

Pumping Systems for ITER, FIRE and ARIES

P. W. Fisher

Oak Ridge National Laboratory

C. A. Foster

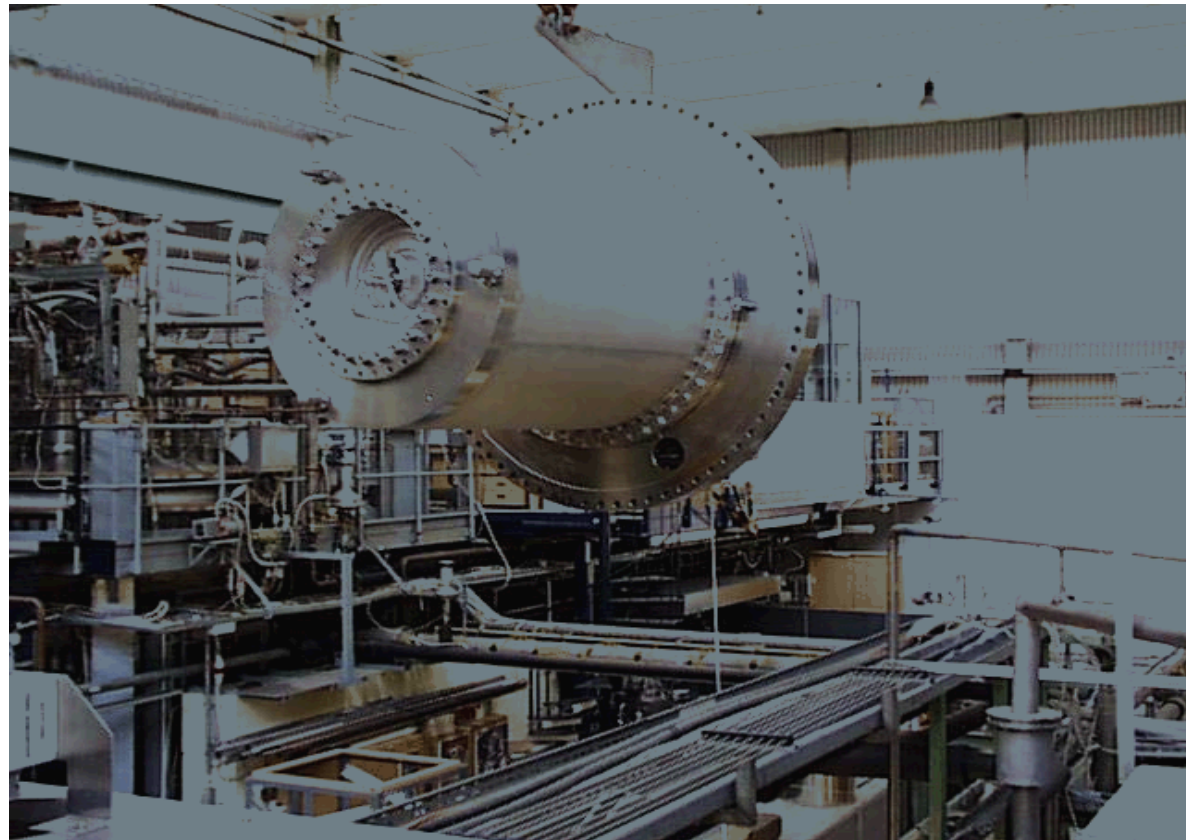
Cryogenic Applications F, Inc.

March 6, 2001

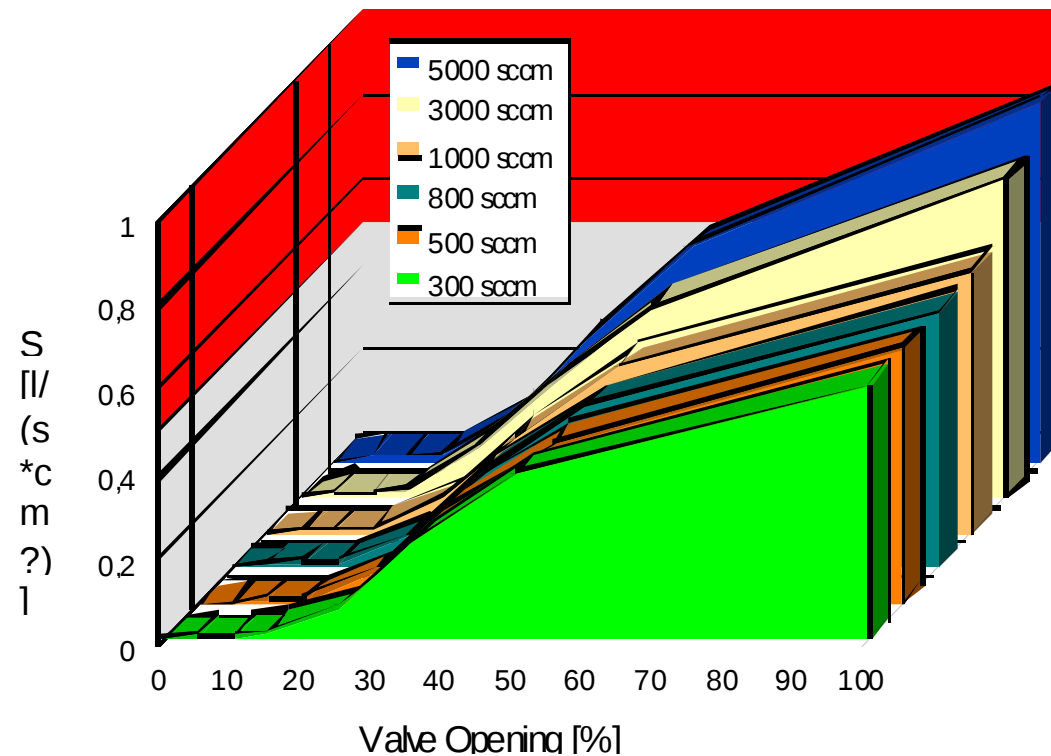
ITER Vacuum System

- Tritium compatible batch regenerating cryogenic pump
 - Pumping speed of $> 200 \text{ m}^3/\text{s}$ for all hydrogen species in the pressure range 0.1 to 10 Pa with six pumps pumping
 - Minimum pumping speed for helium of $200 \text{ m}^3/\text{s}$
 - Minimum capacity of $200 \text{ Pa}\cdot\text{m}^3/\text{s}$ for all hydrogen species with six pumps pumping for $> 400 \text{ s}$ in the presence of the helium from the fusion reaction and impurities
 - Batch operation with a regeneration cycle time $< 300 \text{ s}$, including warm-up to 80 K, evacuation of the desorbed gases, and re-cool to 4.5 K
 - Regulation of pumping speed from 0 to 100% within 10 s
 - Regulation of sorbent panel temperature to suppress helium pumping during leak testing

