US Tritium Plant Activities for ITER

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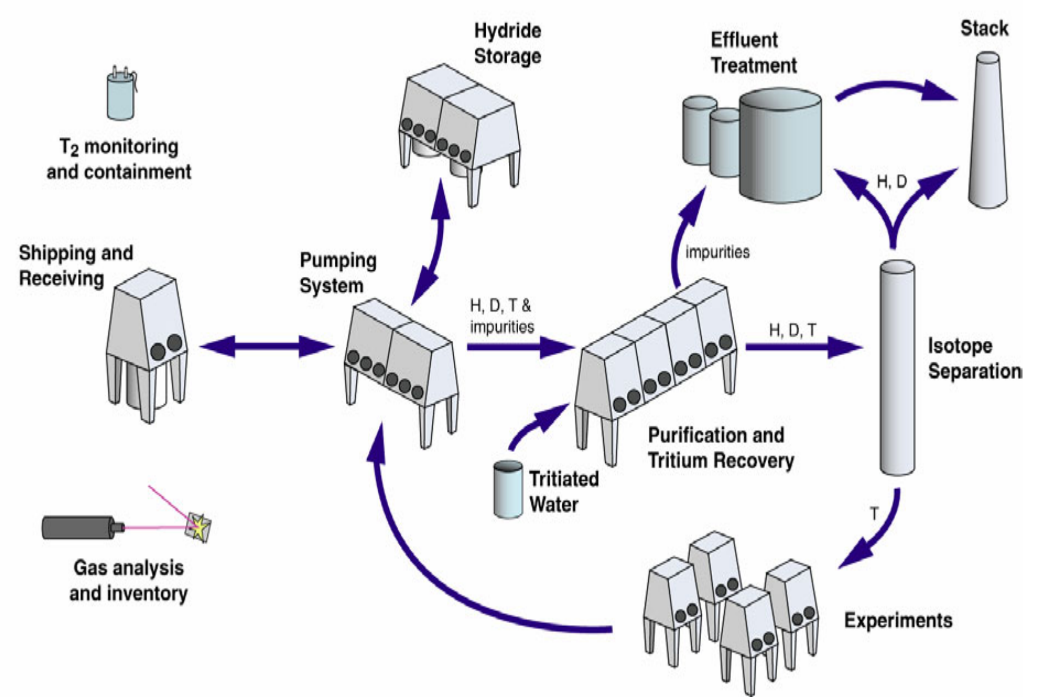
Outline

- ITER Tritium Plant overview
- Tokamak Exhaust Processing System
- Approach to upcoming work
- Schedule
- Key issues

