An overview of the Diagnostic RGA system for ITER

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RGA-User's-1 Workshop
15 July 2011, Oak Ridge, TN, USA

Fusion Energy Division

OAK RIDGE NATIONAL LABORATORY

Managed by UT-Battelle for the Department of Energy

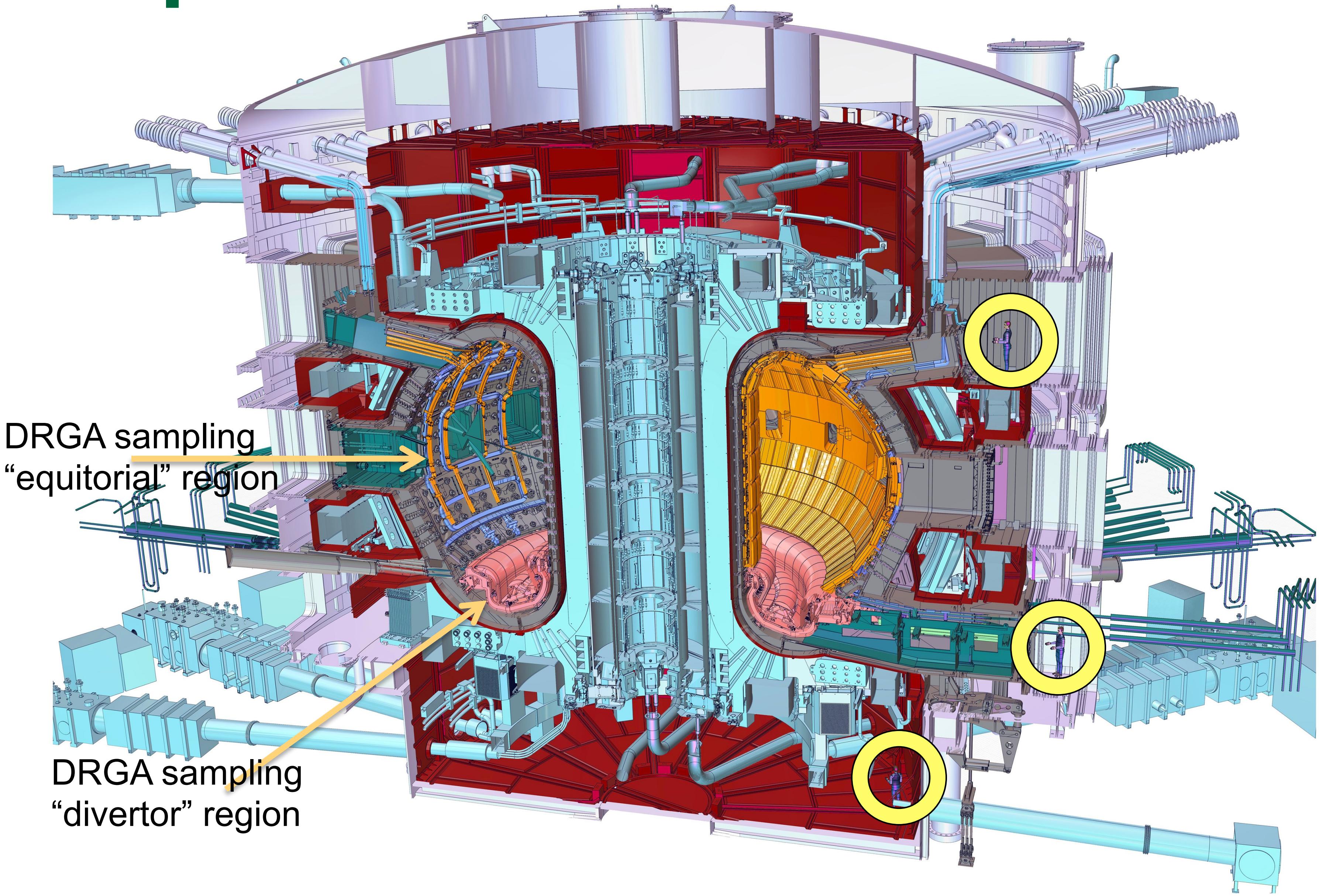
Acknowledgements

- Oak Ridge National Laboratory
  - W. Gardner, D.L. Hillis, C.C. Klepper
- DeNuke Contracting Services
  - Mike Morris
- US ITER (PPPL)
  - D. Johnson, E. Nassar, S. Schoen
- CEA Cadarache, France
  - S. Vartanian
- ITER
  - P. Andrew, S. Hughes, M. Walsh

Outline

- ITER
- Diagnostic RGA system for ITER
  - Equitorial/Divertor sample tubes
  - RGA “head”
- Active areas of R&D
- Schedule/Plans

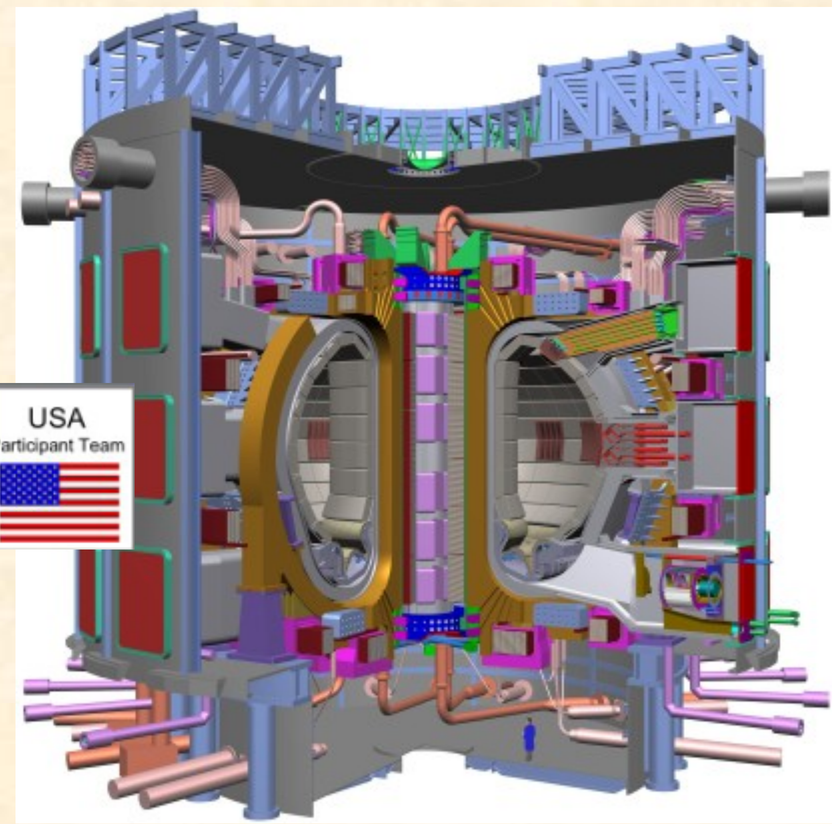
ITER: “International Tokamak Experimental Reactor”



Norbert Hotlkamp, SOFT
Symposium, Warsaw 2006

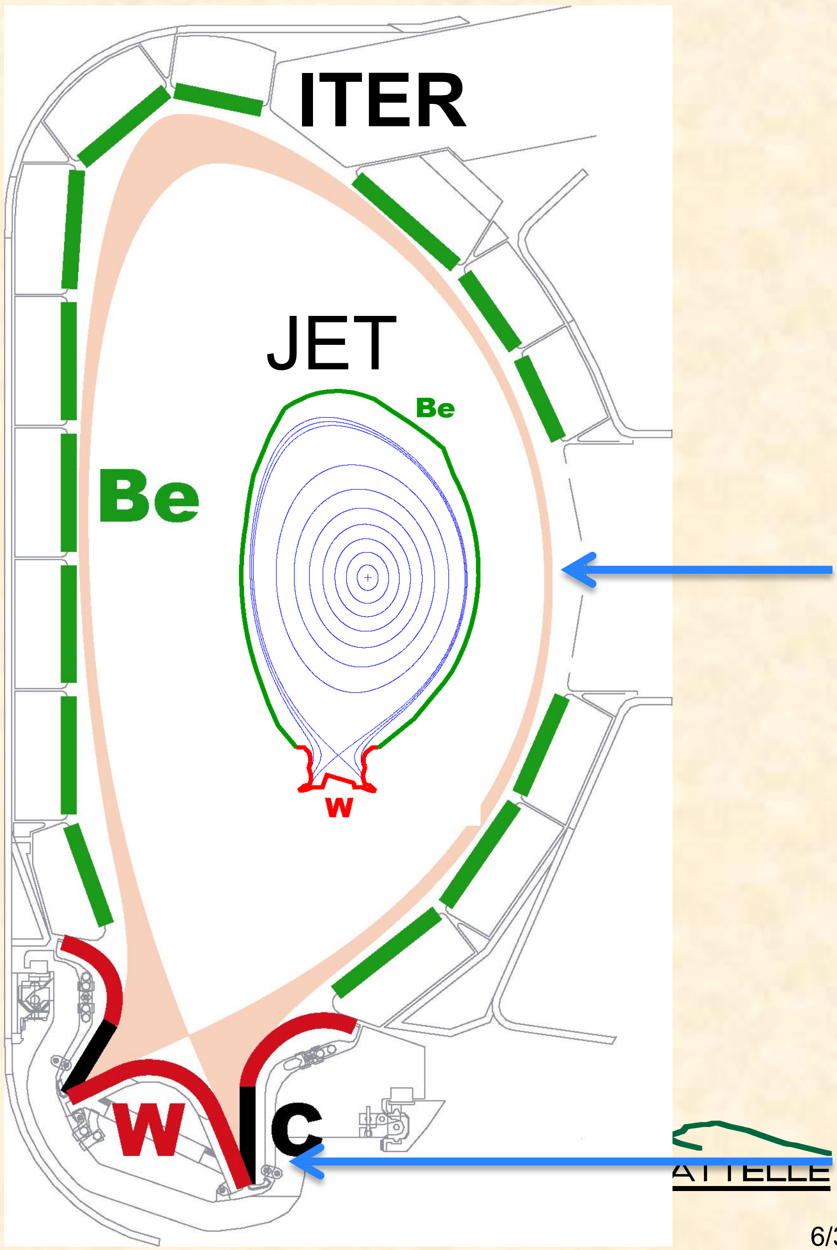
What is ITER Today?