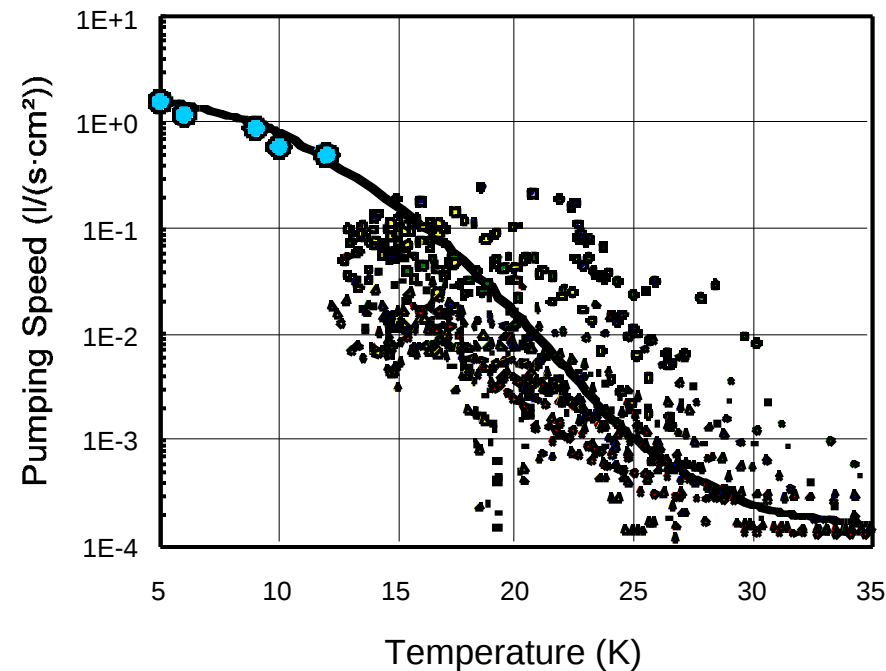
ITER Model Pump Installation at TIMO Test Facility



ITER Model Pump Variation of Unit Pumping Speed vs. Valve Opening



ITER Model Pump Suppression of Helium Pumping vs. Temperature



Pumping system R&D in the U. S.

- The VLT does not have an active program element in the MFE pumping area:
 - DOE has funded Cryogenics Applications F, Incorporated to develop several advanced cryogenic pumping concepts via the SBIR and STTR (small business innovative research) programs
 - the VLT fueling program element provides some oversight of these activities for the VLT and OFES since the technology is relevant to fueling
 - this R&D is transferred to new machines like FIRE through ORNL responsibility for fueling, pumping and disruption mitigation systems
 - The FIRE R&D plan proposes to test a cryopumping module including the 30 K cold entrance duct

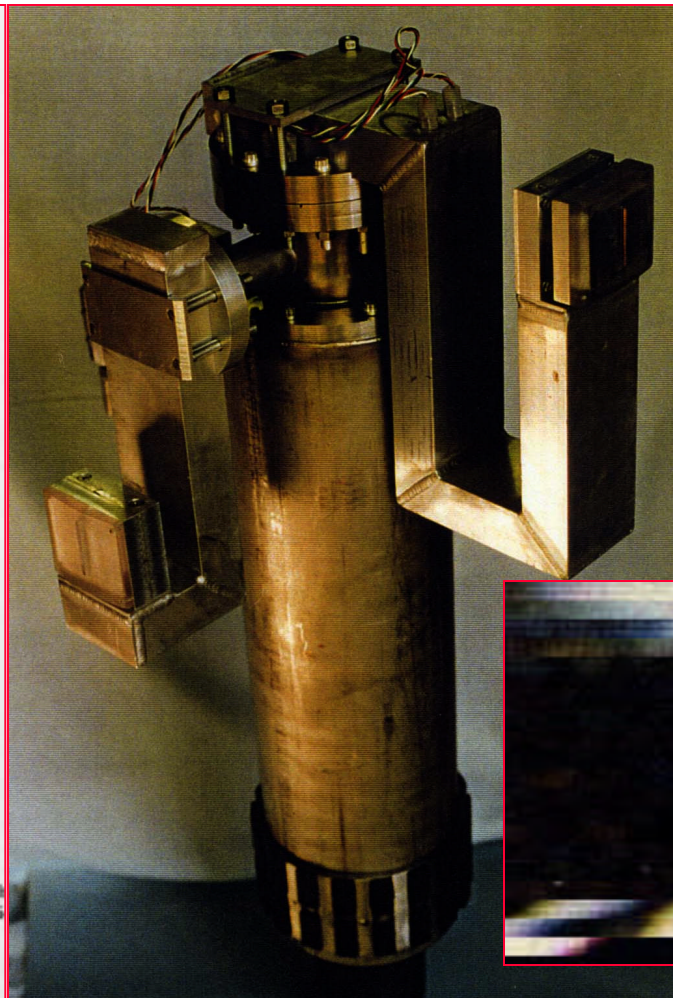
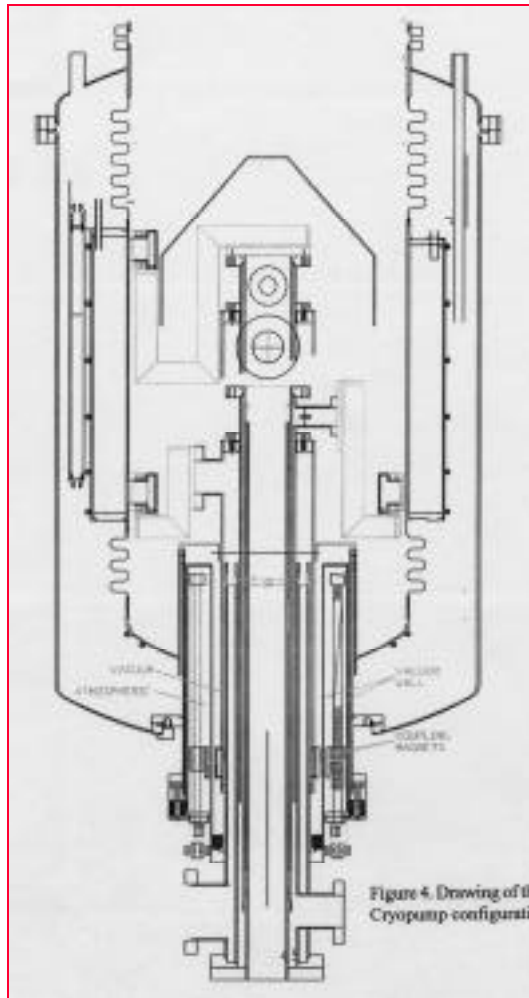
Fusion vacuum technology development by CAFI