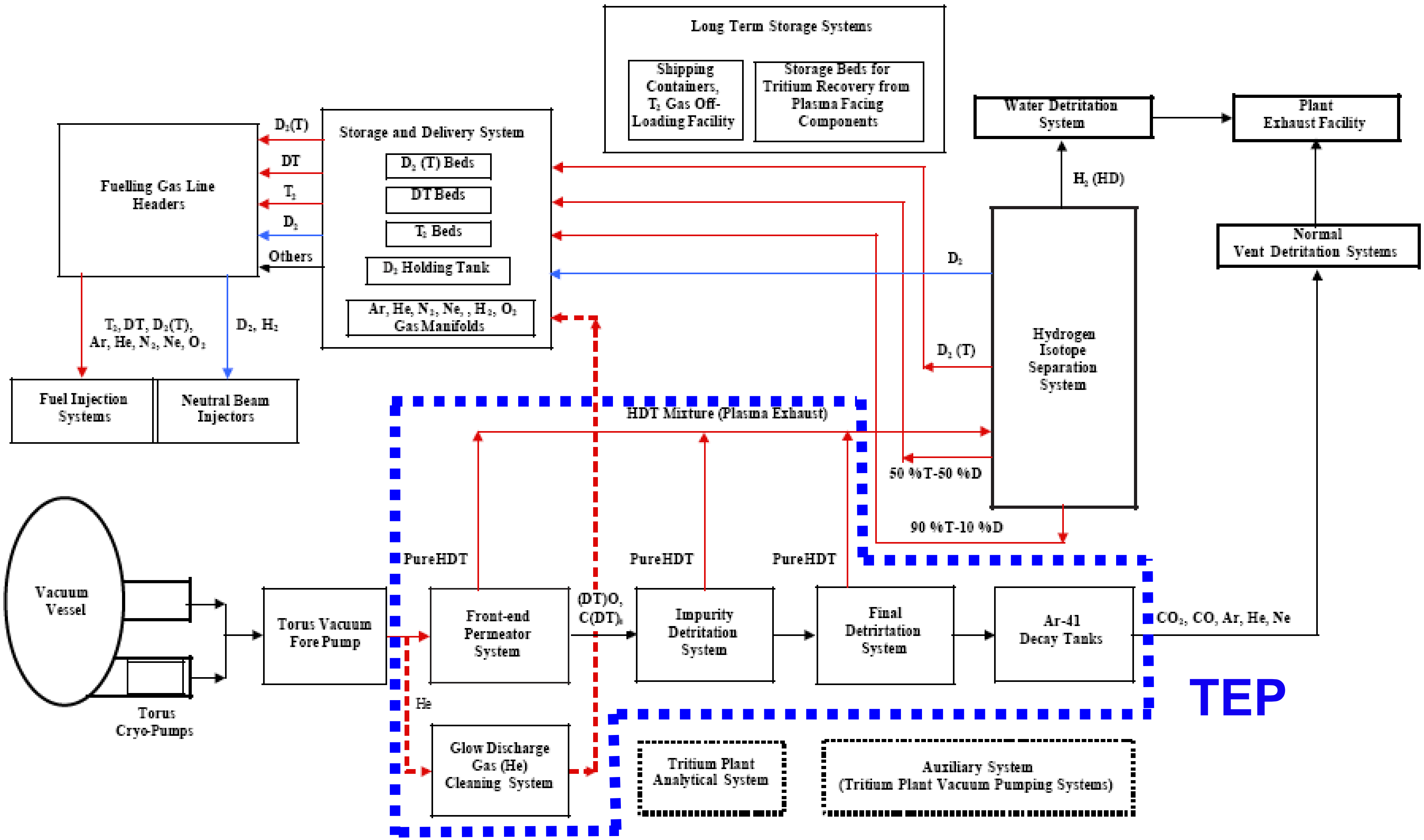
ITER Tritium Plant Overview



- **Core Purpose**: **Process tokamak effluent and other gases, purifying DT for reuse and disposing of detritiated gases.**

- **Sub-Functions**
  - **Separations: Tritium recovered from impurities such as tritiated water and tritiated methane. Hydrogen isotopes must be separated.**
  - **Storage and delivery: Isotopes must be safely stored and delivered as needed**
  - **Effluent cleanup: High efficiency cleanup systems are needed to detritiate gases (e.g., He, CO_x, N_2, Ar) before they are released to the environment**
  - **Analysis: Analyses are required for process monitoring, inventory control and contamination control**
  - **Handling: Tritium must be properly contained with compatible materials**
  - **Control: Aggressive process control is required to deliver on-spec product while maintaining minimal inventory**