- ITER ("the way" in Latin) is the essential next step in the development of fusion.
- Objective - to demonstrate the scientific and technological feasibility of fusion power.
- The world's biggest fusion energy research project.
- An international collaboration.



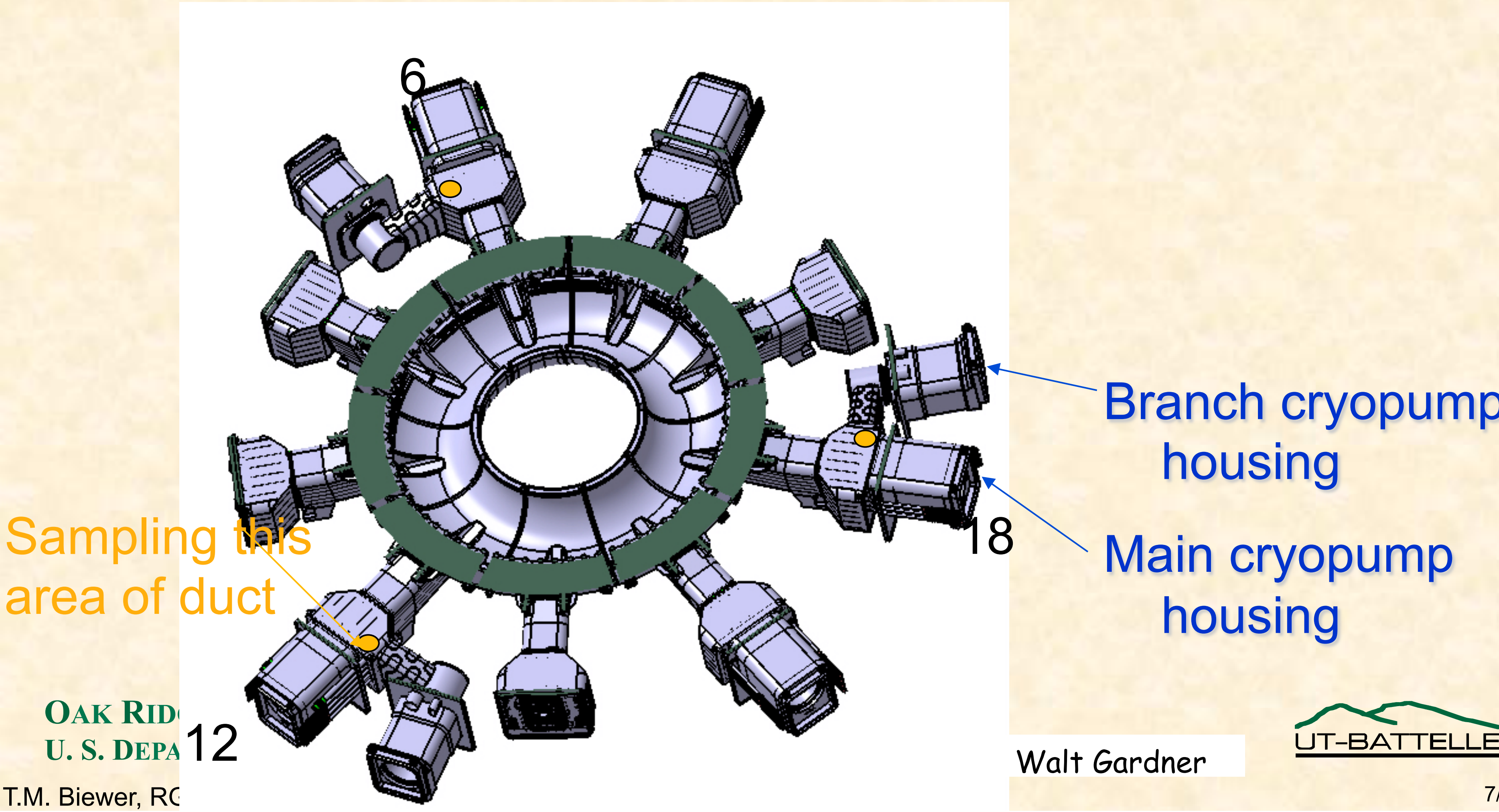
US ITER Project Office (Oak Ridge, TN)

- The US is a 10% partner in ITER
- Among the US allocation of ITER components is the Diagnostic RGA system
  - Equitorial System
  - Divertor System
    - ~100x higher pressure
- Similar DRGA's in use on JET & Tore Supra

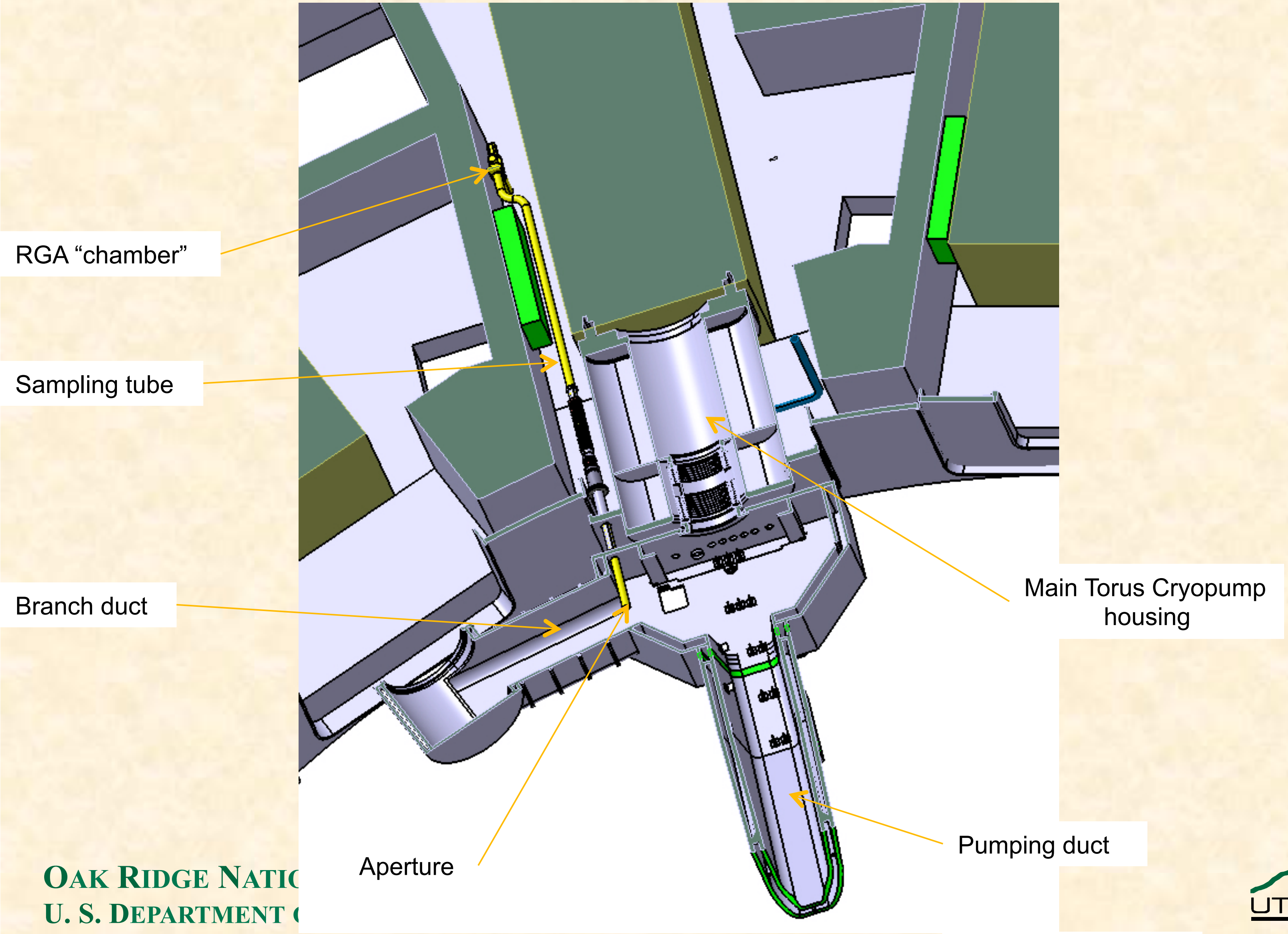


Design Basis - Locations

- 1 Divertor Duct locations (Port 12)
- 1 Equatorial Port Location (Port 11)