- Focus on continuous regeneration
 - eliminate frequent regeneration cycles with attendant cryogenic heat loads and thermal cycling mechanical issues
 - minimize system tritium working inventory
- Design systems that can work at pressures in the range 0.1-10 Pa
 - minimize volume of the pumping system and inlet duct diameters to allow better fit in constrained area around vacuum vessel and divertor, smaller thermal mass.
- Optimize system for helium ash pumping

CAFI Snail Cryopump

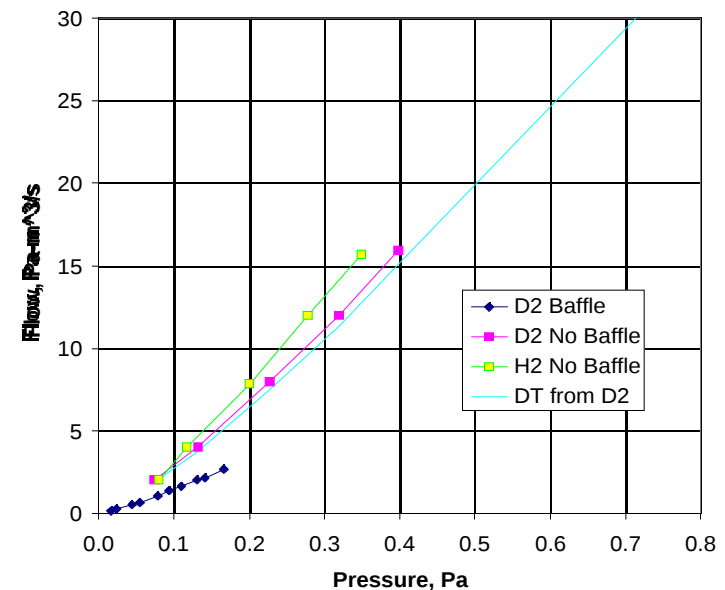
- 1991-1995: DOE SBIR developed 500-mm bore continuous “Snail” cryopump
- High throughput cryocondensation pump with “snail” regeneration heads
- 40,000 l/s at 3 millitorr (0.4 Pa)
- 120 torr-l/s (16 Pa-m³/s) deuterium throughput (~ 1/12 ITER)
 - single pump could operate at about 2x pressure to get ~30 Pa-m³/s
- Compression ratio 1,000

Snail Cryopump



Continuous cryopump: developed under DOE SBIR program

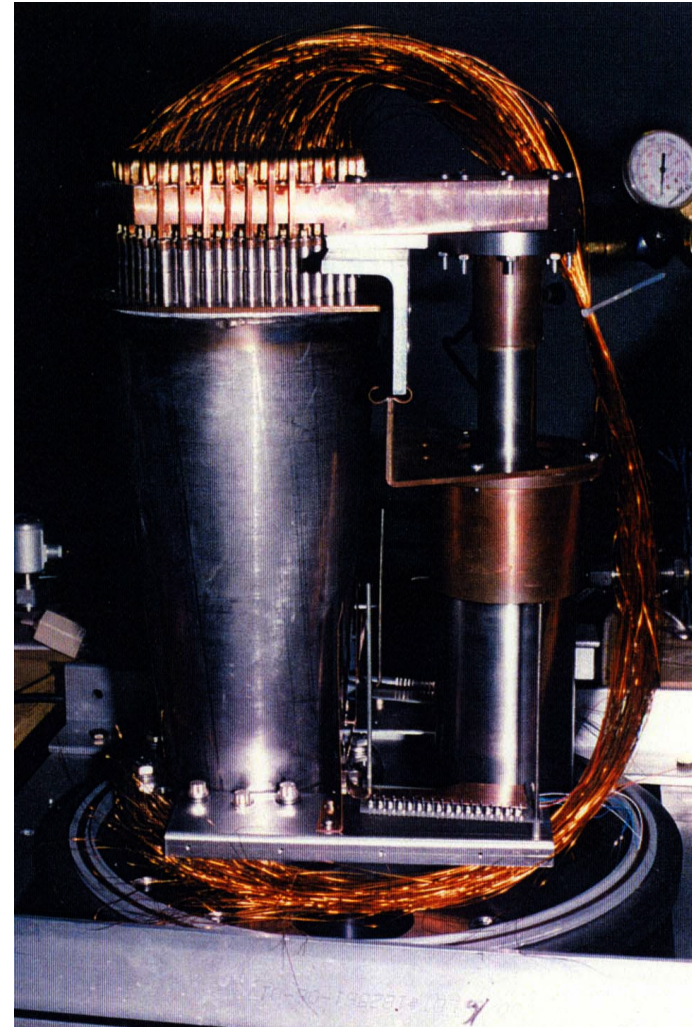
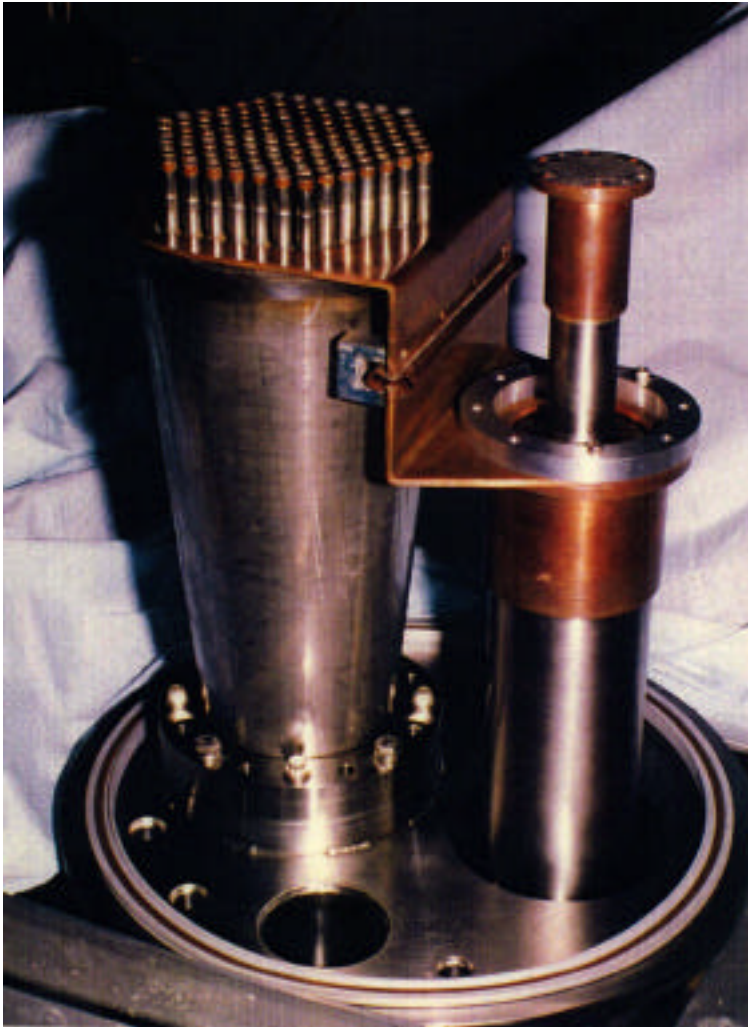
- A prototype pump has been developed and tested with deuterium gas.
- It has a 0.5 m inlet diameter and continuously regenerates via a snail regeneration head with a regeneration cycle time of 270 s.
- The pump has demonstrated a speed of 40,000 liter/s (D) with 0.4 Pa inlet pressure (throughput of 16 Pa-m³/s).
- Points on the plot are data for 300 K gas feed for two cases: D₂ and H₂ into an open throat pump with no chevron or cooling baffle and D₂ into the pump with a 77 K baffle.
- The line shown for DT was extrapolated from the D₂ curve.
- 30 Pa-m³/s is achievable with this pump. The pump inlet pressure at this feed rate would be about 0.73 Pa without a baffle and about twice this value with a baffle.



