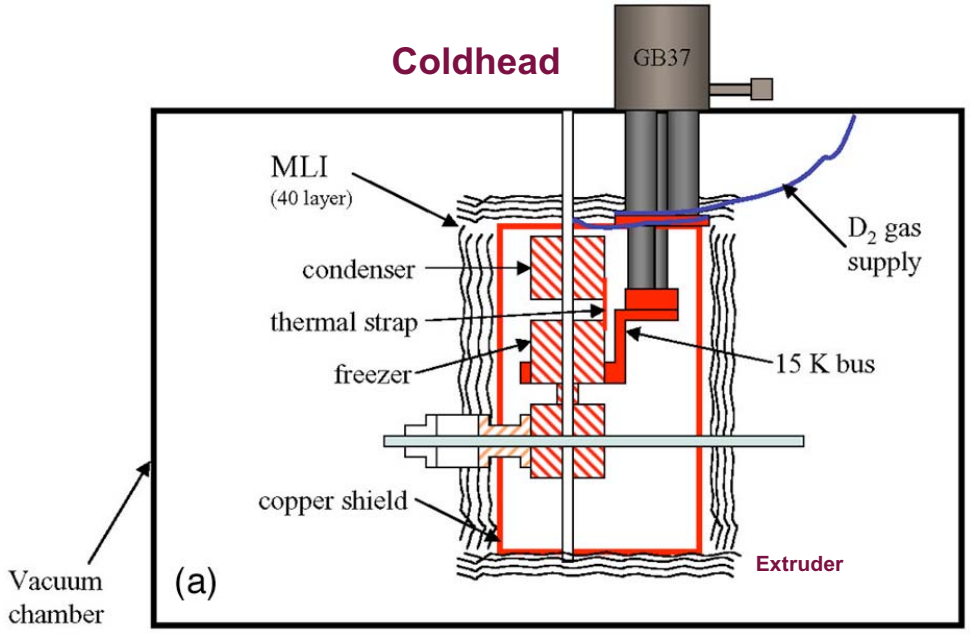
VLT Fueling Technology Development
and
ITER Fueling and Pumping Project

VLT Program Advisory Committee Meeting
March 2-3, 2004

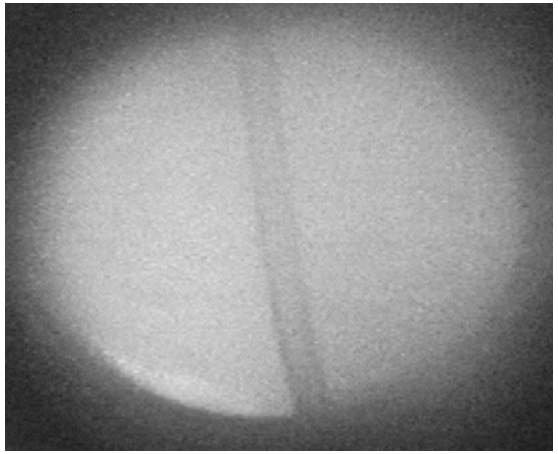
D. A. Rasmussen, S. K. Combs,
L. R. Baylor and C. Foust