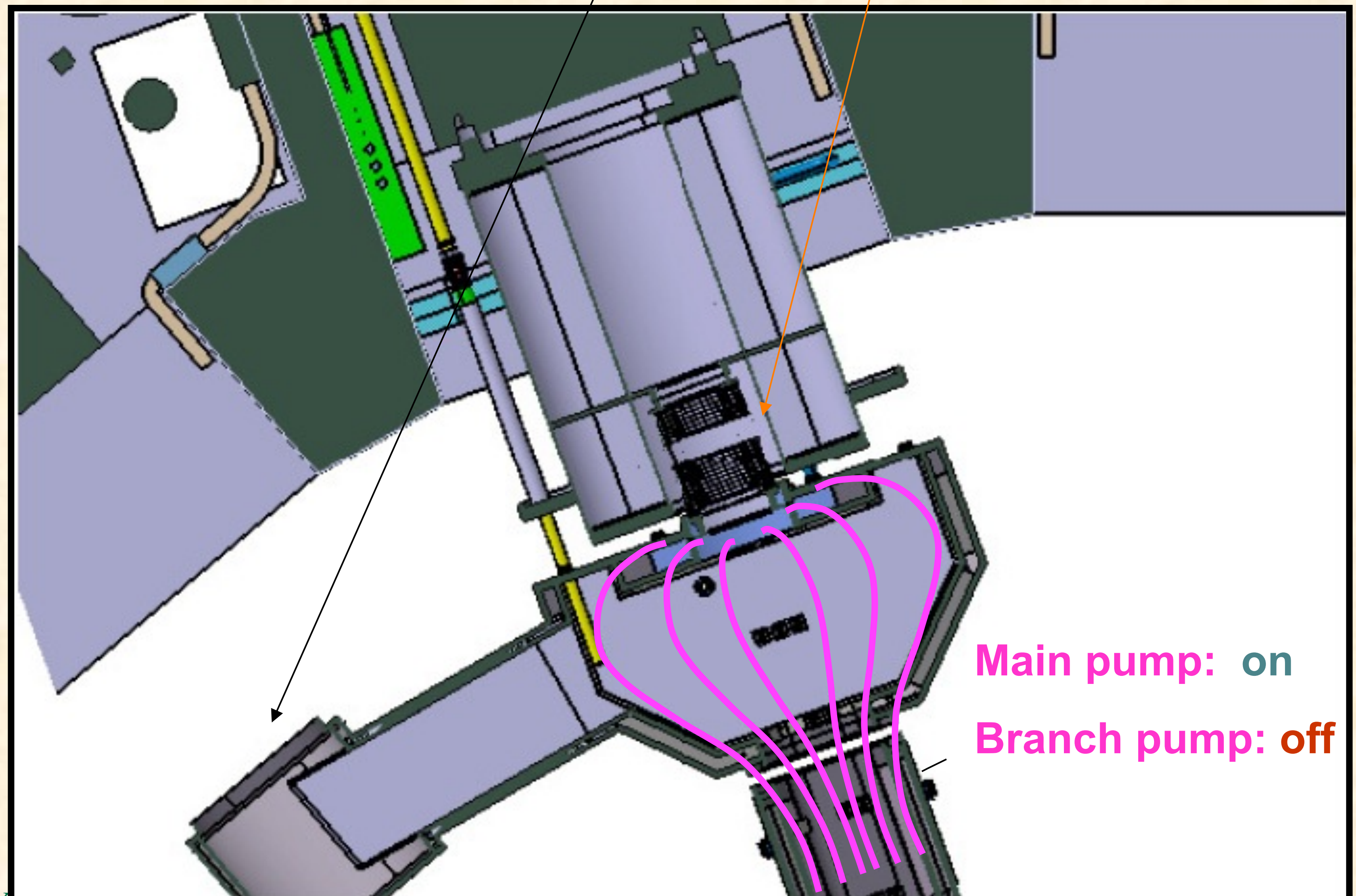
Divertor Design Concept Model



Walt Gardner

Configuration in divertor ports

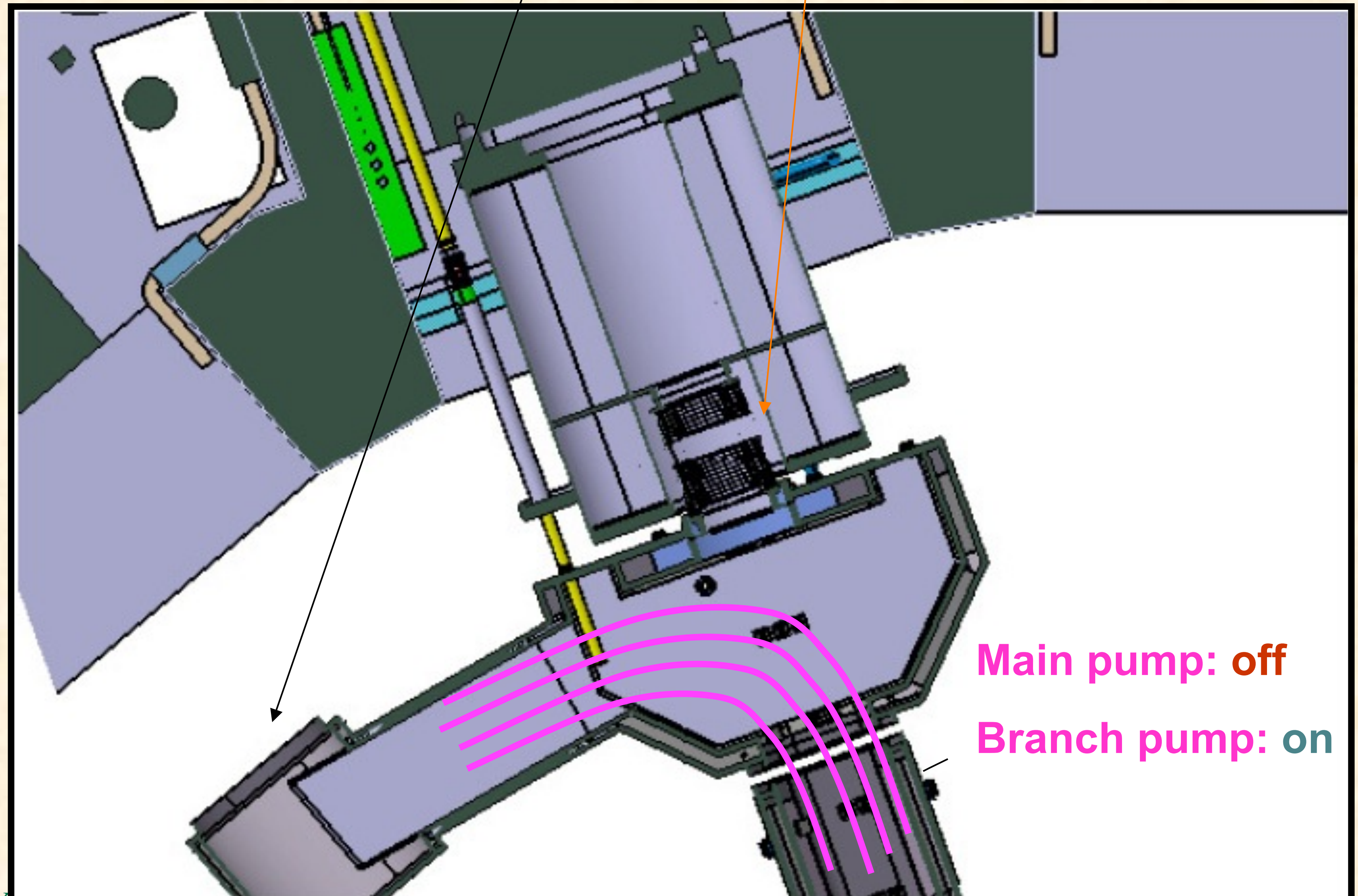
Sample gas at junction between **branch pump** and **main pump**