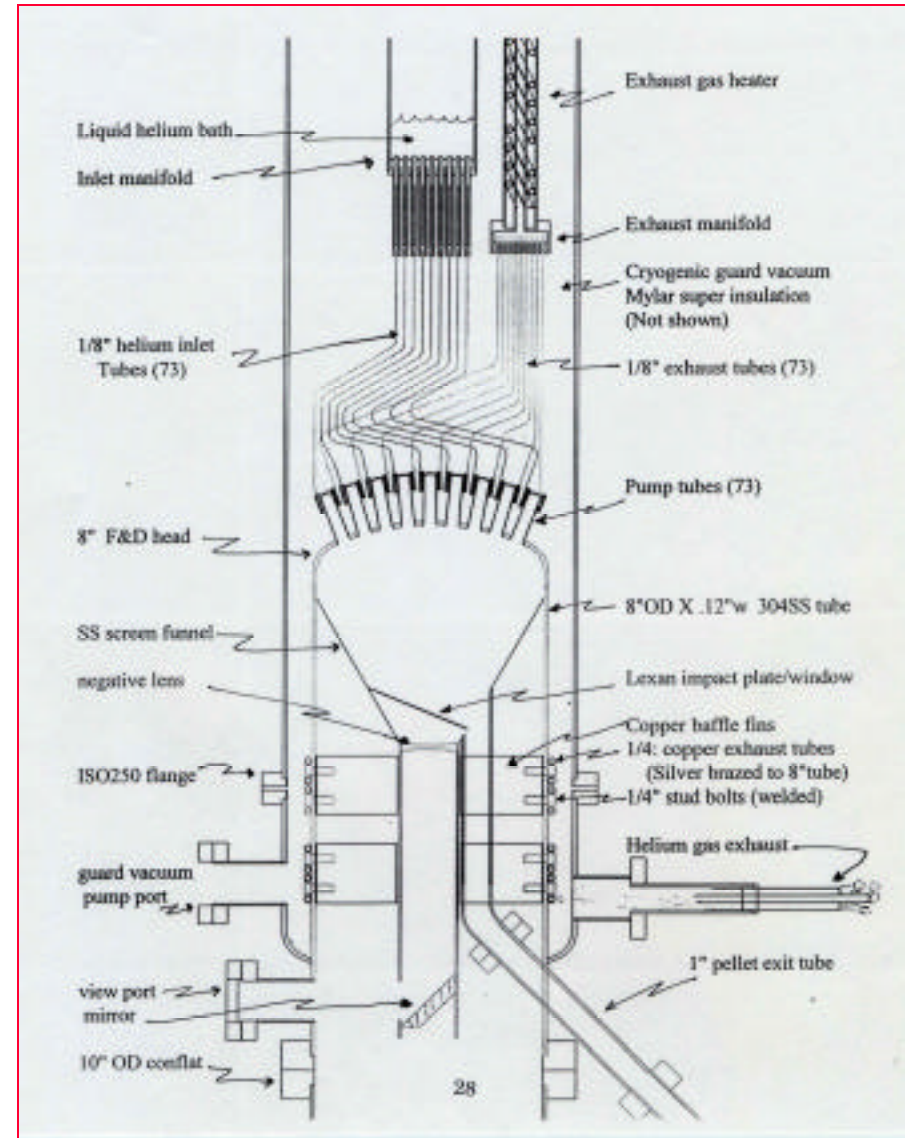
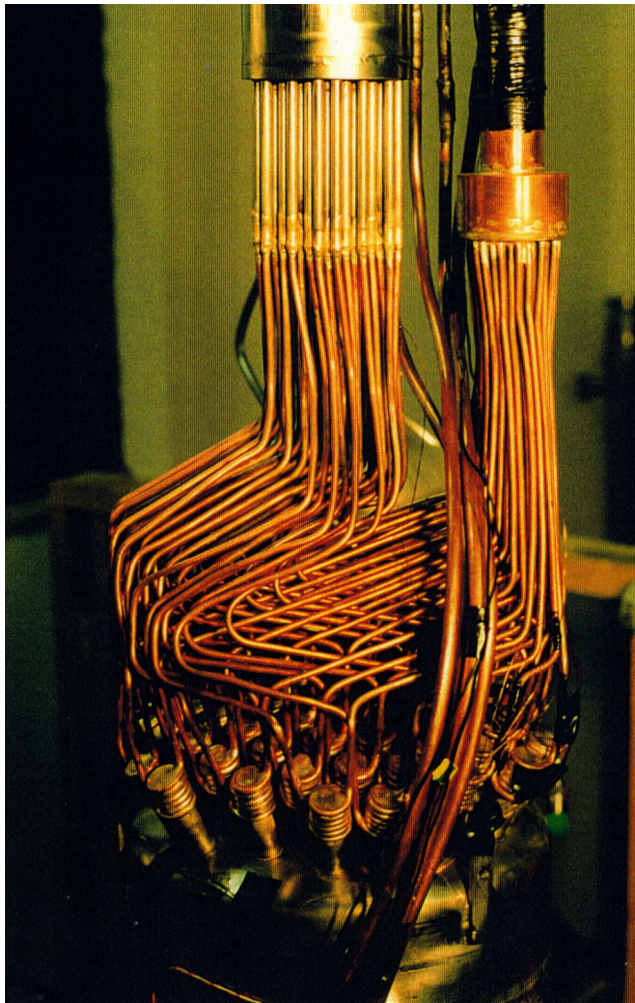
CAFI Pellet Pump