Oak Ridge National Laboratory

H2 Extrusions Achieved with Cryocooler Technology

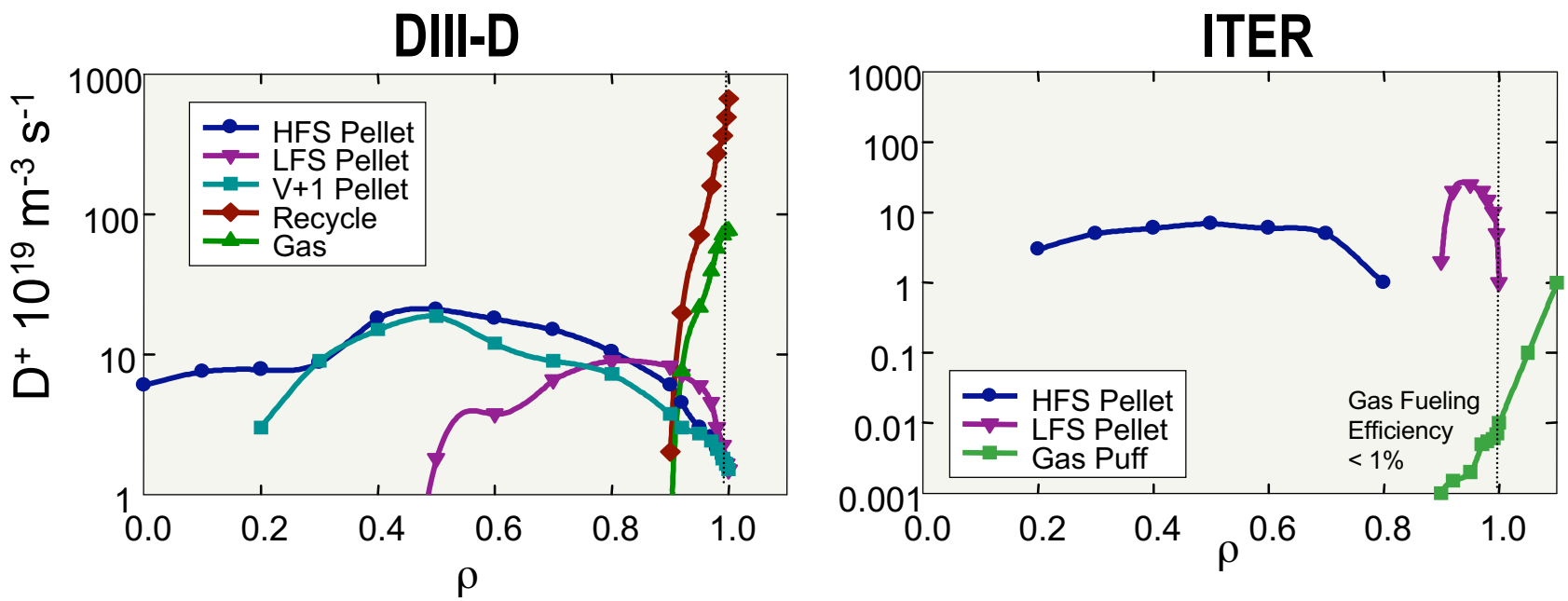


H2 Ice Extrusion



- Work done in collaboration with Prof. J. Pfotenhauer at the UW
- Extruders for long-pulse pellet injectors are usually cooled with LHe (dewars or cryogenic plant)
- Pellet injector with cryocooler offers some advantages
  - low operating cost after initial investment (up to several $K per day for lab operations)
  - independent from LHe dewars or facility cryogenic systems

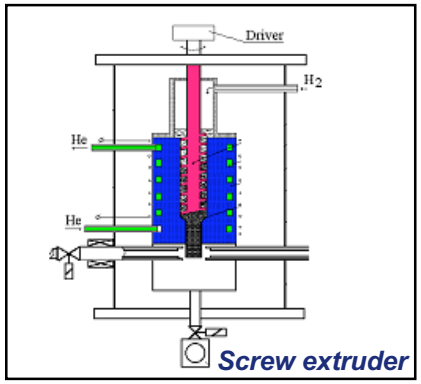
Pellet Injection Will Be Crucial for Effective Core Fueling in ITER
Fueling Source Profile Comparison with DIII-D (Gas and Pellets in H-mode)

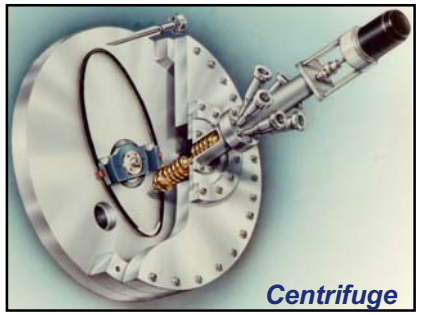


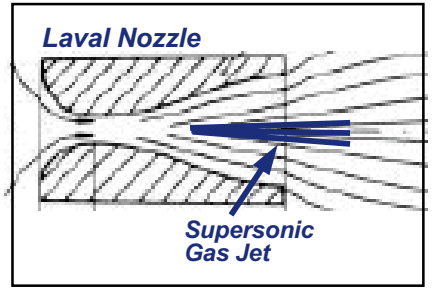
- **Gas puff fueling in ITER will be much less effective in core fueling than in DIII-D; the pellet profiles are from PRL (P. Parks) calculations using a 10-mm pellet extrapolated to 1 Hz operation; a gas fueling rate of ~1000 torr-L/s is used in the ITER case using a B2-Eirene slab calculation (L. Owen and A. Kukushkin)**

New Technical Challenges for ITER Fueling System

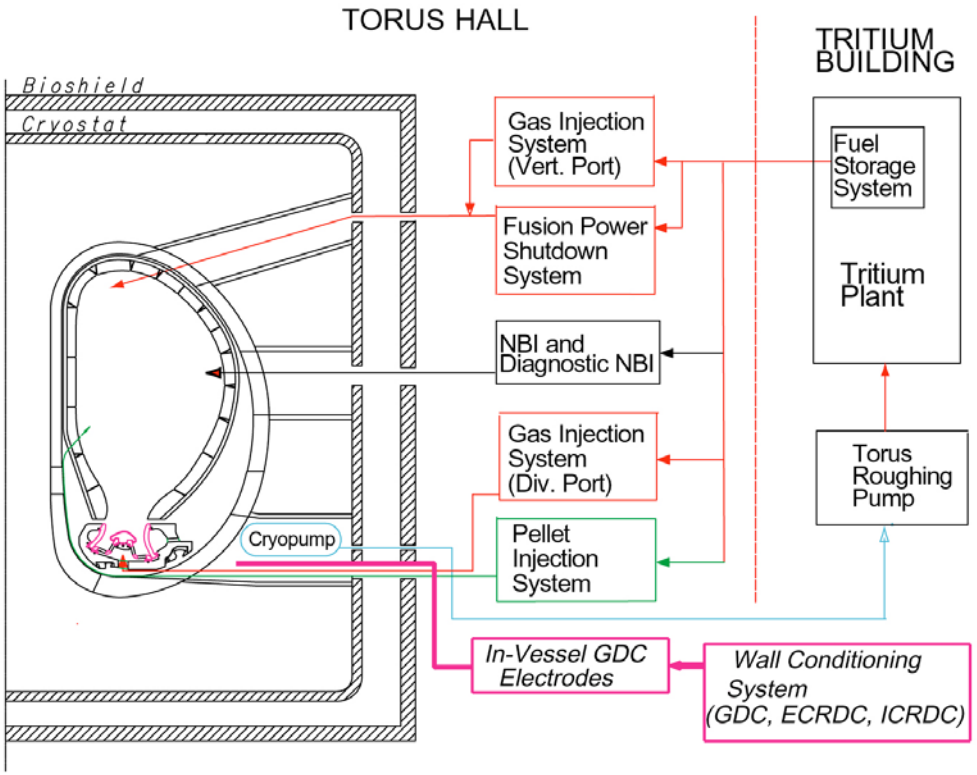
- ITER pellet injector baseline is a centrifuge fed by a continuous screw extruder
- High throughput and tritium compatibility
  - Continuous screw extruder rates are ~5-10 times lower than that required (Viniar, RF)
  - Highest ice flow rates to date are ~67% of ITER requirements using three batch extruders operating in sequence (Combs et al.)
  - Snail pump needed for excess extrusion material
- Centrifuges have not yet achieved the reliability objective (~100% intact pellets).
- Pneumatic injectors can more easily meet reliability requirements, but have a gas load issue.
- Significant R&D effort still required before final ITER design; development and testing program will be needed to validate the proposed design.
- Generic technology development may lead to supplemental approaches (supersonic gas jet, high-speed vertical injector, inner bore PI, etc.)