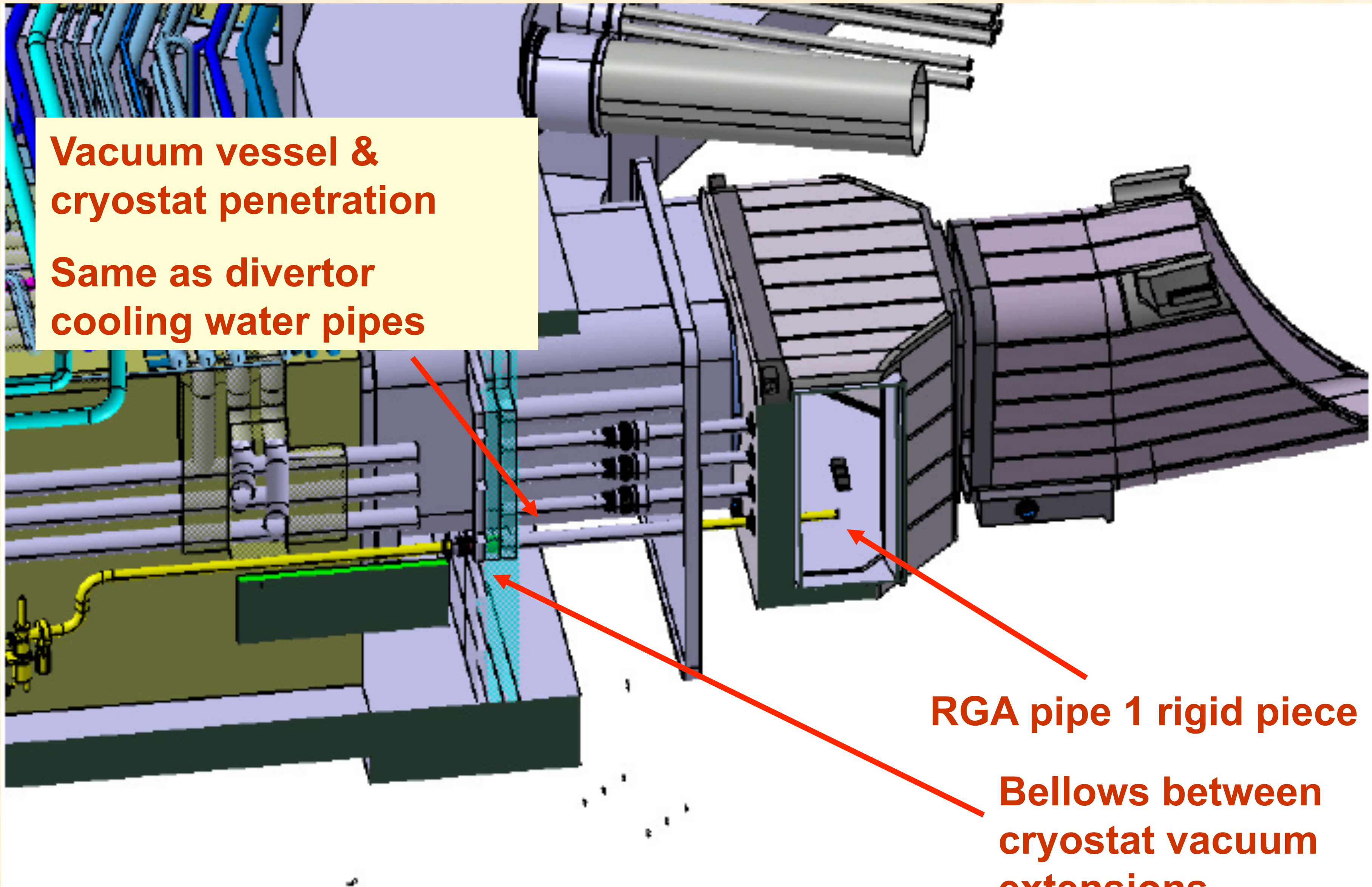
Philip Andrew

Configuration in divertor ports

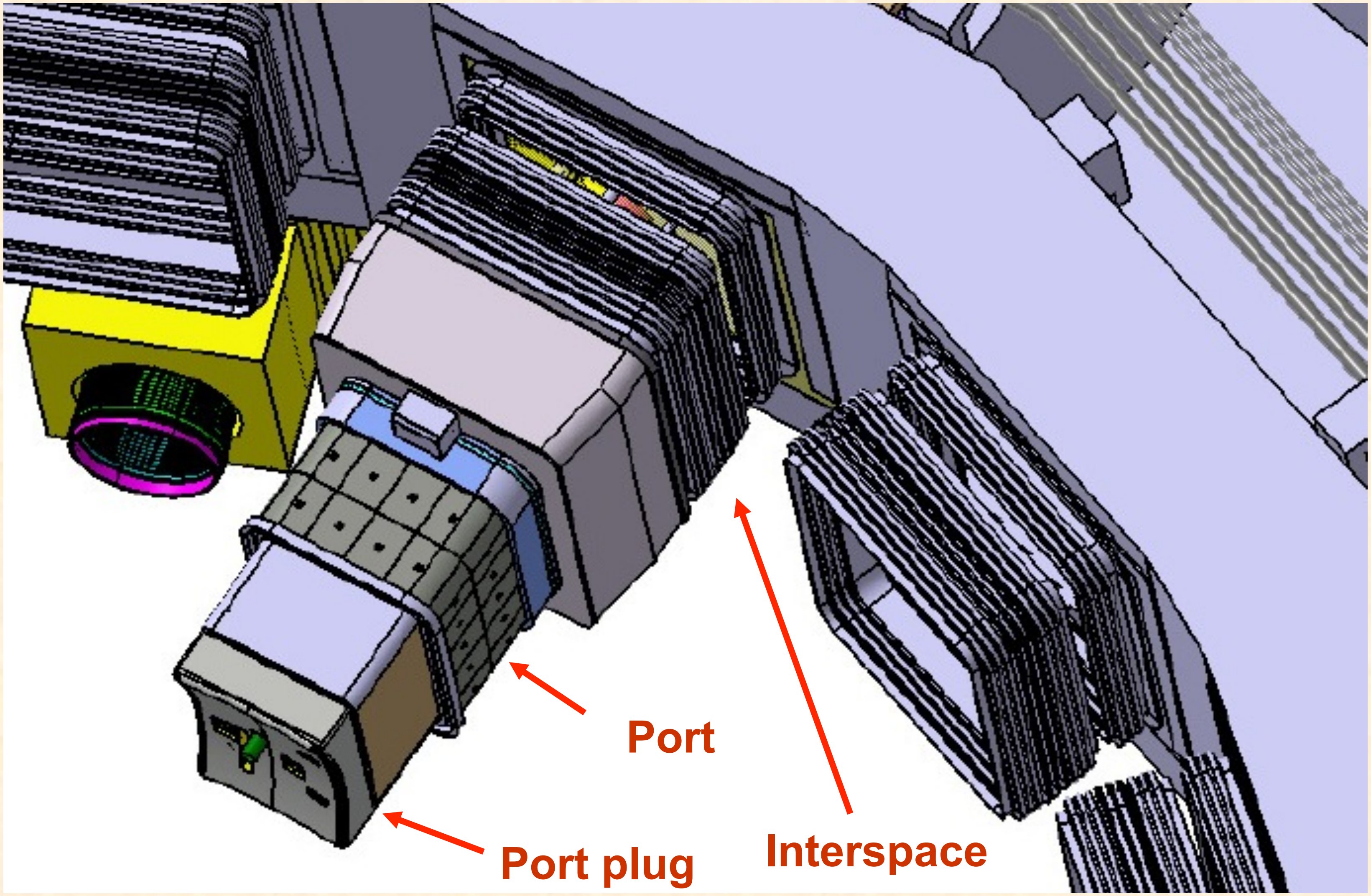
Sample gas at junction between **branch pump** and **main pump**