- 1994-1998 DOE SBIR developed continuous “Pellet Pump” cryogenic forepump
- High throughput cryocondensation forepump
- Inlet gas below triple point pressure
- Exhaust solid pellets with a compression ratio 200,000
- No moving parts
- Two forepumps produced:
 - 6 mm x 6 mm, 144 torr-l/pellet, 27 cell pump
 - 36 torr-l/s, 0.25 pellet/s
 - G-M refrigerator
 - 10 mm x 17 mm, 1,100 torr-l/pellet, 73 cell pump
 - 120 torr-l/s, 0.1 pellet/s
 - Liquid helium refrigerant

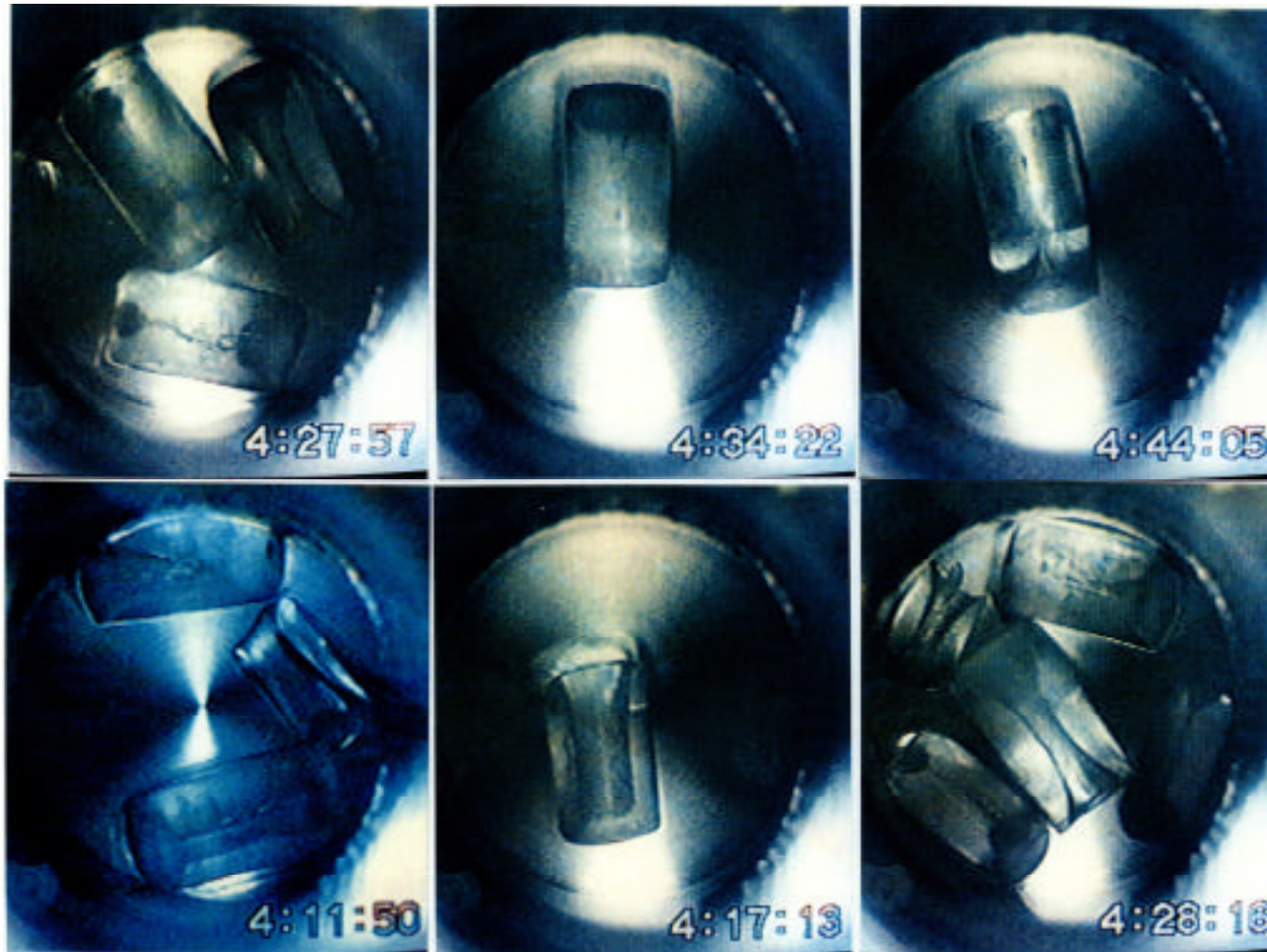
G-M Refrigerator Pellet Pump



Liquid Helium Cooled Pellet Pump



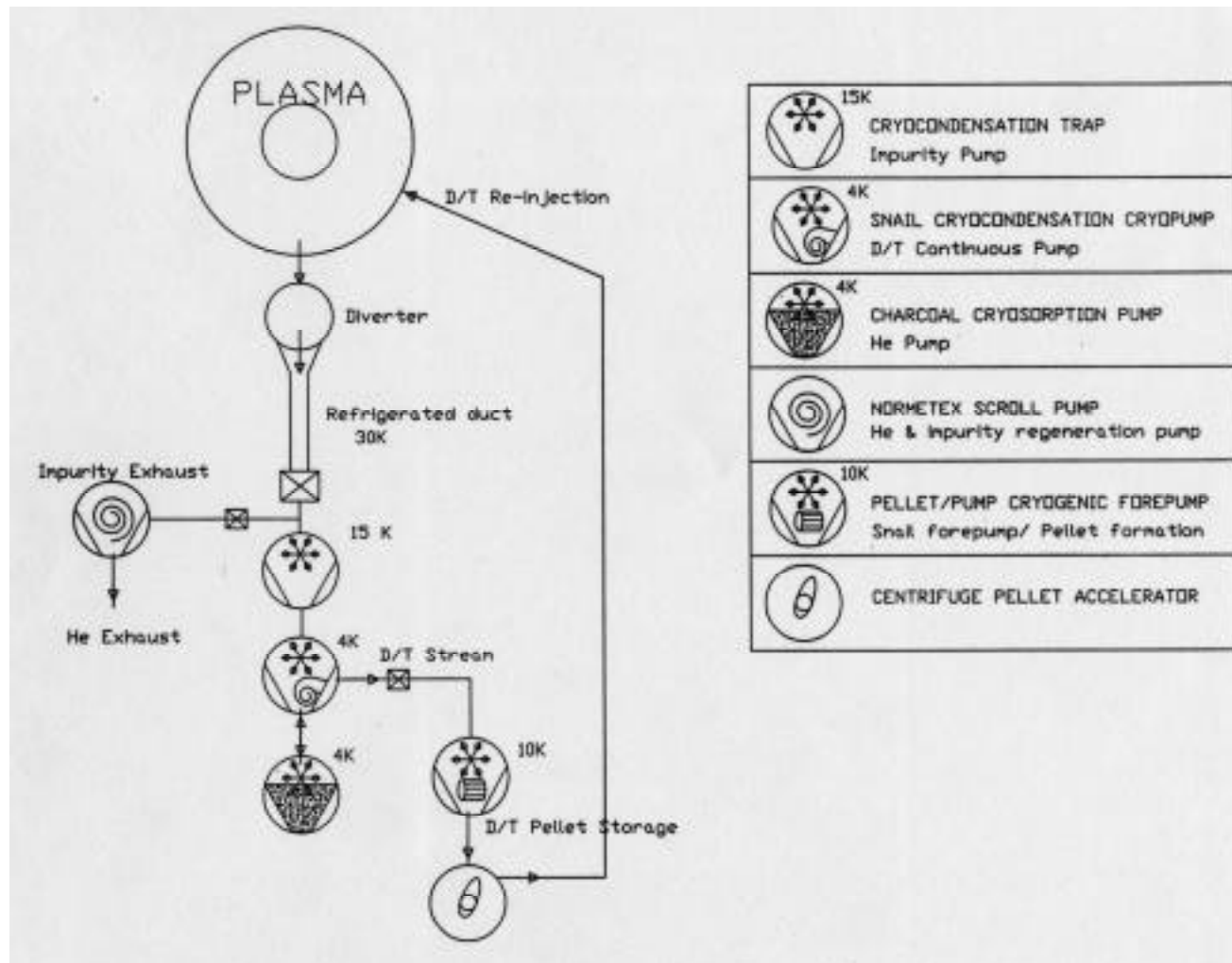
10 mm D2 Pellets from Pellet Pump



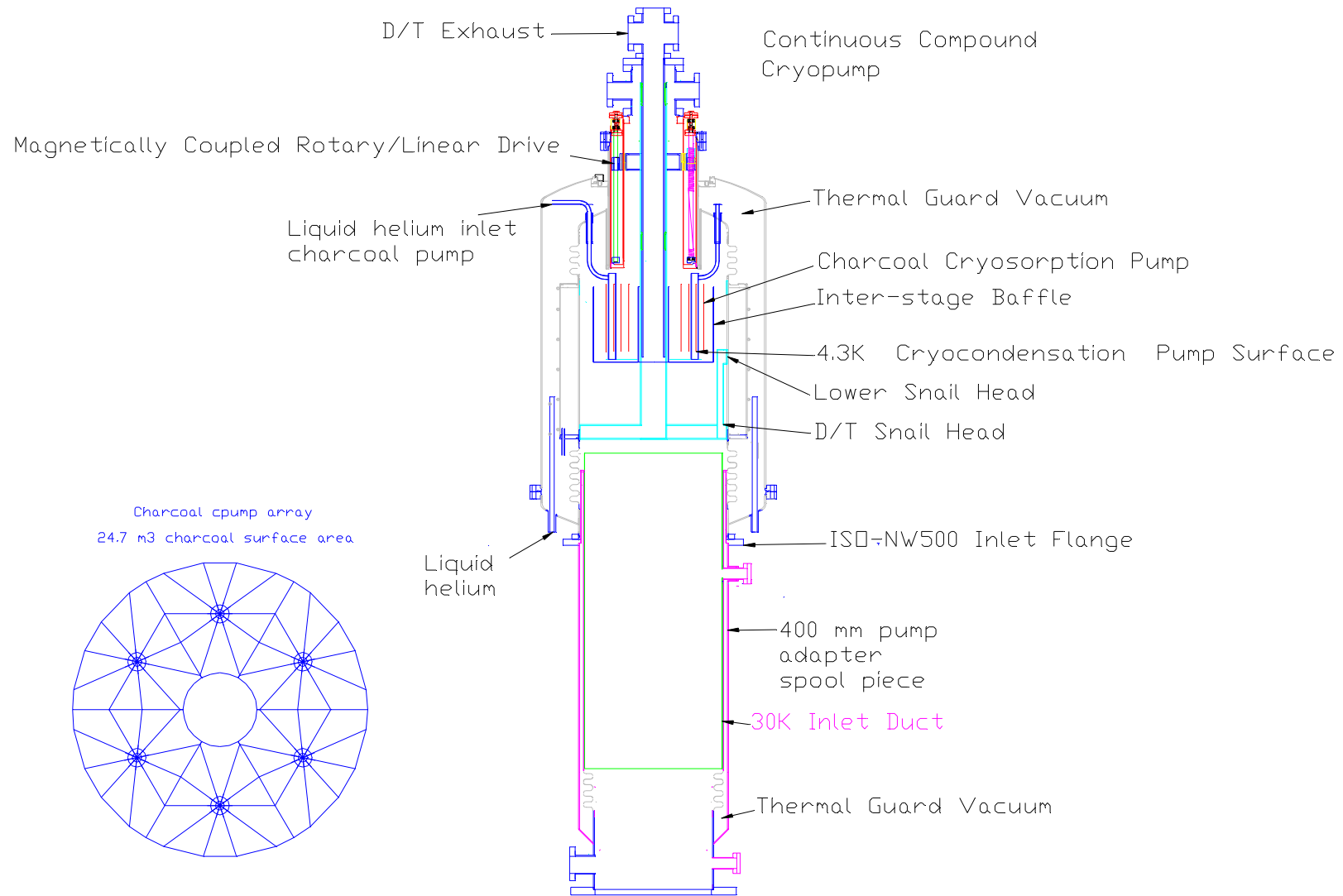
CAFI Snail Continuous Cryopump System

- 1998-Present DOE STTR to construct a low-inventory tritium pumping system
- Combine snail pump with a charcoal pump
 - 15K inlet baffle pumps impurities
 - Snail pumps D/T fraction (95%)
 - Charcoal stage pumps He + 5% D/T with regeneration 1/h
- Pellet pump
 - Backing pump for snail pump
 - Feeds D/T pellets to centrifuge pellet injector
- Scroll pump pumps He during regeneration of charcoal pump

Snail Continuous Cryopump System



STTR Snail Continuous Cryopump



Refrigerated Duct

- Low-temperature duct has lower flow impedance than baffles
- Increasing gas density with reduced temperature through duct produces viscous flow
- D/T viscous flow compresses minority He stream
 - Compression ratio of ~ 30 reduces helium pump speed requirement
- This CAFI DOE STTR-developed concept was transferred to the FIRE pump design

FIRE Pumping System

- Σ Provide all vacuum pumping for torus during
 - bakeout
 - normal operation
 - discharge cleaning
- Σ Base pressure:
 - Σ 10^{-7} torr, for fuel gases (H, D, T)
 - Σ 10^{-9} torr for impurities
- Σ Gas load: ~ 200 torr-l/s of H, D, T and some He
- Σ Operating pressure $\sim 10^{-4}$ to 10^{-3} torr
- Σ Must be compatible with tritium (oil free, all metal)
- Σ H, D, T inventory must remain below deflagration and tritium limits