ITER Fueling System Diagram and Pellet Injection System Design Criteria



Pellet Injection System Spec

- Two centrifuge injectors for redundancy (also supports coincident impurity injection)
- Steady-state operation with DT
- Screw extruders for pellet production and supply (LHe cooled)
- Pellet sizes and rates:
  3 mm @ 50 Hz
  6 mm @ 7 Hz
- Each injector assembly housed in cask (~6 m L x 4 m H x 3 m W) (secondary containment)
- Pellets delivered through single guide tube connected to inner wall through a divertor port
- Includes a diagnostic/control and data acquisition system

FY05 Fueling and pumping development tasks

ITER specific milestones

Conceptual design of reliable compact centrifuge for ITER POP test on DIII-D	12/04
High-throughput guide tube test with ITER-relevant pellet flow rates & pumping	06/05
Design high-speed compact vertical injector system for HFS fueling of burning plasma proof-of principle test on DIII-D or JET (ITER relevant)	09/05
Evaluate continuous extrusion technologies for ITER pellet fueling	01/06
Complete conceptual design of ITER pellet injection system	09/06

ITER specific R&D tasks (subtotal)	$650 K
1) Multiple pellet, high throughput, inner wall guide tube testing	$150 K
2) Prototype centrifuge development	$200 K
3) Continuous extruder development and evaluation	$100 K
4) ITER pellet injector design	$100 K
5) High speed vertical injector design	$100 K
Generic R&D - Multiple collaboration milestones and move (subtotal)	$375 K
1) Compact pellet injector for alternative concept exp. (MST, LTX, NSTX))	$150 K
2) Cryocooler integration with extrusion technology (UW)	$100 K
3) Pellet specific diagnostic development (MST, DIII-D, JET, Tore Supra)	$ 75 K
4) Supersonic cryogenic gas jet (DIII-D)	$ 50 K
Base total	$1025K

FY05 Task increments in priority order

1) Fueling and pumping ITER IT support	$200 K
ITER increment total	$200 K

FY06 Fueling and pumping development tasks

ITER specific milestones

Evaluate continuous extrusion technologies for ITER pellet fueling	01/06
Complete conceptual design of ITER pellet injection system	09/06

	-10%	Flat	Flat+incr
ITER specific R&D tasks	$650 K	$650 K	$1150 K
1) Multiple pellet, high throughput, inner wall guide tube testing	$ 50 K	$ 50 K	$ 50 K
2) Prototype centrifuge development	$250 K	$250 K	$ 400 K
3) Continuous extruder development and evaluation	$100 K	$100 K	$ 300 K
4) ITER pellet injector design	$150 K	$150 K	$ 300 K
5) High speed vertical injector design	$100 K	$100 K	$ 100 K
Generic R&D	$275 K	$375 K	$425 K
1) Compact pellet injector for alternates. (MST, LTX, NSTX)	$150 K	$150 K	$150 K
2) Cryocooler integration with extrusion technology (UW)	$ 75 K	$100 K	$100 K
3) Pellet diagnostic development (MST, DIII-D, JET, Tore Supra)	$ 50 K	$ 75 K	$ 75 K
4) Supersonic cryogenic gas jet (DIII-D)	$ 0 K	$ 50 K	$100 K
Total	$925 K	$1025K	$1575K