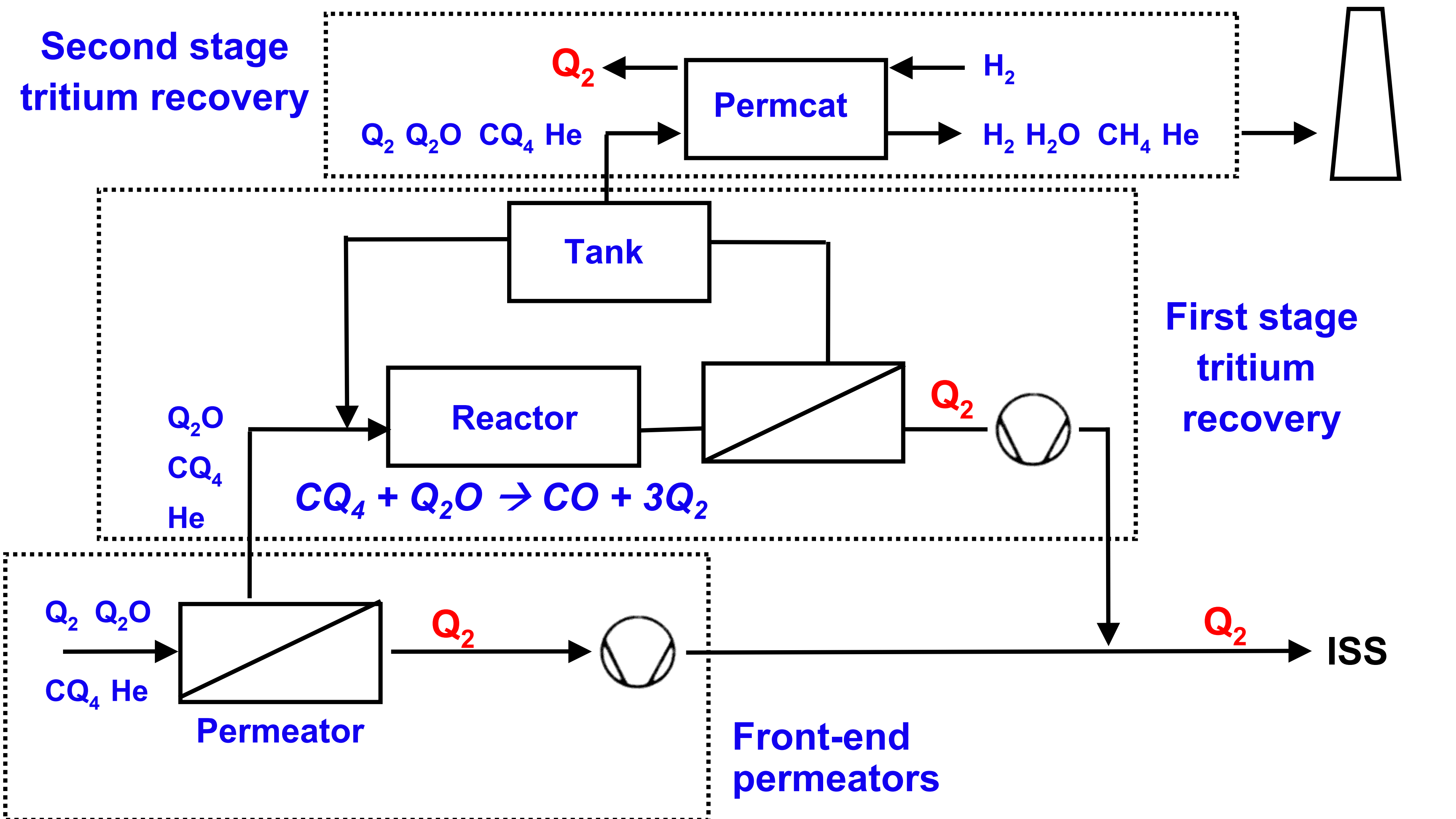
Overview of ITER Tritium Plant



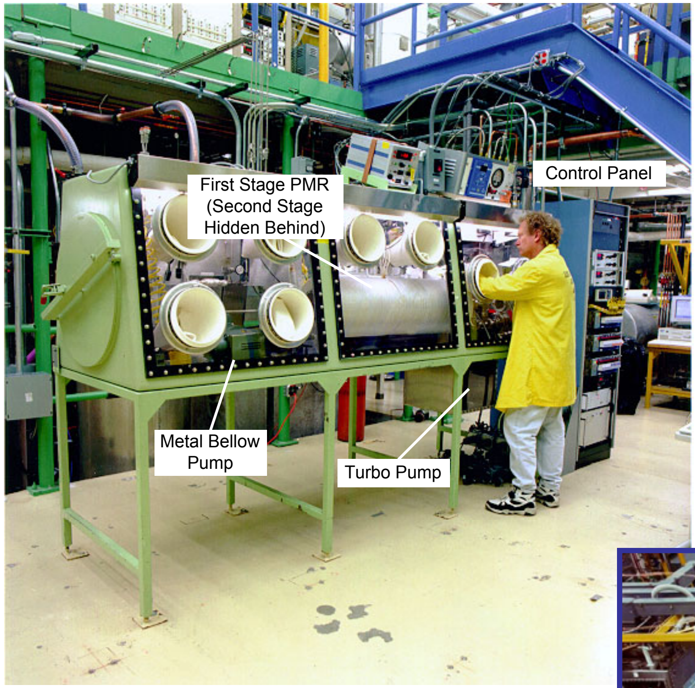
ITER Tritium Plant breakdown

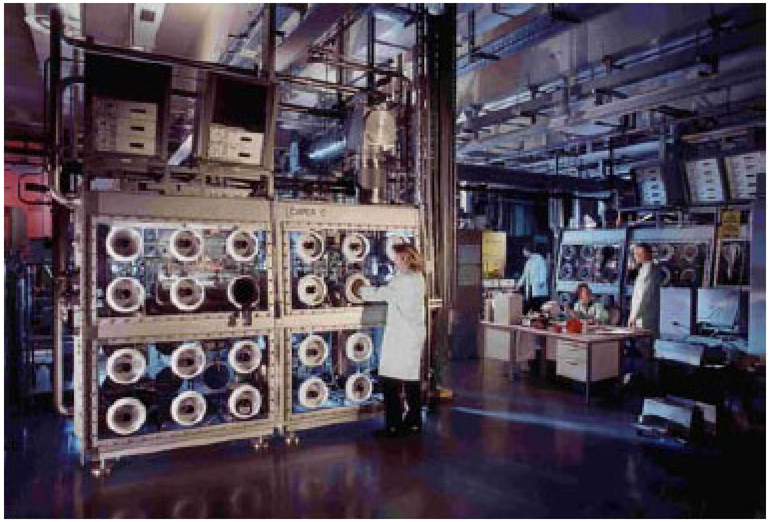
- **The Tritium Plant construction is broken into seven procurement packages**
  - **Tokamak Exhaust Processing (TEP)**
  - **Hydrogen Isotope Separation System (ISS)**
  - **Storage And Delivery System**
  - **Water Detritiation System**
  - **Atmosphere Detritiation Systems**
  - **Analytical System**
  - **Automated Control System**
- **The US has been tentatively assigned responsibility for the TEP procurement package**
- **The TEP must**
  - **Recover hydrogen isotopes from impurities such as water and methane**
  - **Deliver purified, mixed hydrogen isotopes to the ISS**
  - **Dispose of non-tritium species**

