDS
  - Tritium leakage monitoring system
- **Most of them are available except WDS, which needs to be further scaled-up: 120kg·h^{-1}, 8000h/a**
- **Tritium safety standard with safety limit values should be established：**
  - Allowable tritium release: 20Ci/d ?
  - Dosage for working staff and the public: 5 mSv/a, 1mSv/a ?
  - Tritium decontamination factor: normally >1000 ?
  - ……

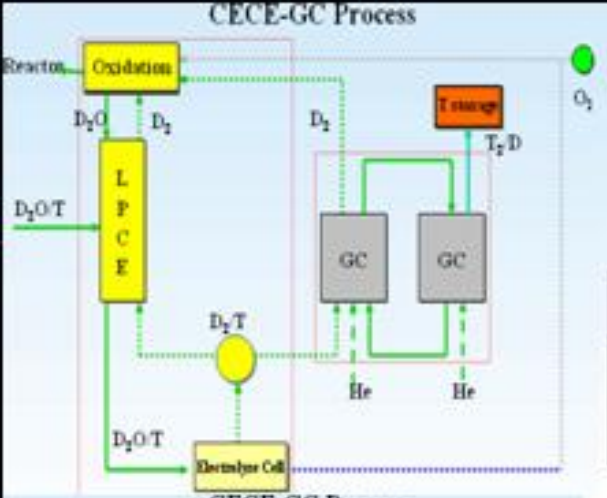


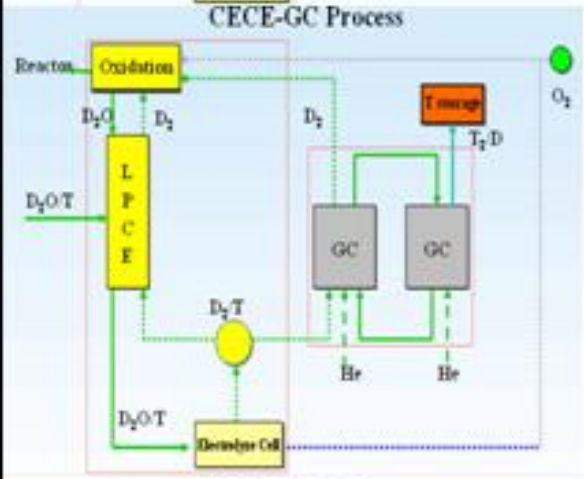


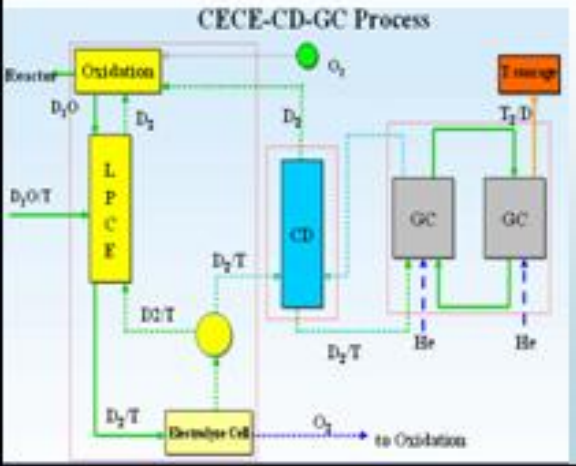
ITER tritium confinement and detritiation system

Tritium safety system

- Three kinds of treatment techniques have been developed: CECE (Combined Electrolysis Catalytic Exchange) -GC, CECE-GC-CD and CECE-CD-GC
- Many kids of hydrophobic catalysts, such as Pt-PTFE、Pt-SDB、Pt-C-PTFE,etc. have been developed to satisfy the treatments of tritiated gas or tritiated water
- And the detritiation system have be applied in the vent system in the detritiation of tritiated gases from glove box
- Some kinds of tritium detection method have also been developed





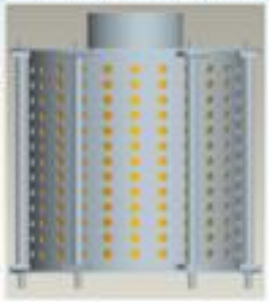


Electrolyze Cell related system

Catalysis Exchang System

Tritium surface contamination detector

- The lowest detected contamination standard could be 0.2Bq/cm²
- The detection base is lower than 80cpm
- The efficiency is higher than 55%
- Theweight is only 2kg