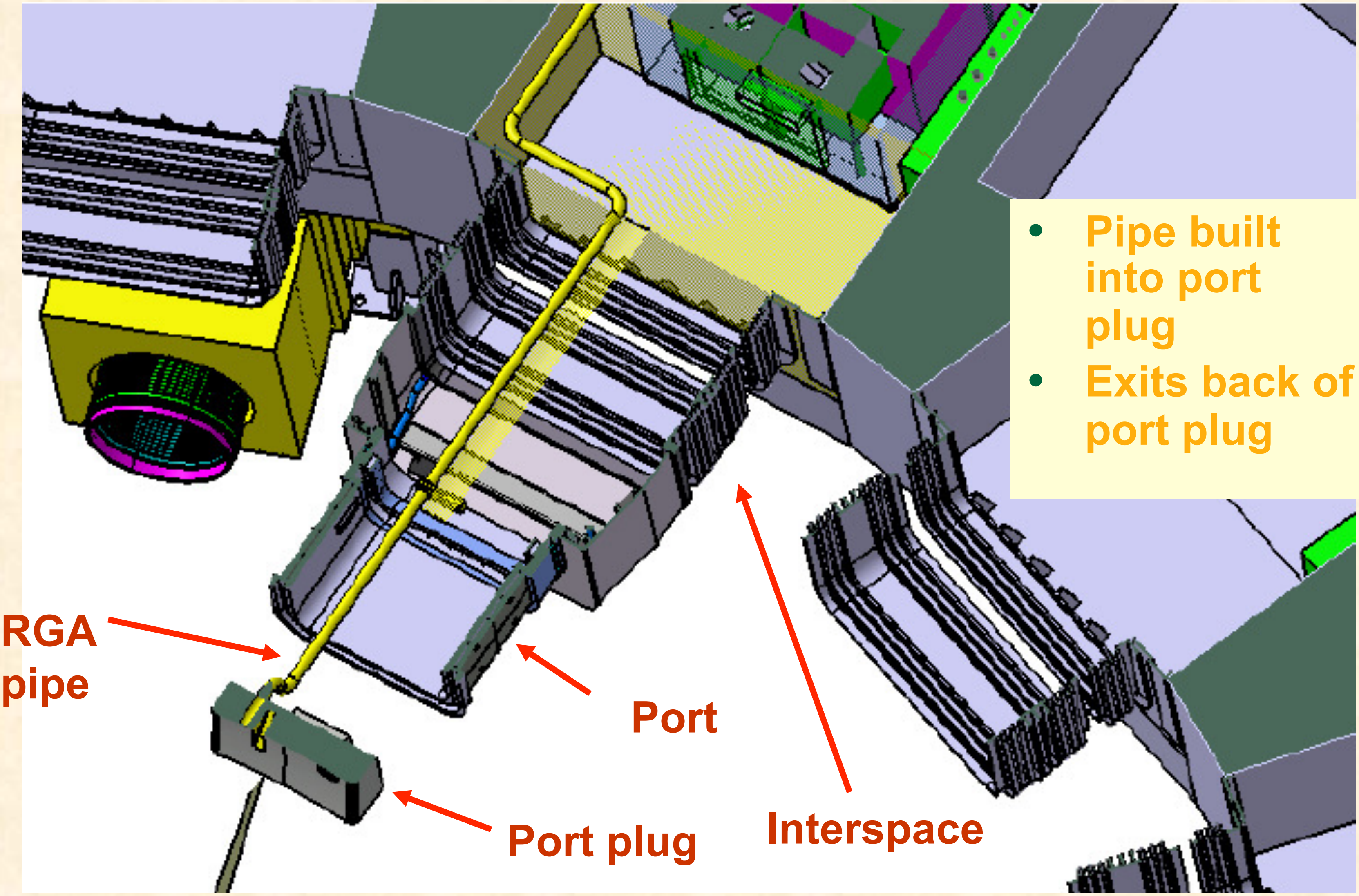
Divertor level



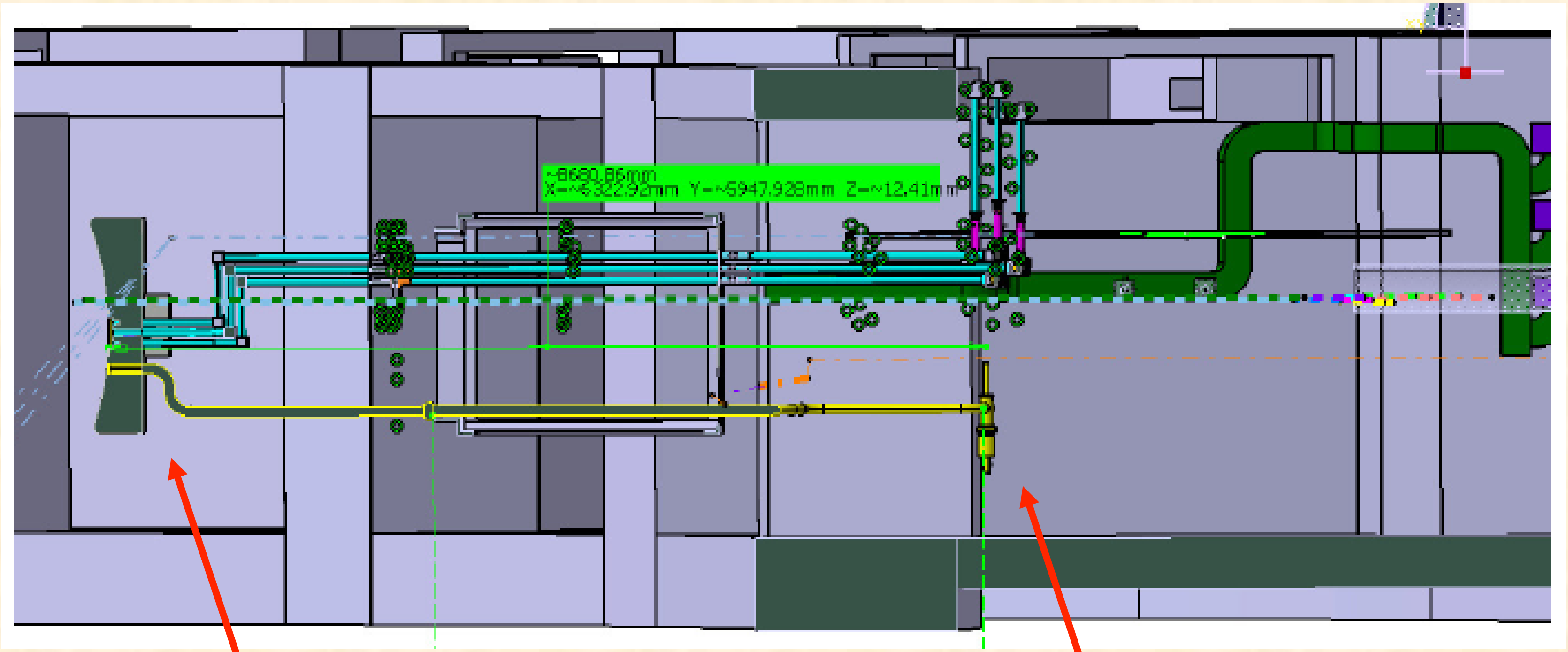
Configuration at equatorial port



Configuration at equatorial port



Configuration at equatorial port



Double bend in pipe inside port plug for neutron shielding

Pipe 1 rigid section. No bellows.

In port cell, support weight of pipe, but allow sideways movement (differential thermal expansion)

Environmental Conditions

- **The main conditions affecting Diagnostic RGA equipment operation:**
  - **Magnetic field: Expected maximum magnetic field levels in the Divertor and Equatorial port cells is ~150mT*. The DRGAs shall be shielded against this maximum value to the extent they will meet their measurement requirements.**
  - **Radiation field: The DRGA equipment and components in the port cells shall be designed to operate at radiation doses up to [TBD] GY**

* See for instance magnetic_field_map__plan_view_32HFEK_v1_0[1]

DRGA Measurement Requirements

- Sample gas in pumping ducts (divertor exhaust) and main vessel (equitorial port)
- Measure fuel ratios, He, and impurities
- Mass range: 1 – 100 amu (emphasis on lighter gases)
- Resolution: 0.5 amu or better
- Pressure range: (1 – 1E-04) x Pmax [20 Pa in divertor duct or ~100 x less in main chamber]
- Time response (sample aperture to RGA detector): <1 s for divertor pumping duct; <10 s for equatorial main chamber

Design concept – Diagnostic RGA

- **Sampling aperture: 0.25-mm diam.**
- **Sampling tube: 100-mm diam.; ~7m (divertor), 12 m (equitorial)**
- **RGAs (Two complementary types)**
  - **Quadrupole Mass Spectrometer** (full mass range; poor D2/He resolution; needs magnetic shielding)
  - **Optical Penning Gauge*** (good H, D, T, & He resolution/response; optical emission species only)
- **Turbomolecular drag pump**
  - **Magnetically shielded**
  - **Optical Penning sampling at intermediate stage to accommodate its operating pressure range**
  - **Exhaust to Type 2 foreline**
- **Pressure gauges, isolation valves, baking, etc.**
- **Connection to Service Vacuum System**
  - **Venting/purging**
  - **Containment interspace monitoring**

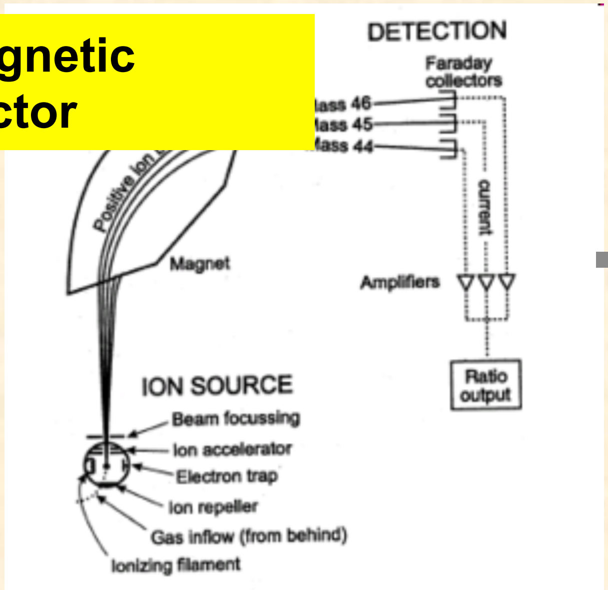
* D. L. Hillis, et al., Rev. Sci. Instrum., Vol. 70, No. 1, January 1999

Dual Sensor Design
(Mass Spectrometer and Optical Gas Analyzer)

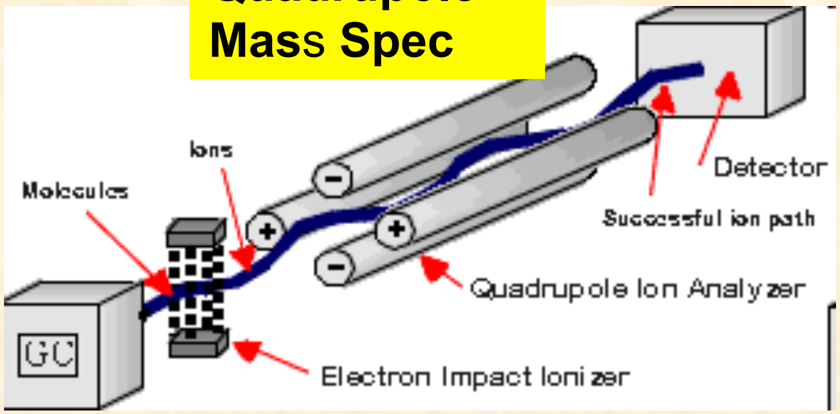
- **The Dual Sensor design (MS + OGA) allows each DRGA system to meet the measurement requirements**
  - **MS provides 50 to 100 atomic/molecular masses to be acquired simultaneously**
    - **Existing models can be applied to the spectra to resolve CO/N_2, CD_4/D_2O**
  - **OGA resolves He/D_2 and can provide more direct H_2/D_2/T_2 measurement**