TEP process flow diagram



Considerable TEP R&D was performed during the EDA

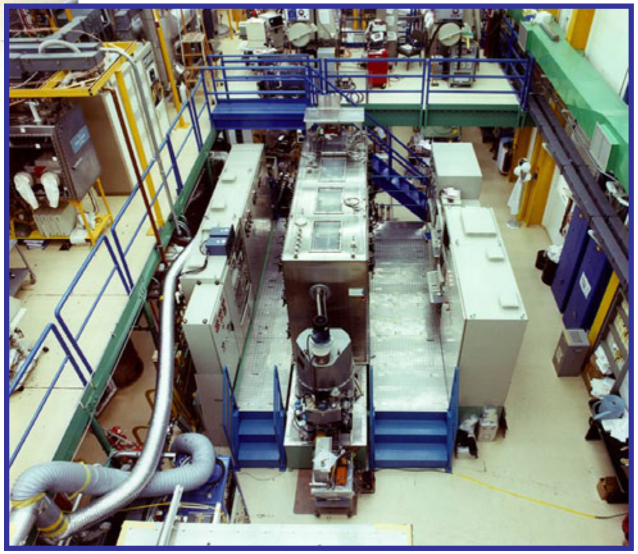




Caprice/Caper-EU
Shift catalyst/
Permeator/
Exchange

PMR-US
Membrane reactors

EDA testing performed at ~ 6 SLPM



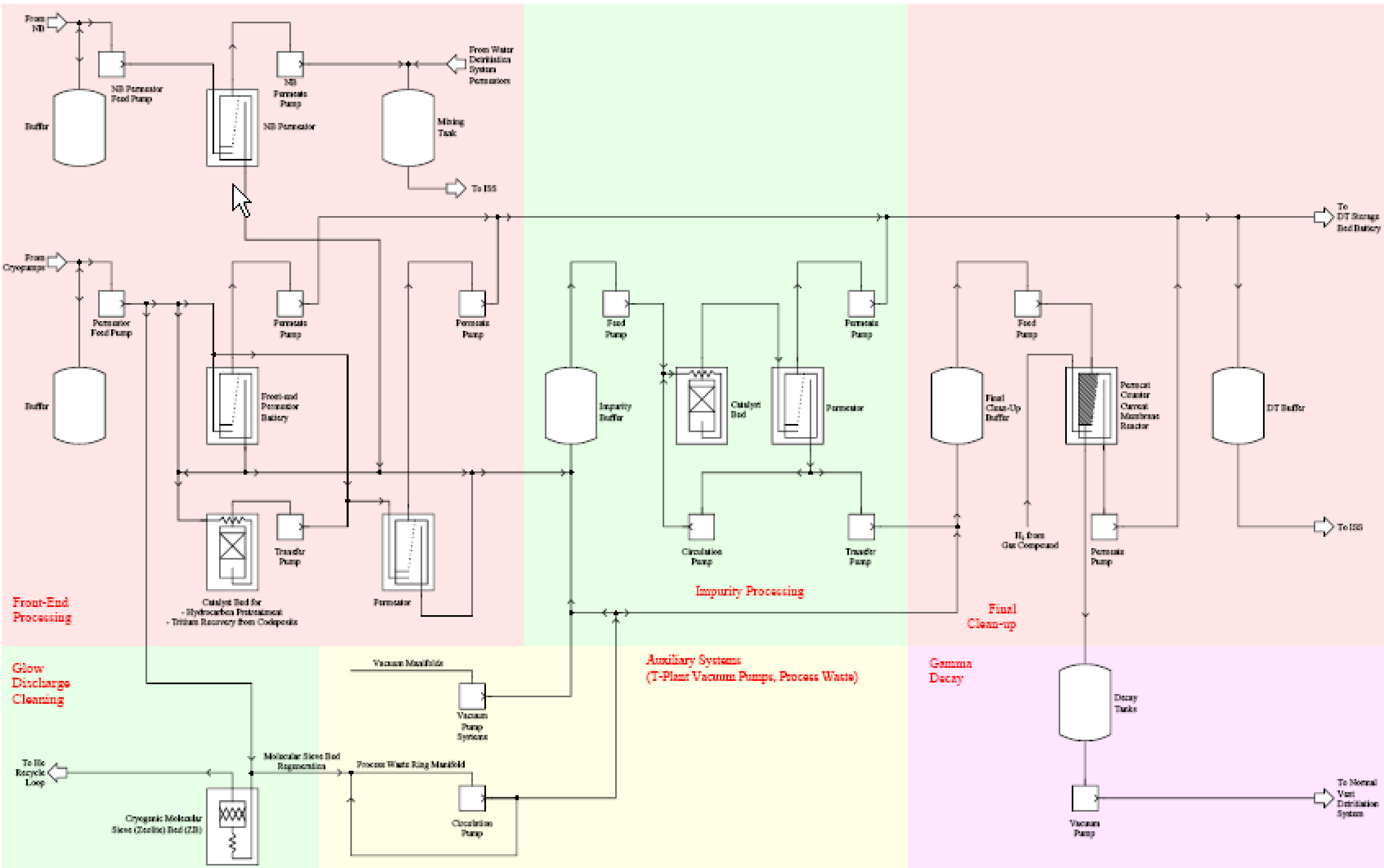
JFCU-JA(US)
Permeators/
Oxidation/
Electrolysis