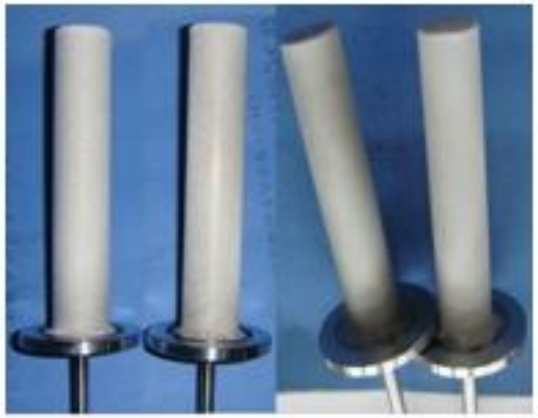


"Open-Type" Ionization

- The lowest detected concentration could be 3.7×10^{5}Bq/m³
- The memory influence could be most lowered
- It could be widely used in various circumstance

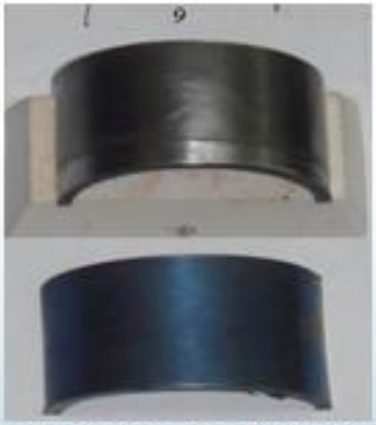
Tritium permeation barrier technology

On inner surface for pipes

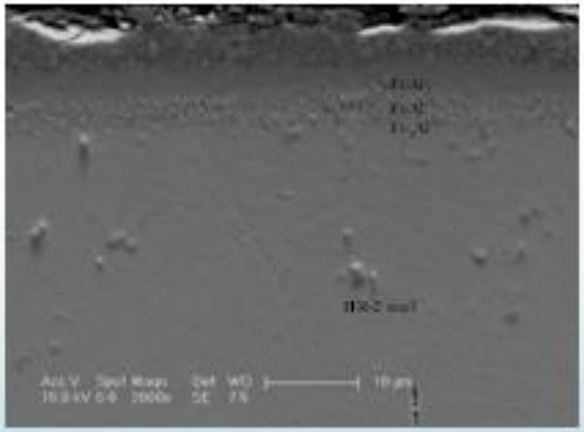


On outer surface for container

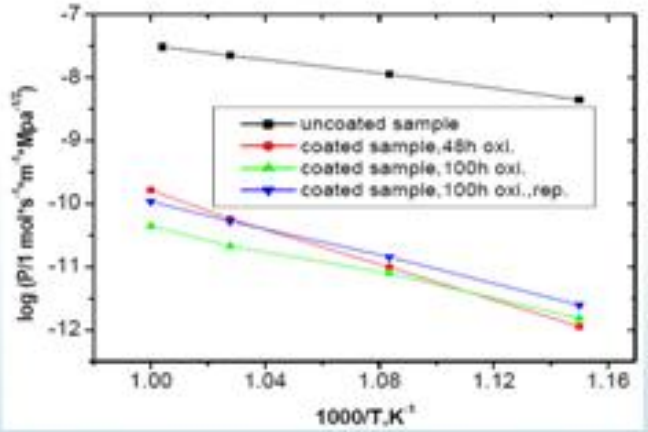
Selective oxidation at 700℃



thermo shock test of 30 cycles

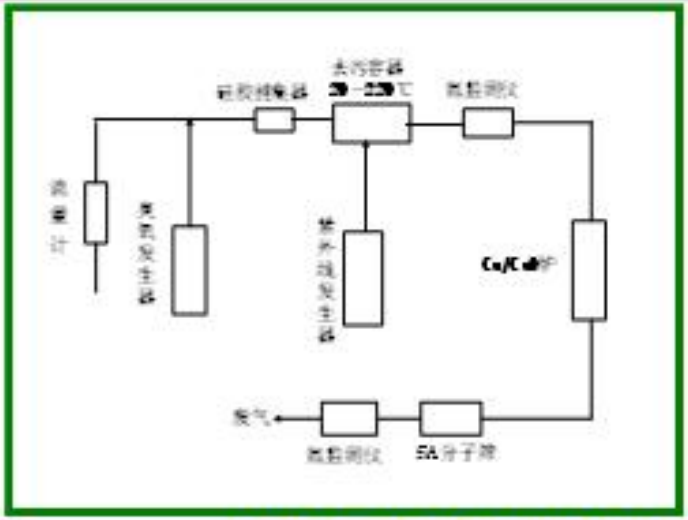


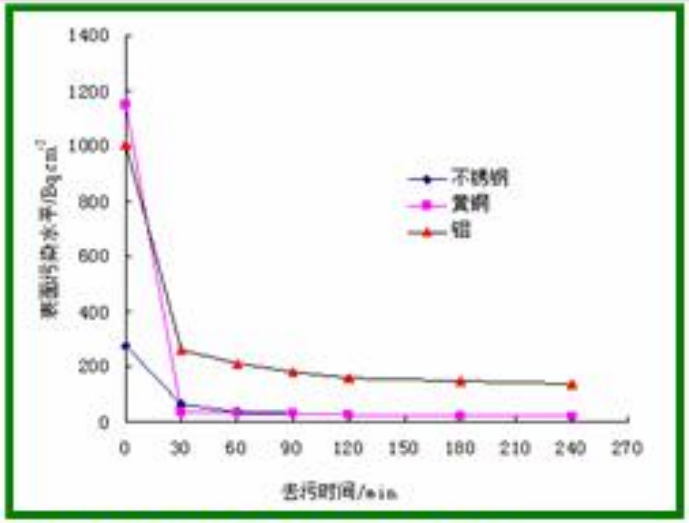
Cross section of adhesion



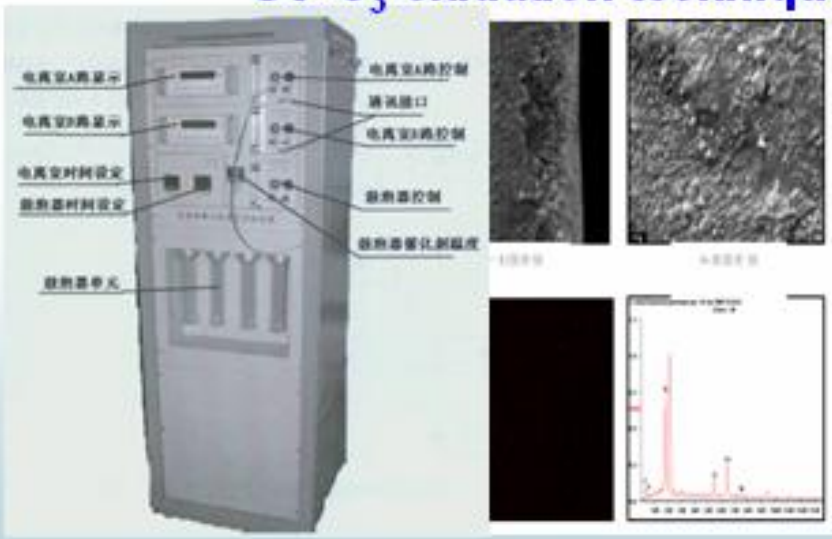
TPRF （700℃：100；500℃：3000）

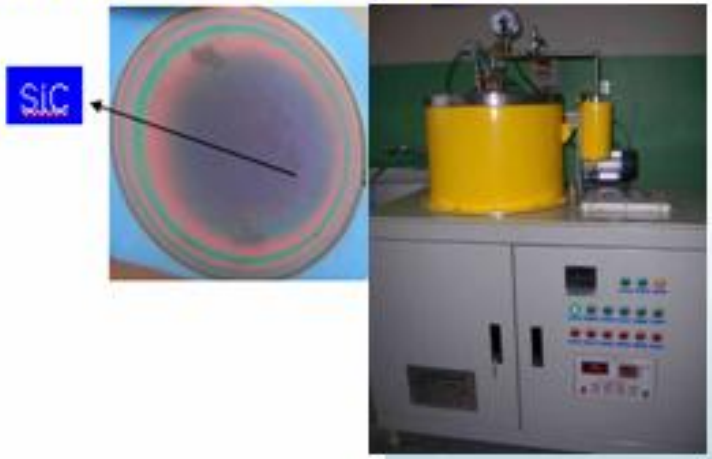
Tritiated waste disposal system