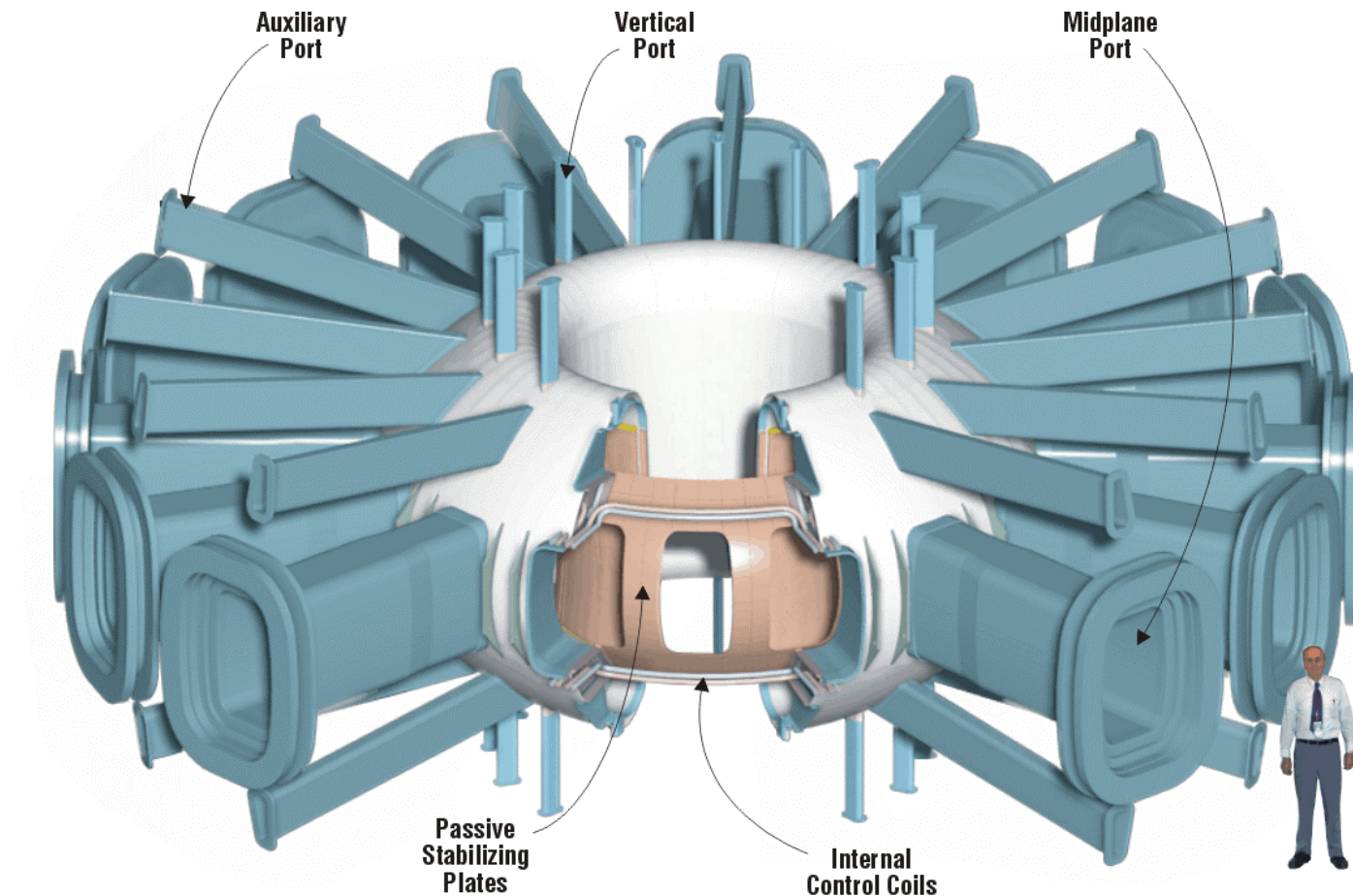
FIRE Vacuum Vessel Pumping

- Current baseline is cryopumps: 16 total with 8 each top and bottom, close coupled to torus, no interface valve (i.e. regenerate to torus):
 - cryocondensation/diffusion pumps backed by turbo/drag pumps
 - designed to pump in both the free-molecular and viscous flow regimes
 - water is pumped on the ID of the 160 mm diameter by 1 meter long, 30 K entrance duct which connects the divertor to the cryocondensation pump.
 - other impurity gases and hydrogen are pumped by cryocondensation on a stainless steel tubing coil refrigerated by liquid helium
 - the 2 torr-l/s helium gas produced by the D-T fusion reaction is compressed by viscous drag in the entrance duct by a factor of up to 100. The compressed helium gas is carried from the cryopump to a turbo/drag pump located outside the biological shield through the divertor duct
 - cryogenic cooling requirement for the 16 pumps at a pumping rate of 200 torr-l/s and the nuclear heating loading (estimated at 0.03 watt/cm^3 at the proposed cryopump location) is 3 watts per pump. The liquid helium cooling rate required during a shot is 64 l/h for the 16 pumps.