Key TEP design specifications

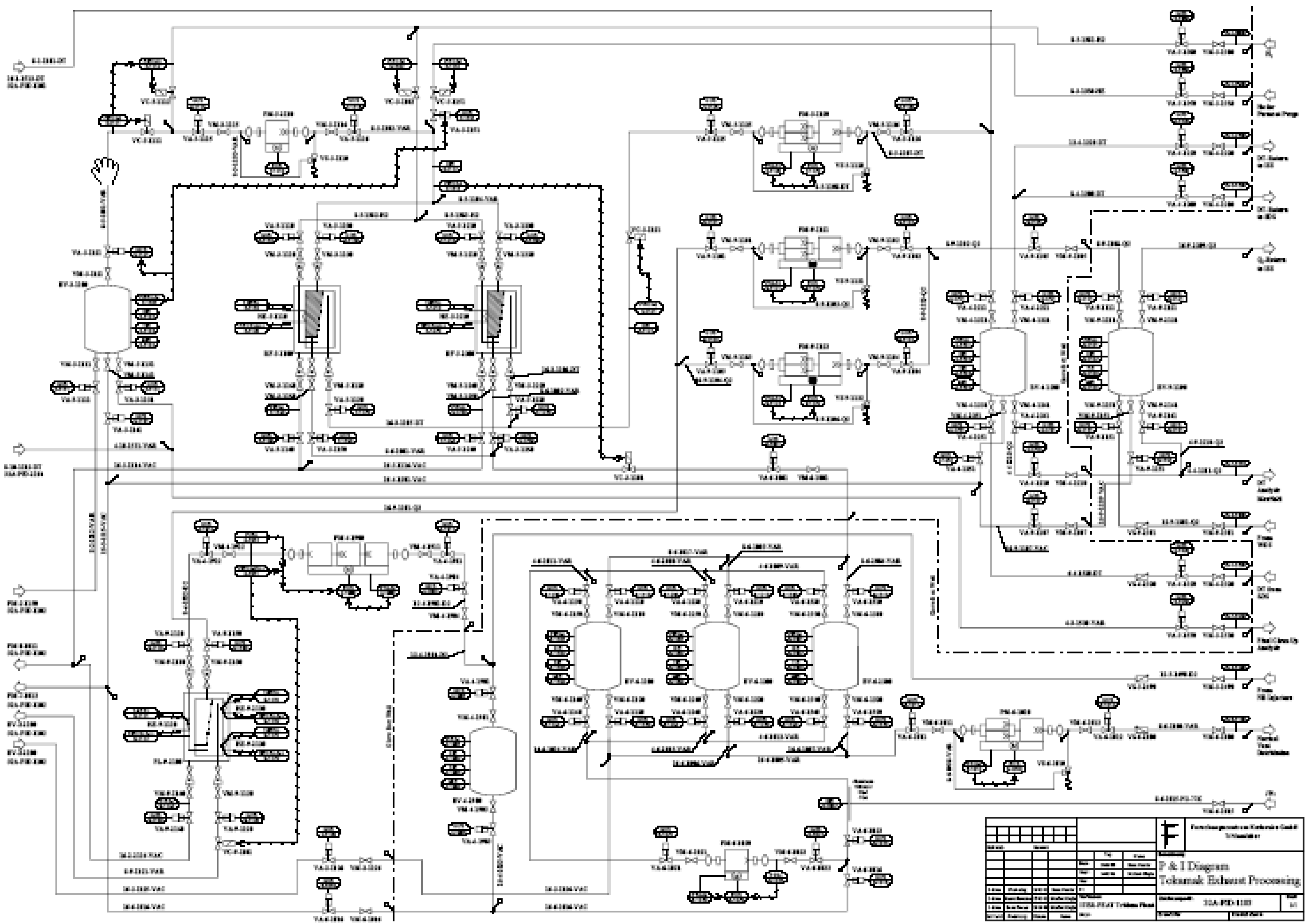
- Lose no more than 1 Ci/day to the Vent Detritiation System
- Overall decontamination factor (DF) of 10^8
- Process gas from 450 s and 3000 s pulses at a flowrate of 150 SLPM (253 Pa m^3/s)