UV-O_3 oxidation technique for detrition form metal

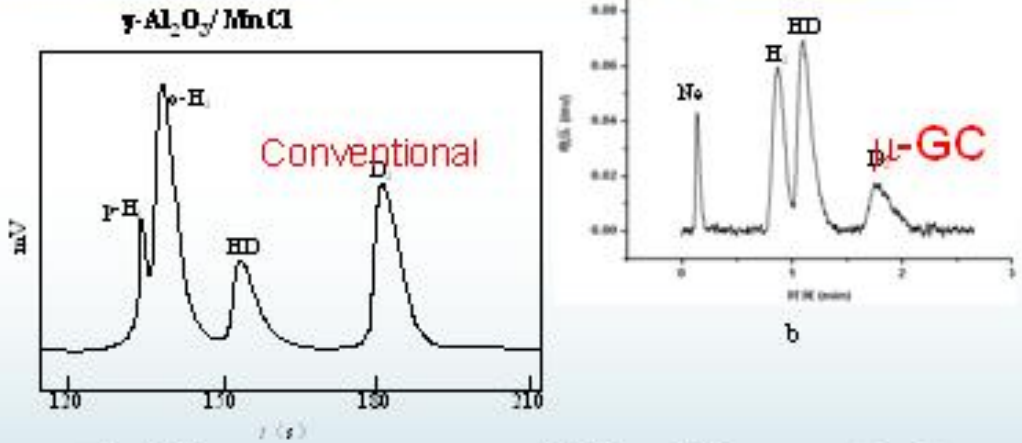




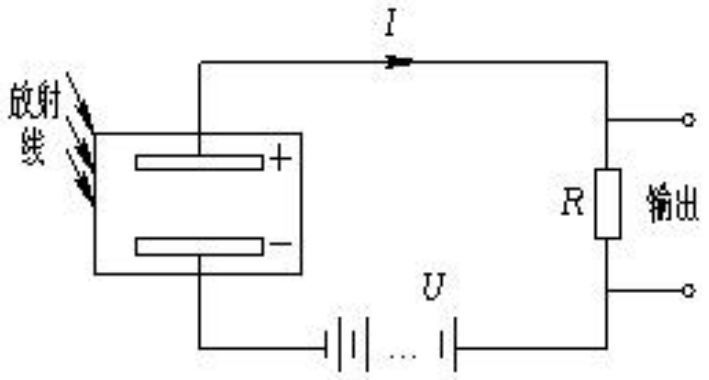
Package technique for tritiated wastes

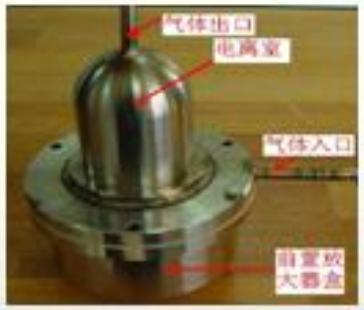
Organic tritiated wastes treatment technique

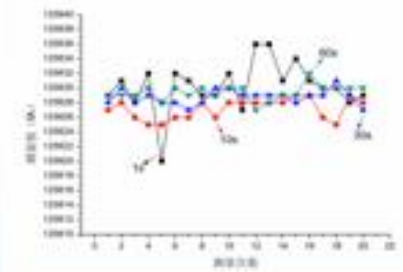
Tritium analysis and detection system



Tritium compatible Micro GC



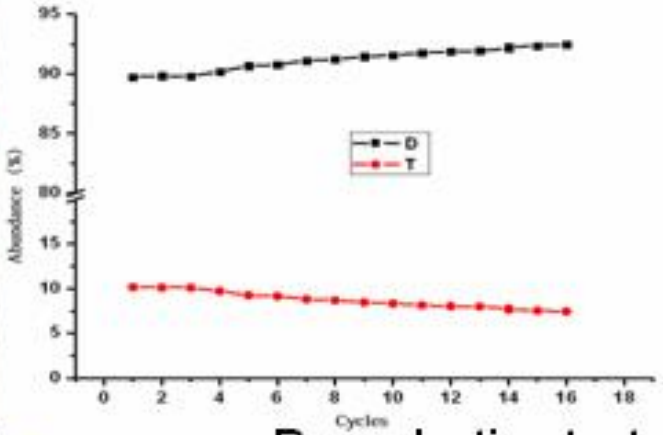




Low memory ionization chamber
(10^4 Bq/mL~5×10^8 Bq/mL)

Tritium analysis and detection system

Fast sampling and hold-up system: <1s



Reproduction test

Times	Concentration of D_2	Average	Standard difference	R.S.D
1	23.78%	23.82%	0.02%	0.08%
2	23.83%			
3	23.83%			
4	23.83%			
5	23.81%			
6	23.81%			
7	23.82%			
8	23.82%			

QMS-on-line and real time analysis

Some considering for fuel circulation and waste disposal

Preliminary tritium resource for CFETR to start-up
- **CANDU reactor ?**
- **Accelerator ?**
- **…**

Large scale Tritium delivery
Large scale tokomak exhaust processing system—Catalysts ?
Large scale of tritium isotopic separation—CD or GC?
Large scale Tritium safety system— WDS, etc. ?
Large scale Tritiated waste disposal system — IR, etc. ?
Tritium compatible materials
- **Organic sealing material for high temperature (>500℃) ?**
- **Tritium transference pumps for high temperature ?**
- **…**

Tritium measurement on-line
- **Micro GC ?**
- **Ionization chamber ?**
- **…**

Pumps—Evacuation of plasma exhaust and delivery?

…

Thank you for attention!