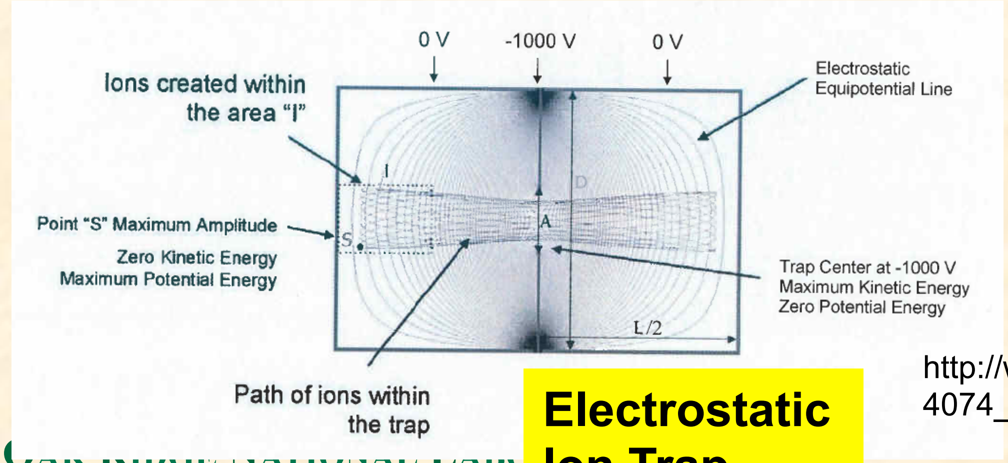
Types of Mass Spec Analyzers

Magnetic Sector



Quadrupole Mass Spec

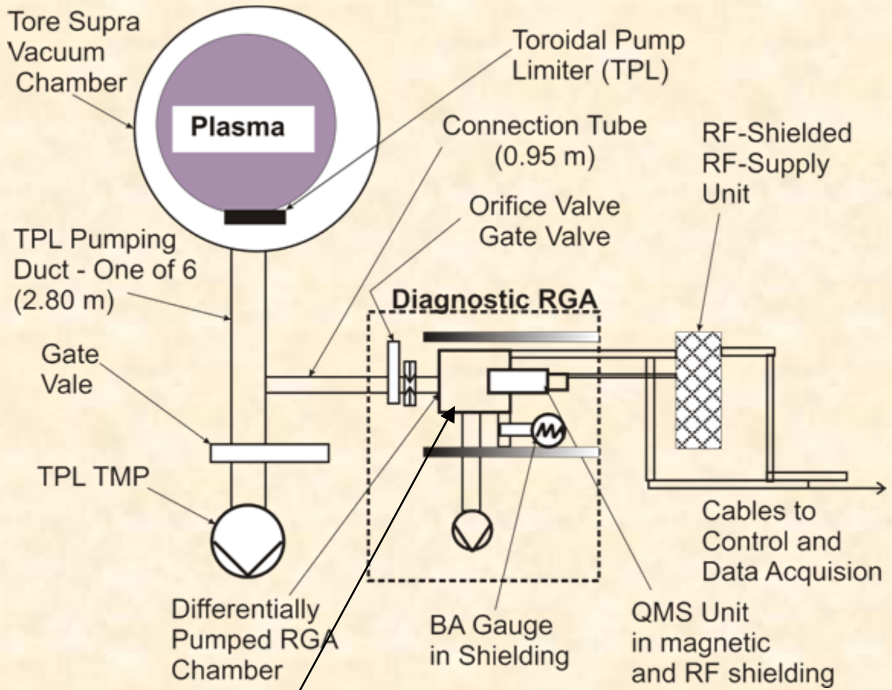




Electrostatic Ion Trap

http://www.brooks.com/pages/4074_simplicity_solutions_partial_pressure_instrumentation.cfm

Precedent of Continuous Mass-Spec DRGA on a Tokamak

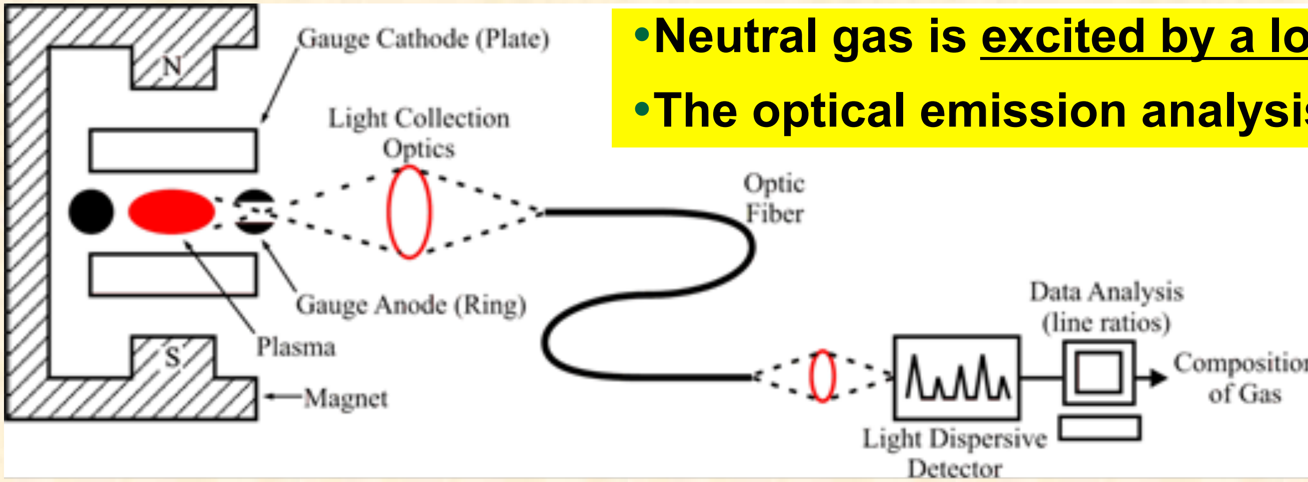


Uses commercial Balzers QMG-421 Mass-Spec

- **Tore Supra currently has a DRGA with a quadrupole mass spectrometer (magnetically + EMI) shielded for operation during plasma operation**
- **Continuous data acquisition and data transfer (15 channels/ 32ms)**
- **Have successfully used with shots up to 6 min [Recent HTPD-2010 paper/ poster]**

OGA Concept and Current Use

- **Neutral gas is <u>excited by a local plasma discharge</u>**
- **The optical emission analysis → gas composition.**



- **A Optical Gas Analyzer based on the Penning gauge discharge (« Penning Optical Gas Analyser » or Penning-OGA) is already in use on DIII-D, JET and Tore Supra.**
  - **Originally developed to distinguish He from D_2 (both M = 4)**
  - **On DIII-D it also measures Ne/D_2 and Ar/D_2**
  - **On JET it measures H_2/D_2 and T_2/D_2**
  - **On Tore Supra it measures He/D_2**