- FDR (Final Design Report) design flowrate was ~75 SLPM

Current official TEP process flow diagram



Design has progressed to the P&ID level



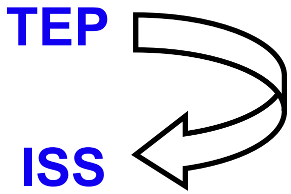
TEP design comparison with FDR

- **Core Technology Selection**
  - The FDR included multiple options for the TEP
  - In 1998 the US withdrew from ITER
  - In the following years the TEP design settled on the Caprice and Caper concepts

- **Additions**
  - Further analysis resulted in increased flowrate (~2x)
  - Activated gas (Ar-41) holding tank
  - Gas holding system for NB regeneration
  - ISS feed treatment
  - Overpressure protection for He-GDC processing system

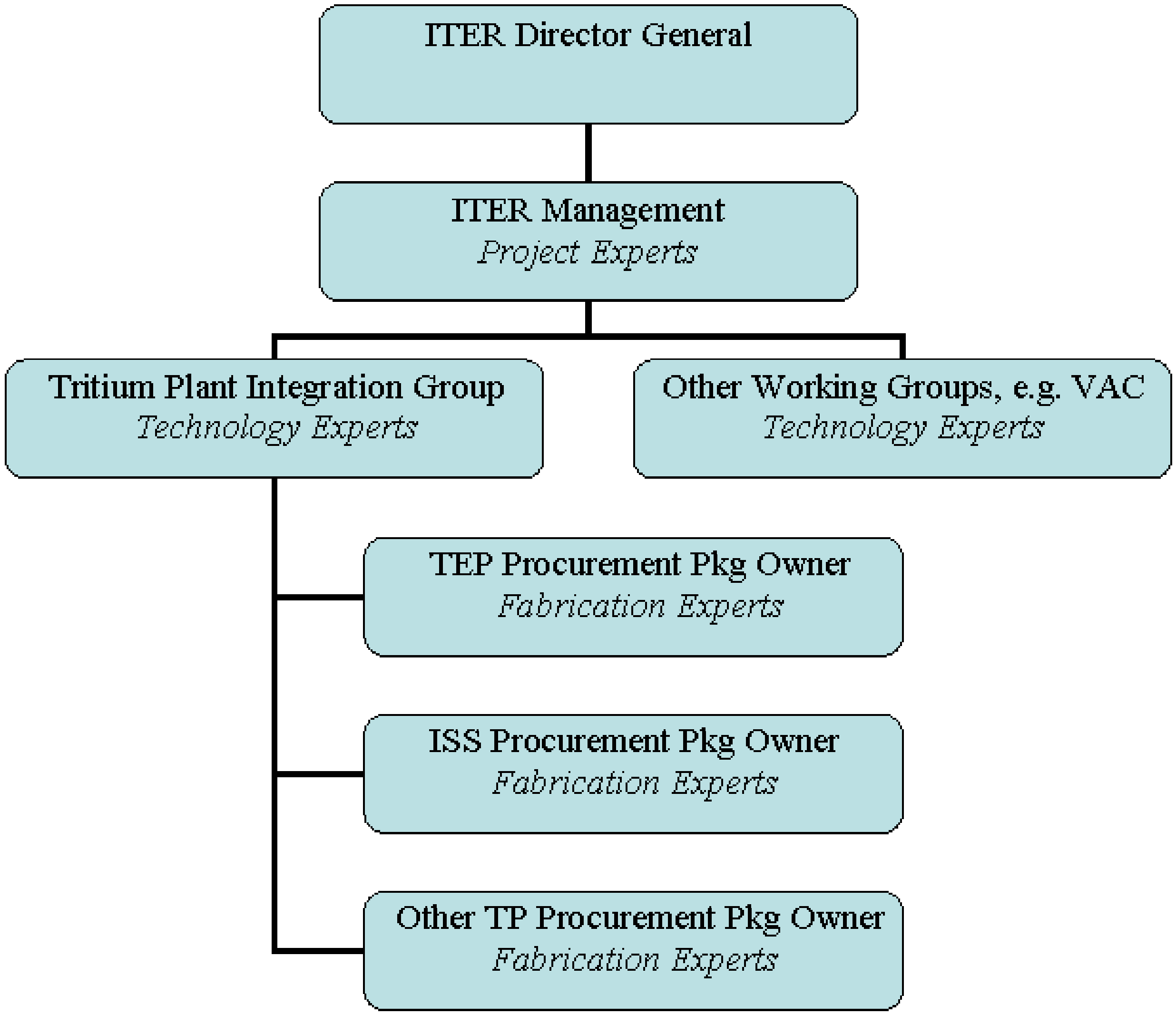
Procurement integration issues

- The tritium plant is divided into logical procurement packages centered around “unit operations”
- These units are directly linked to each other, i.e. exhaust from one is the feed for another
- Examples



- How should the overall Tritium Plant be integrated while giving procurement package responsibility to individual parties?
- An appropriate management structure is needed to ensure integration

Proposed procurement package integration organization



The work associated with delivering the TEP falls into many categories

- Overhead costs
- Detailed design (manufacturing design, e.g., shop drawings)