FY06 Task increments in priority order

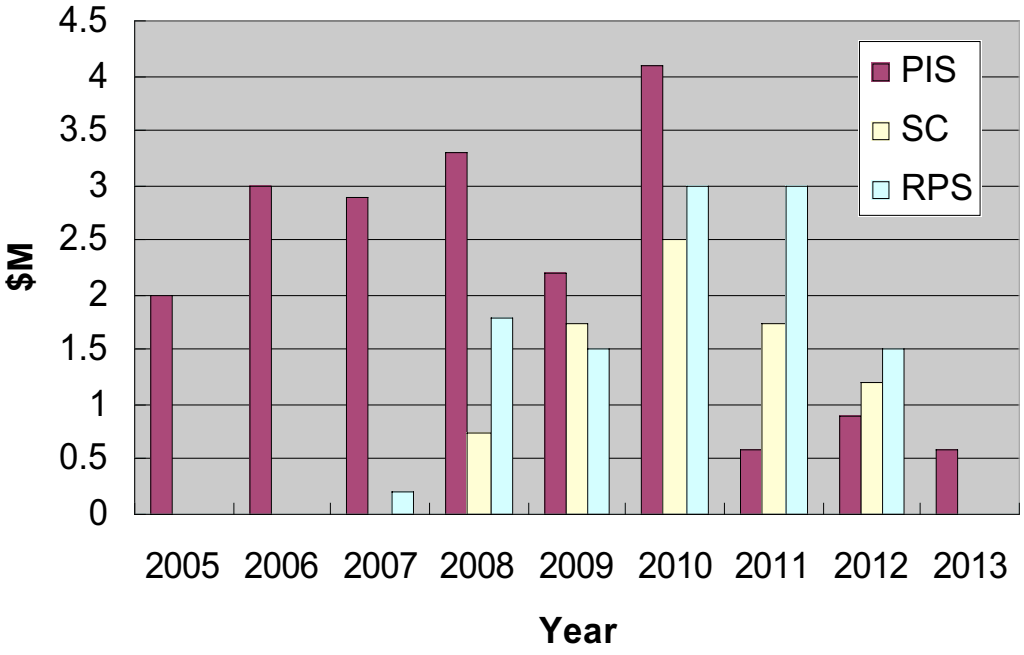
1) Prototype centrifuge development	$150 K
2) Continuous extruder development and evaluation	$200 K
3) Fueling and pumping ITER IT support	$400 K
4) ITER pellet injector design	$150 K
ITER increment total	$550 K

FY05 and FY06 ITER project funded tasks Incremental request

- **Fueling and pumping ITER IT support:** Provide research staff to act as US lead and liaison to the International Team for the ITER Fueling and Pumping System, and to coordinate design and R&D activities among the IT, US, and other participants.
  FY05 0.4 FTE
  FY06 0.8 FTE

Funding Profile for PIS, RPS, and SC

- PIS R&D and preliminary design must start early
- Vacuum pumping packages are in out years, but must be complete for early installation



Key concerns/issues

- Pellet injector conceptual design
  - ITER pellet injector workshop May 2004 in Garching
  - Centrifuge injector is the baseline design
  - Gas gun is an alternative if percieved to have an advantage
  - Maximum pellet speed for inner wall guide tube needs to be determined experiementally
  - A conceptual design for the extruder needs to be developed
  - A “central solenoid” injector has been proposed but it may not be feasibile
- Subcontract roles for international partners
- Test facilities will need to be upgraded

FY03/04 Technical Highlights/Accomplishments

- Solid hydrogenic extrusions using a Gifford-McMahan cryocooler. Lower installation and operating costs than liquid helium.
- Pellet survivability tests performed for FIRE inside launch. The limit for this compact high field machine is ~ 200 m/s.
- Tests of massive gas puff technology in curved guide tubes. Allows more advantageous locations on DIII-D and other machines.
- Initial evaluation of ITER R&D cost and schedule

Incremental request for Cryo pump testing for ITER pellet injector (Scott Willms)