Penning-OGA at JET with T runs*

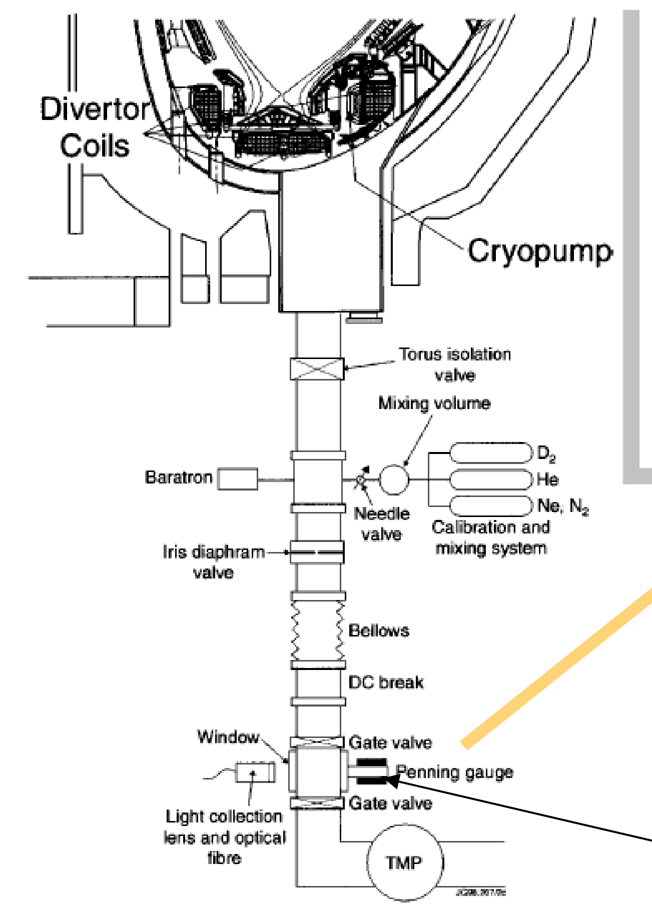
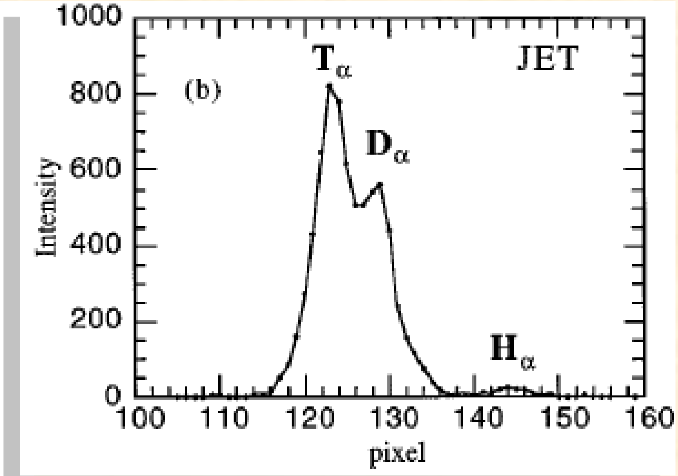
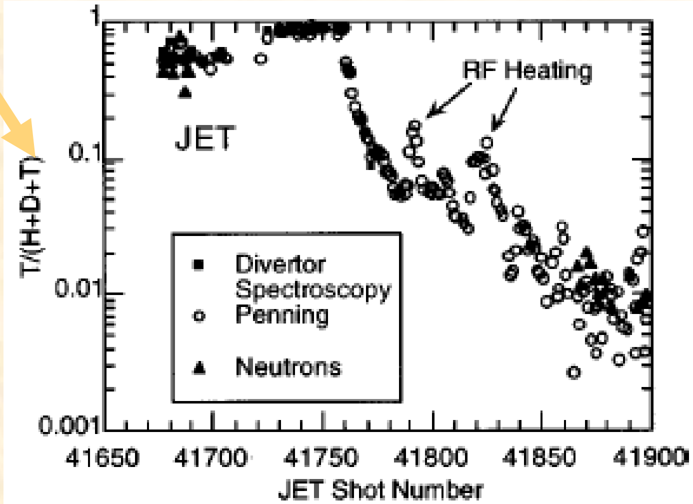


FIG. 1. Penning gauge diagnostic system for the measurement of the tritium concentration in the divertor of JET.



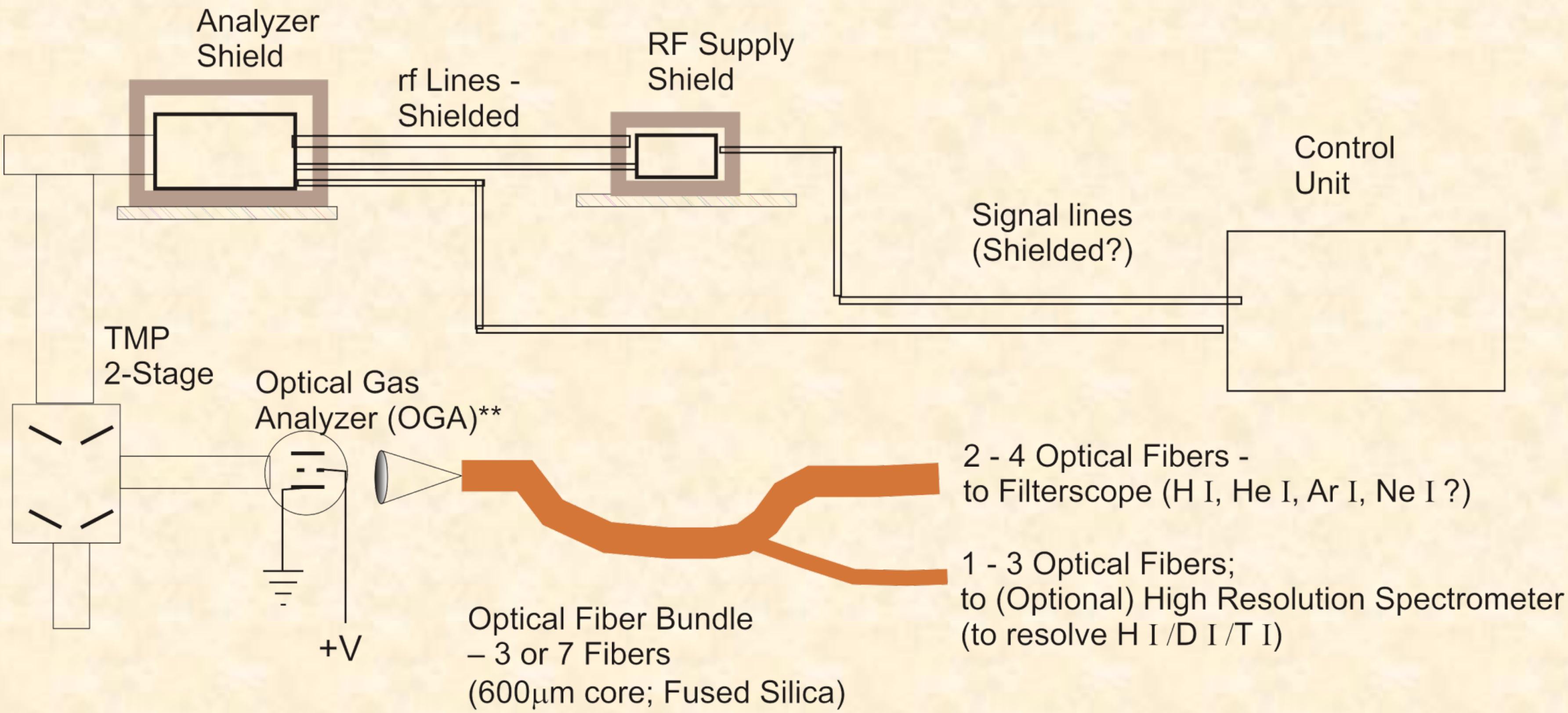
- OGA T_2/D_2 measurement is "self-calibrating"!
- JET study is best proof-of-principle for OGA on ITER



OGA: Uses commercial [**no longer** being produced] **Alcatel CF2P Penning Gauge Tube**

*** Hillis, et al., Rev. Sci. Instrum., Vol. 70, No. 1, January 1999**

ITER DRGA Component Diagram

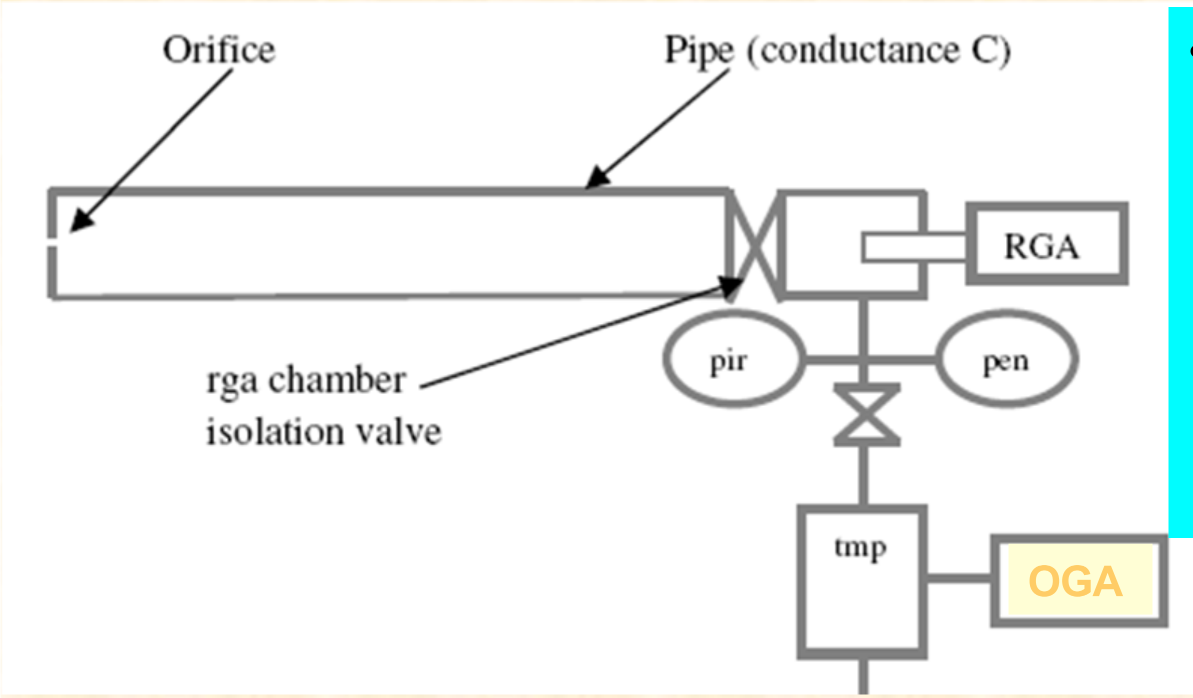


****Initially based on Penning-discharge excitation; RF solutions expected in future**

Innovative Vacuum Interface

- **MS and OGA sensors require different base pressures for optimal operation**
  - **P(MS) <~ 1×10^{-3} Pa**
  - **5×10^{-2} Pa < P(OGA) <~ 1 Pa**
- **Innovative vacuum arrangement and interface was developed to**
  - **Provide optimal sensor pressures**
  - **Minimize differential pumping stages**
  - **Avoid stagnation points**
  - **Meet time response requirements**