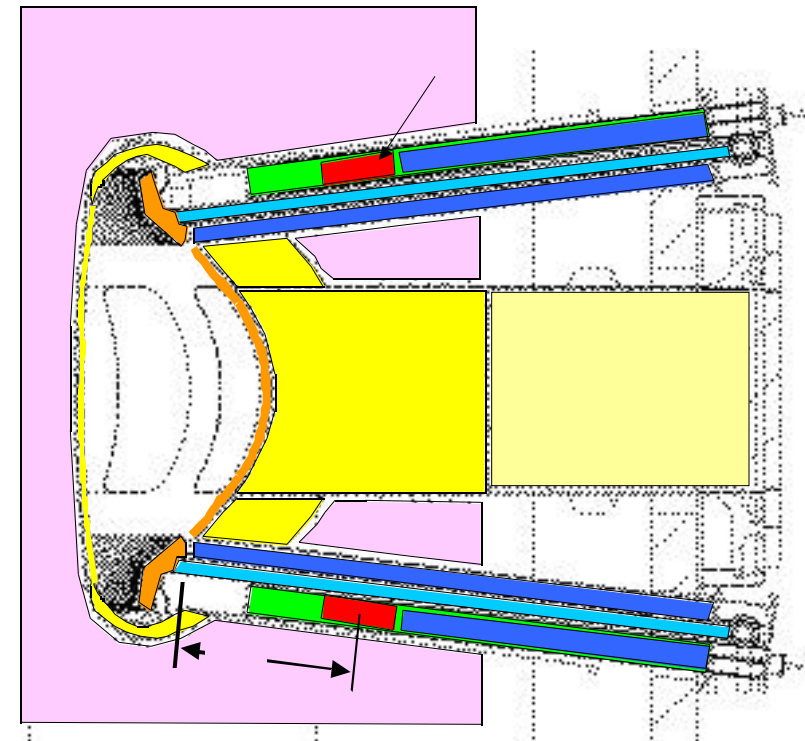
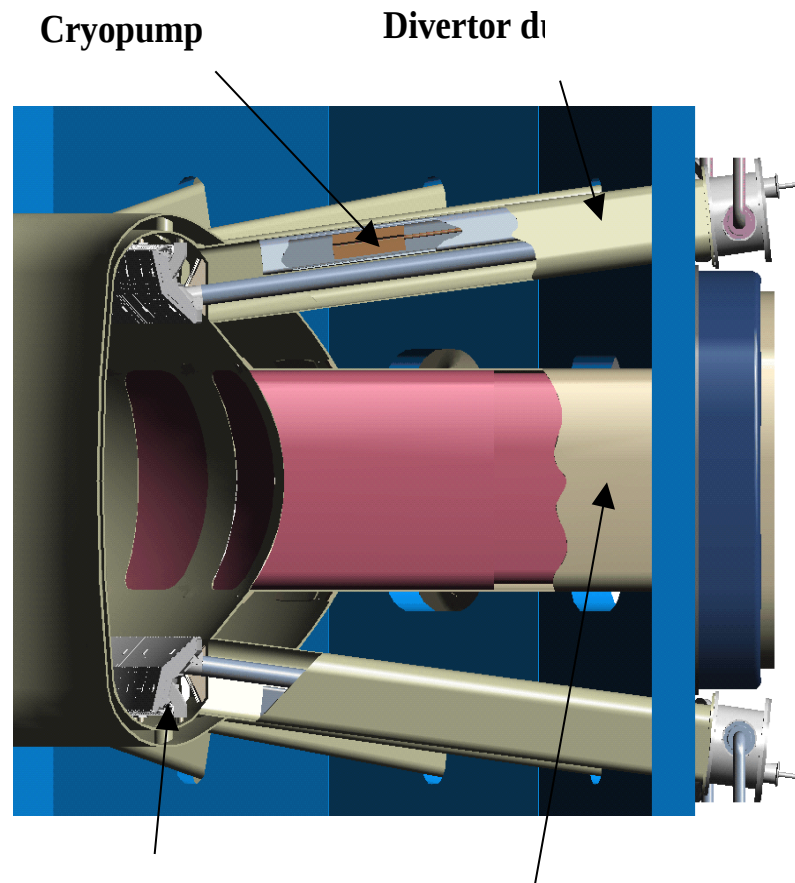
FIRE Vacuum Vessel Pumping

- Option to minimize in-vessel tritium inventory by cryopump regeneration cycle times:
 - between shots the helium flow will be stopped to allow the pumps to regenerate into the compound turbo/drag pumps
 - the 4,000 torr-l of DT pumped during the shot will raise the 18 m³ torus chamber to 0.2 torr. The pumping time constant for the 16 turbo-drag pumps with 3,200 l/s combined speed will be 6 seconds.
 - the 16 turbo/drag pumps may be backed with a single 3.3 l/s scroll pump backed with a metal diaphragm pump.
 - this will limit the tritium contained on the cryopumps to less than 1 gram for a 20 sec. discharge.

Cutaway view of FIRE vacuum vessel with port extensions.



Pumping system for FIRE



- Green = thermal shroud for cryopump.
- Red = cryopump located inside thermal shroud
- Light purple = TF coil and intercoil structure (filled with polyethylene shielding)
- Yellow, dark blue = good steel/water shielding
- Blue = divertor piping (mostly water)
- Orange = FW/passive plates, mostly copper

FIRE vessel and port dimensions