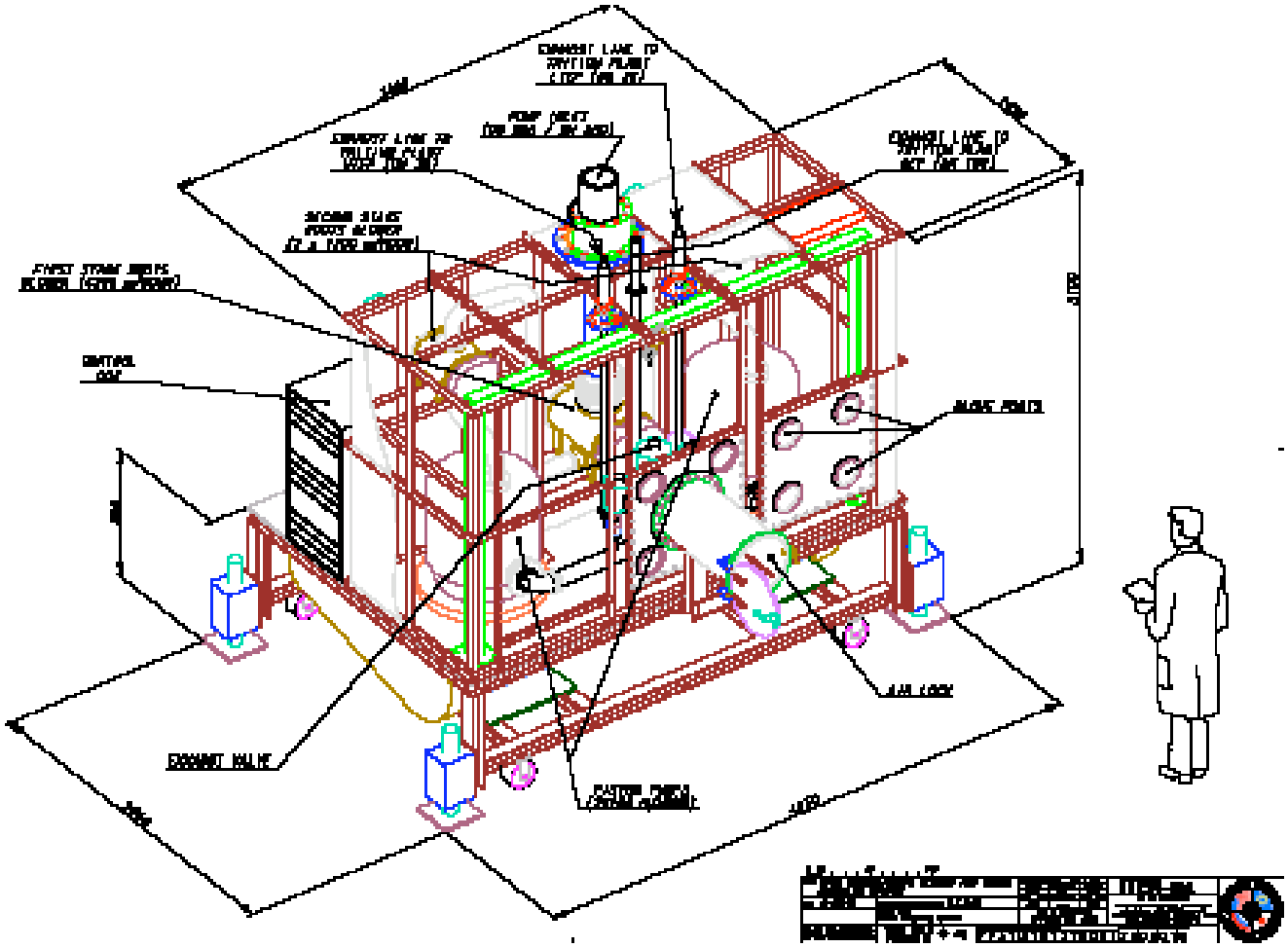
FY05 (125k); Install pump in vertical position. Test pump with H and D.
FY05 (50k); Test pump with H and D.

ITER Fueling Systems Requirements and Present Design

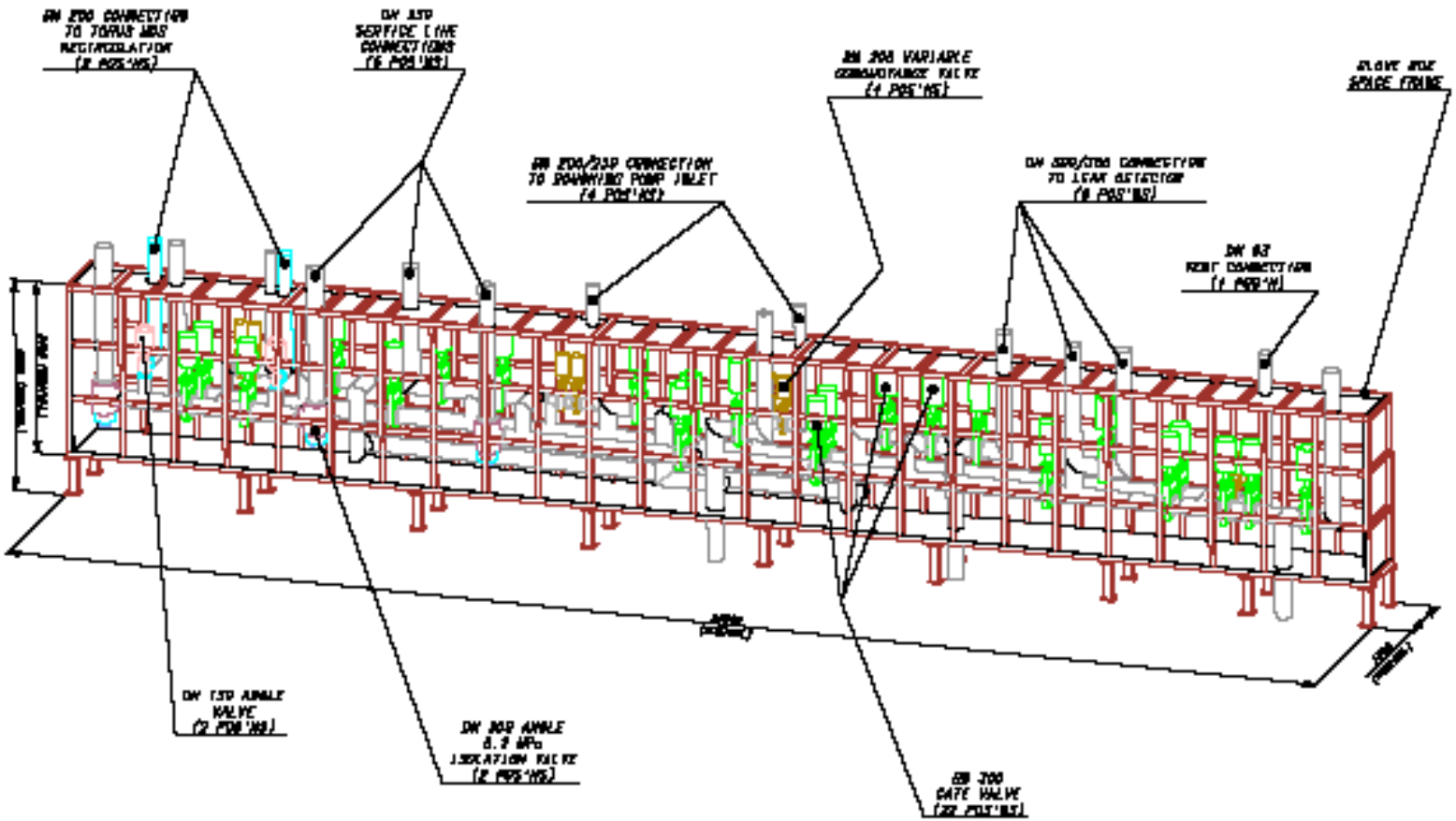
Plasma Density (n_{GW})	0.4 - 1
Fuel Isotope	Pellet (90%T/10%D)
DT Burn Rate	Unknown
Gas Fueling Rate (torr-L/s)	Up to 3000
Pellet Fueling Rate (torr-L/s)	750 DT (375 for 90%T/10%D)
Pulse length (s)	Up to 3000