- Purchasing/fabrication
- Factory testing
- Packaging and transportation
- On-site installation/assembly
- On-site testing
- Documentation and QA
- Technical supervision
- Recommended spares
- Contingency
- Supporting R&D
- Incorporation of FMEA results into design
- Detailed design (pre-manufacturing design specifications)
- Engineering follow
- Installation integration
- Design basis documentation
- Design integration

Present ITER schedule delays TEP procurement until late in construction

ITER Agreement	2005
ITER Construction Start	2006
TEP Contract RFQ	2011
TEP Contract Award	2012
Fabrication complete	2013
Installation	2014
Testing	2015
Full Tritium Plant DT operations	2016
ITER Trace Tritium operations	2017
ITER full DT operations	2018

- This schedule does not allow enough time for bringing this "first-of-a-kind" system to full operational capability, especially when it has to be integrated with other "first-of-a-kind" systems

Currently proposing to complete TEP package five years prior to full ITER operations

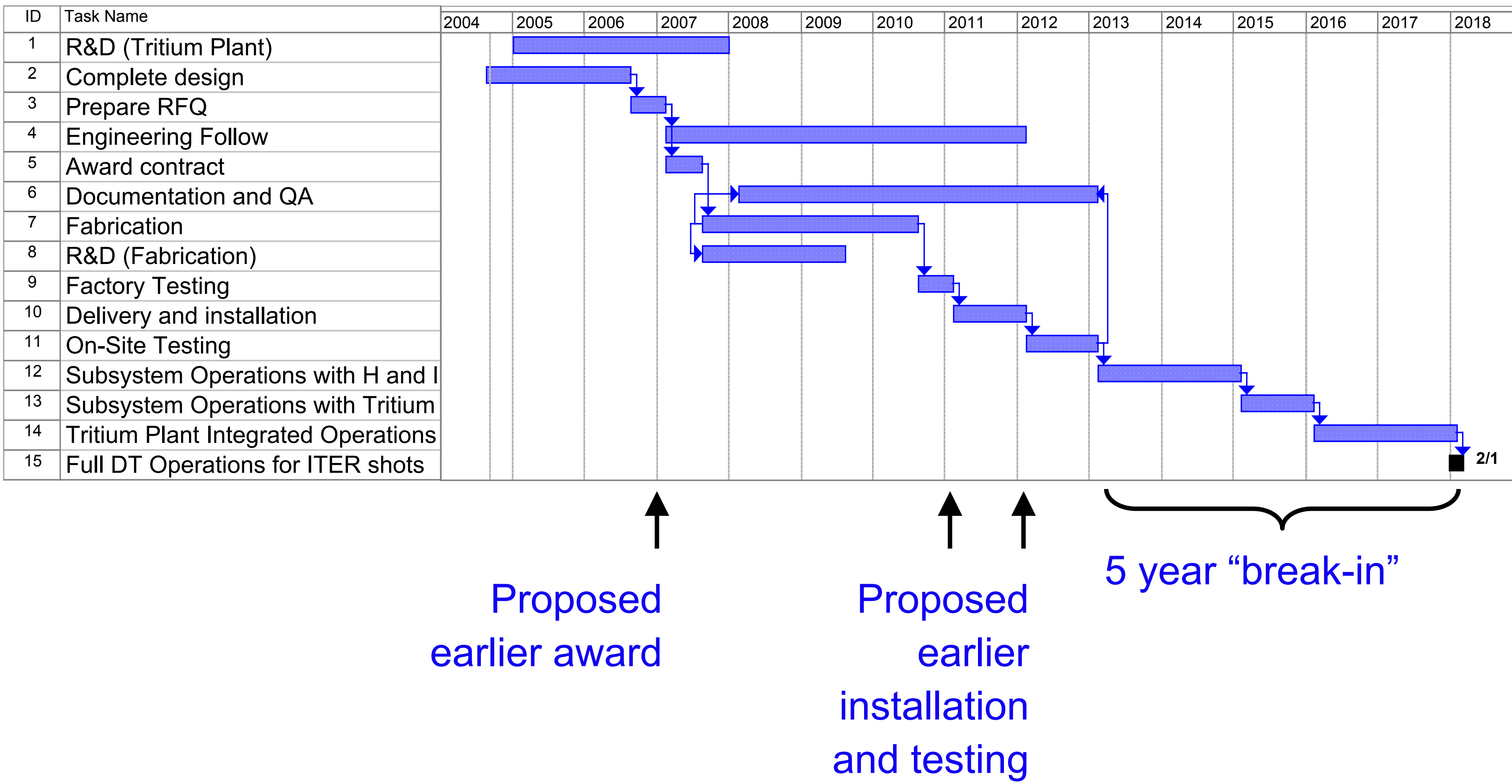
- Full DT operations planned for 2018 (trace tritium in 2017)
- Propose five years for:
  - 2 yrs for TEP H/D testing
  - 1 yr for TEP tritium testing
  - 2 yrs for Tritium Plant integrated operations with H/D and T
- Example activities that must be completed in this time