- Gas injection system
  - Supplies H_2, D_2, T_2, DT, Ar, Ne, and He via a gas manifold
  - Makes use of conventional gas handling hardware and requires minimal R&D
- Pellet injection system
  - Supplies H_2, D_2, and DT pellets: 3 to 6 mm diam (50 to 7 Hz, respectively)
  - Only at pre-conceptual design level and significant R&D support still needed

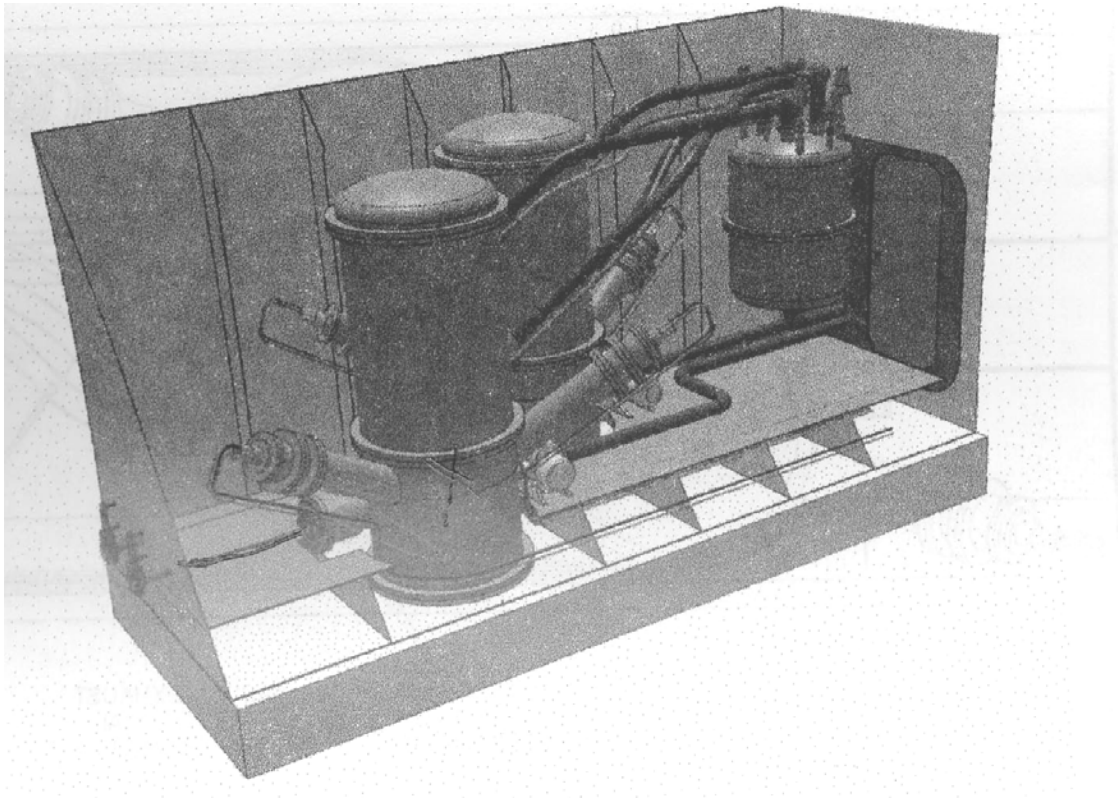
ITER Torus Roughing System - Blower Assembly