- staffing
- training program completion
- completion of operator training (five shifts)
- readiness reviews
- corrective actions
- nuclear facility license completion
- tritium inventory management systems
- calibrations
- control system tuning
- as-built performance characterization
- as-built drawing completion
- operating procedure preparation, shake-down, revision and publication
- alarm/interlock testing
- rework/replacement of systems
- incorporation of Tritium Plant control into overall ITER control system
- etc.

Five-year "break-in" period justified by the challenges associated with the ITER Tritium Plant

- Tritium Plant is
  - Clearly nuclear facility (i.e. risk to on- and off-site personnel w/o controls)
  - Much larger (by multiple measures) than any prior fusion tritium facility
- Many tritium facilities have taken considerable time to become fully operational
- Tritium inventory
  - Initial ITER charge of tritium will be ~1000 gm, expensive, and ~5% of available supply
- Tritium is
  - Easily mobilized
  - A major tritium release from the world's flagship fusion machine would be very bad for fusion

Proposed revised TEP procurement schedule



A brief risk assessment was performed

- A number of risk areas were identified
- The most striking observation is that, compared to present experience, the ITER Tritium Plant is
  - 20x's flowrate
  - 10x's inventory (or more)
  - 1/10th the processing time
- This risk can be mitigated by
  - "Industrial-strength" dynamic process modeling for control system development and design improvement
  - Constructing the ITER Tritium Plant earlier than originally planned
  - Including substantial contingency in ITER Tritium Plant budget
  - Correcting issues that arise during "break-in" period

Major next steps

- Incorporate other ITER parties into Tritium Plant process
- Study and understand current state of Tritium Plant design
- Bilateral information exchanges
- Design integration team activities
- International team staffing (after ITER agreement)
- Hold ITER construction Tritium Plant design review

Conclusions

- The US is reengaged in ITER and has been tentatively assigned responsibility for the Tokamak Exhaust Processing system procurement package
- An initial assessment of the TEP has been performed
- Tritium Plant design integration will be crucial and a management approach has been proposed. The Tritium Plant Integration Group is being formed.
- Scale-up from present experience to ITER is striking. Targeted supporting R&D is needed.
- Tritium Plant construction should be completed earlier than presently planned to allow sufficient “break-in” prior to full ITER operations

TEP technologies considered

- **US-1 (FCU)**
  - Oxidation: $CQ_4 + 2O_2 \rightarrow CO_2 + 2Q_2O$
  - Hot metal bed: $Q_2O + M \rightarrow MO + Q_2$
- **CA (HiTEx)**
  - Isotopic swamping, $CQ_4 + H_2 \rightarrow CH_4 + Q_2$
- **Japan (JFCU)**
  - Oxidation: $CQ_4 + 2O_2 \rightarrow CO_2 + 2Q_2O$
  - Electrolysis: $2Q_2O$ + electricity $\rightarrow 2Q_2 + O_2$
- **Germany (Caprice/Caper)**
  - Reforming: $CQ_4 + 2Q_2O \rightarrow CO_2 + 4Q_2$
  - Permeation: Q_2 separation to promote more reaction
  - Isotopic exchange membrane reactor: $CQ_4 + H_2 \rightarrow CH_4 + Q_2$
- **US-2 (PMR)**
  - Membrane reactor: Combined reforming and permeation
  - Low pressure membrane reactor: Same backed by turbo pump