ITER Roughing Pump Change Over Valve Box Assembly

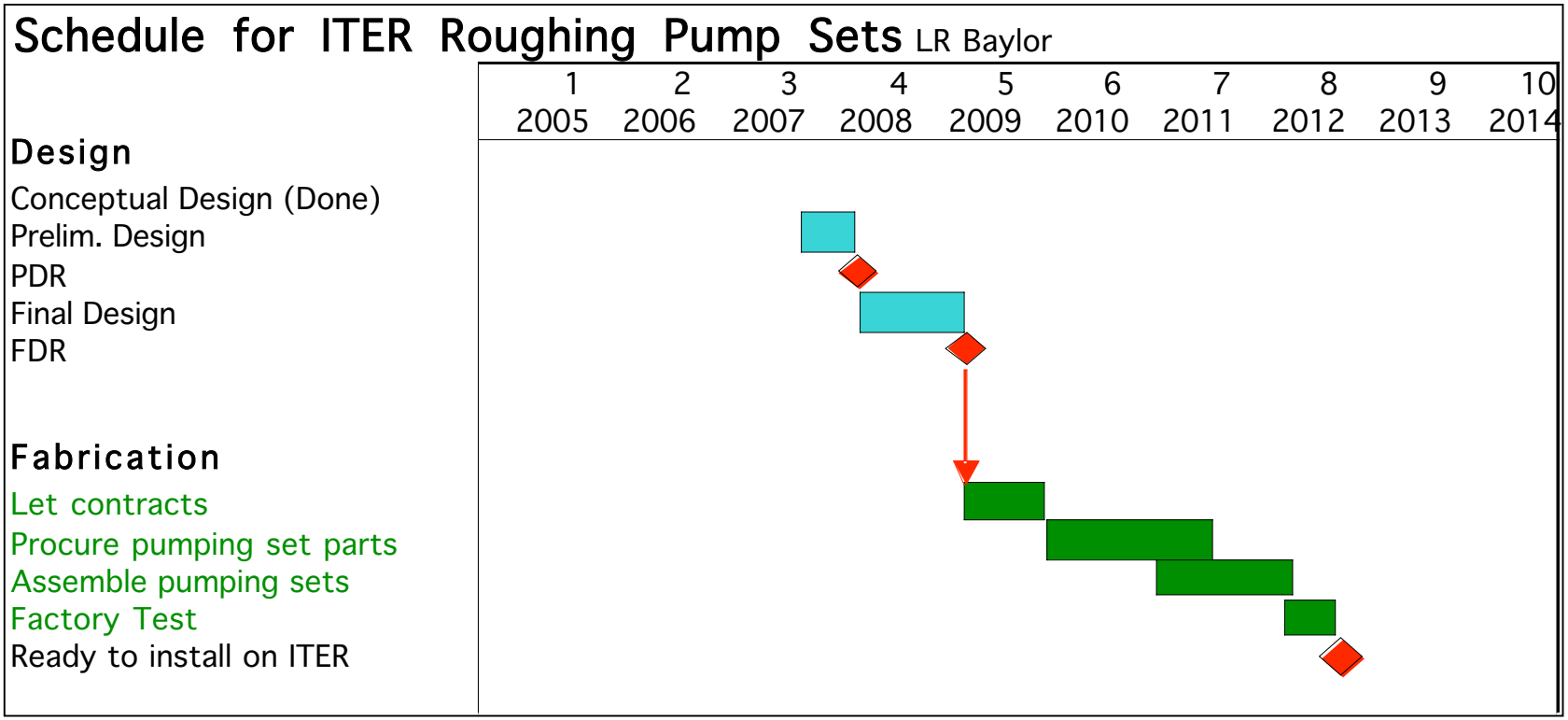


ITER Pellet Injection Cask Layout by EFDA (UKAEA Group)

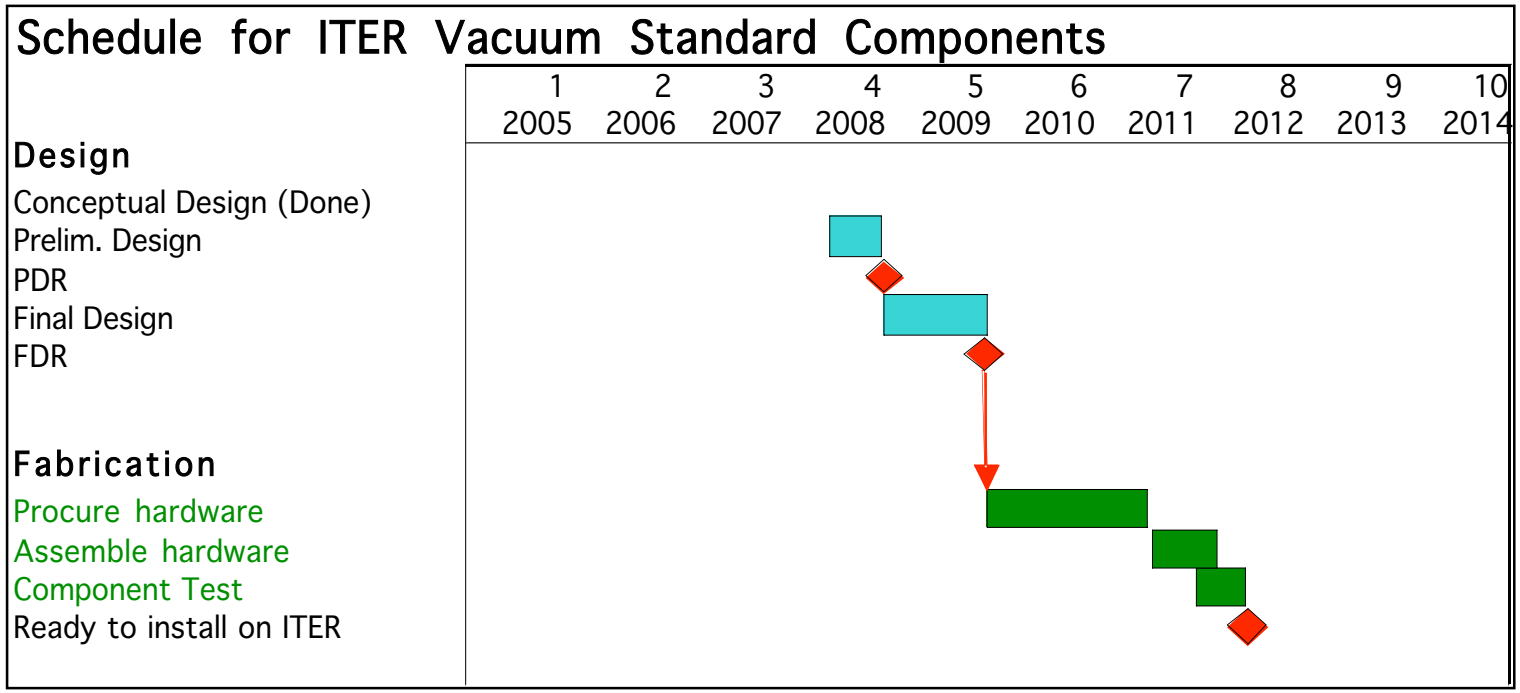
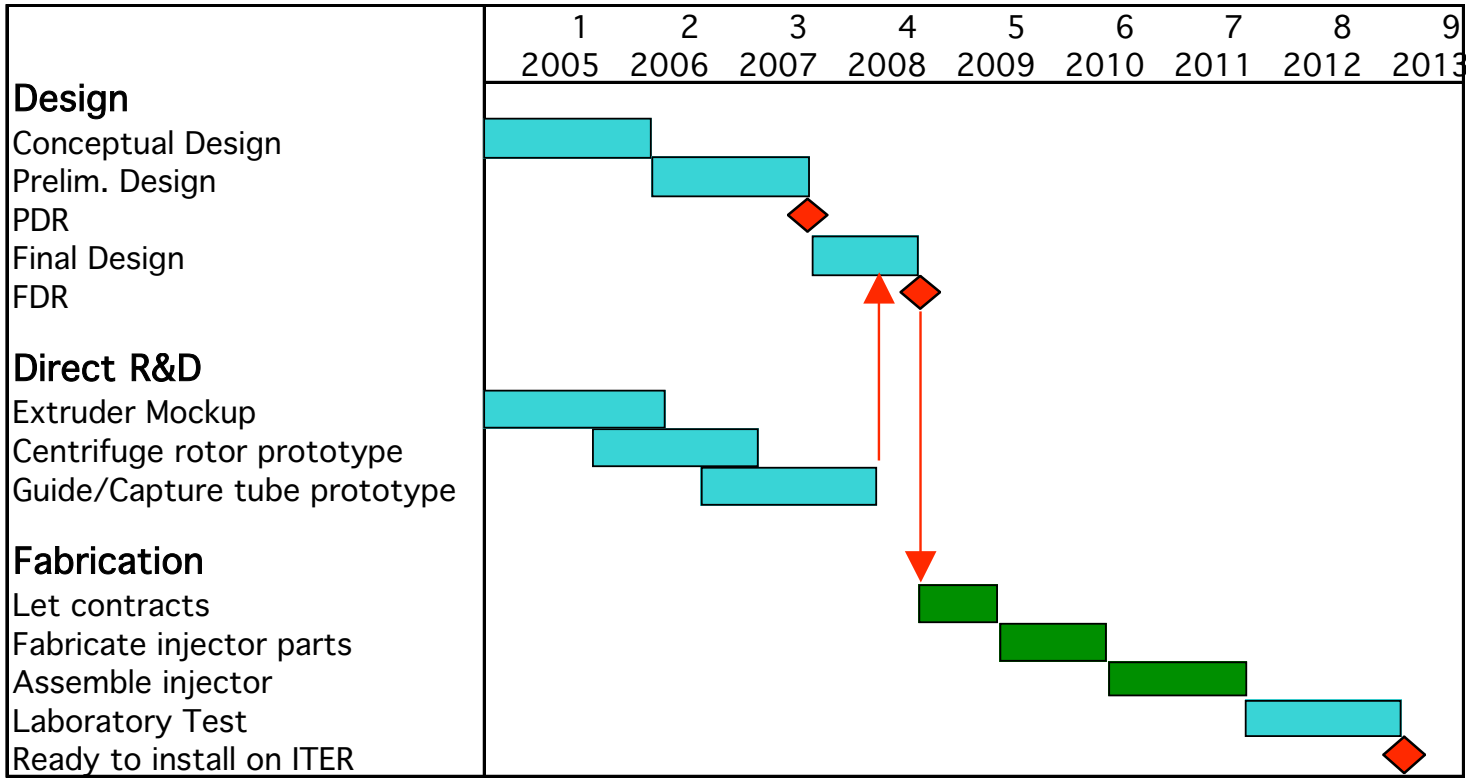


- The ITER pellet injection system layout inside the cask as envisioned by the Culham group based on the JET centrifuge design. (M. Watson, EFDA report, 2003)

Tentative Schedule for ITER Roughing Pump Sets



Tentative Schedule for ITER Vacuum Standard Components



Tentative Schedule for ITER Pellet Injection System