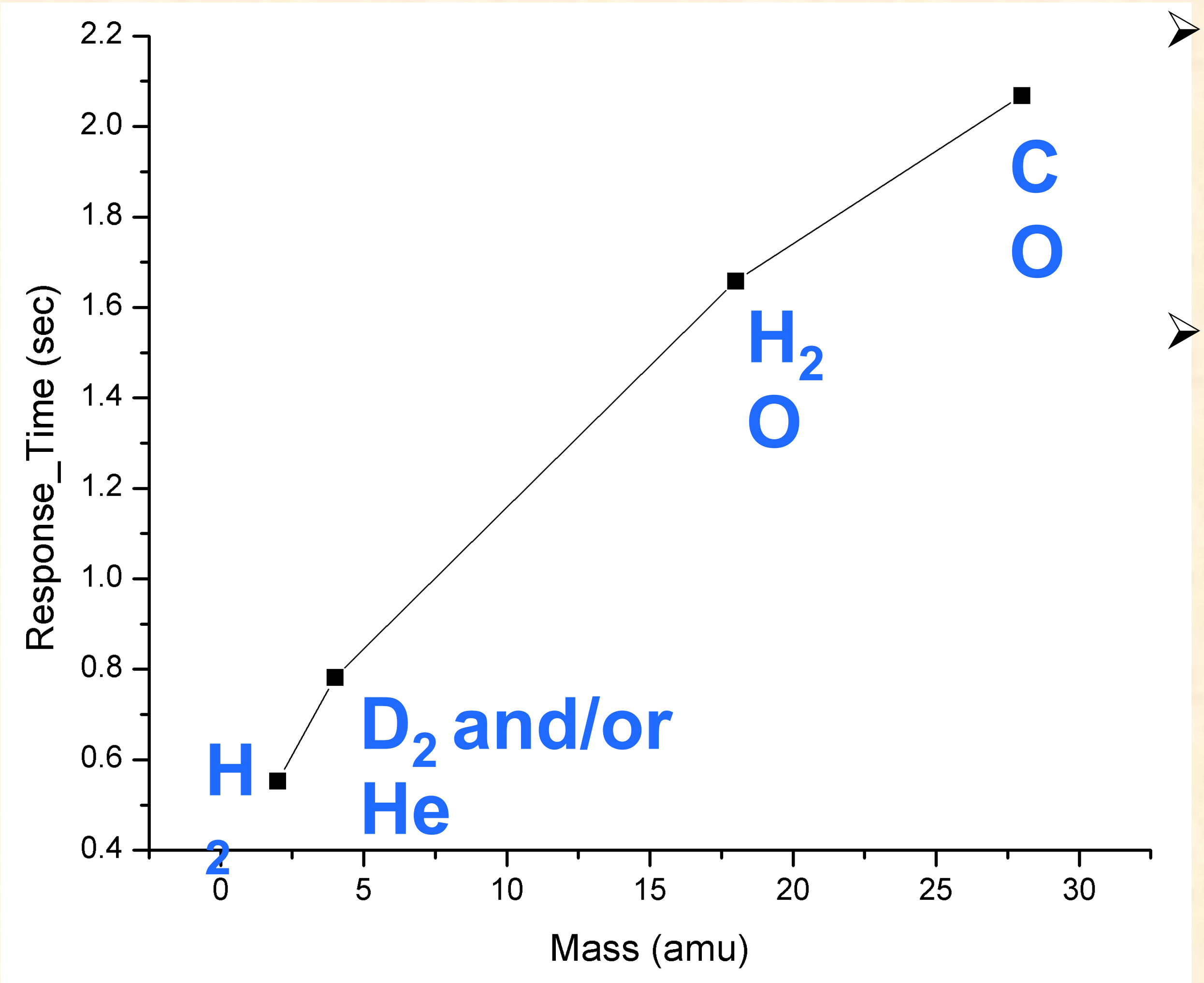
Innovative Vacuum Interface



- Orifice at the sampling region side designed for the anticipated pressure
  - ~10 Pa in divertor duct
  - ~0.1 Pa in outer mid-plane

- **The conceptual design calls for option (tooling) to replace the orifice, if actual pressures substantially depart from expected values.**

Response Time



- Present design is compatible with ~1s response time requirement
- For the mid-plane RGA, ~identical design will provide same ~1s response time

- ➔ 10x better than requirement.

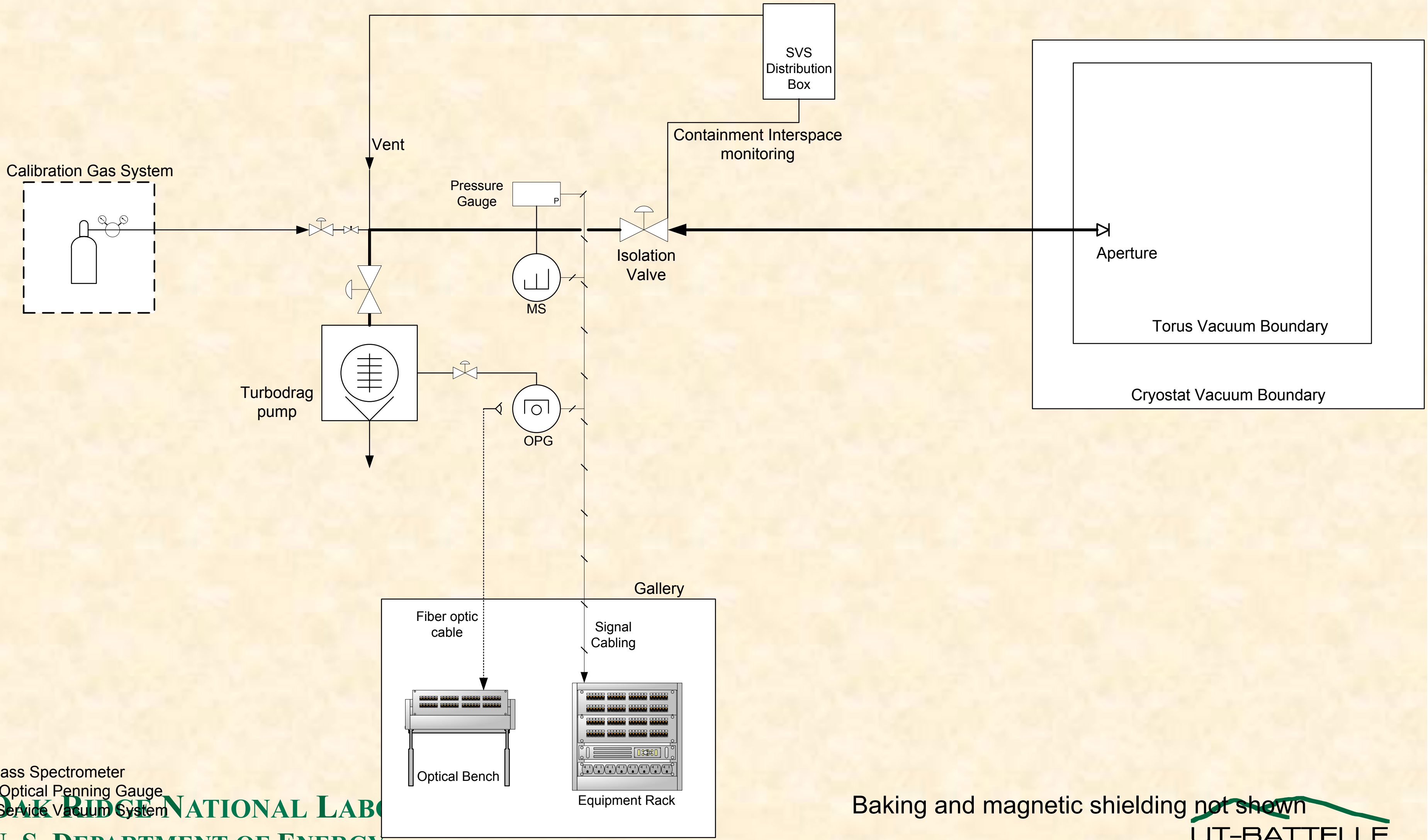
External Error Sources

- **Possible impact from external B-field:**
  - Avoid with proper shielding;
  - Present design uses proven (on JET) magnetic shielding technology
    - ➔ Attenuates the expected 150 mT fringing field down to 5 mT considered safe.
- **Tritium:**
  - Beta-emitter; has been found to shift the MS spectra zero level; can correct in the analysis
    - (Work by Robert Pearce, ref. in design documents)
- **Neutrons and Gammas**
  - New Rad-Hard MS model with RF source + control electronics 15m away
  - MS analyzer unit accessible for replacement
  - Spectrally resolved detection of OGA signals can overcome any scintillation issues in the optical fibers.

Manufacturability

- The DRGA systems will be manufactured from off-the-shelf equipment and readily available or easy to fabricate components.
- System configuration will be designed for ease of assembly, installation, testing, and maintenance
- No hazard or availability issues are foreseen for choices of materials
- No issues are foreseen for compliance with ITER codes and standards

DRGA System Schematic



MS – Mass Spectrometer
OPG – Optical Penning Gauge
SVS – Service Vacuum System

Baking and magnetic shielding not shown

Schedule/Summary

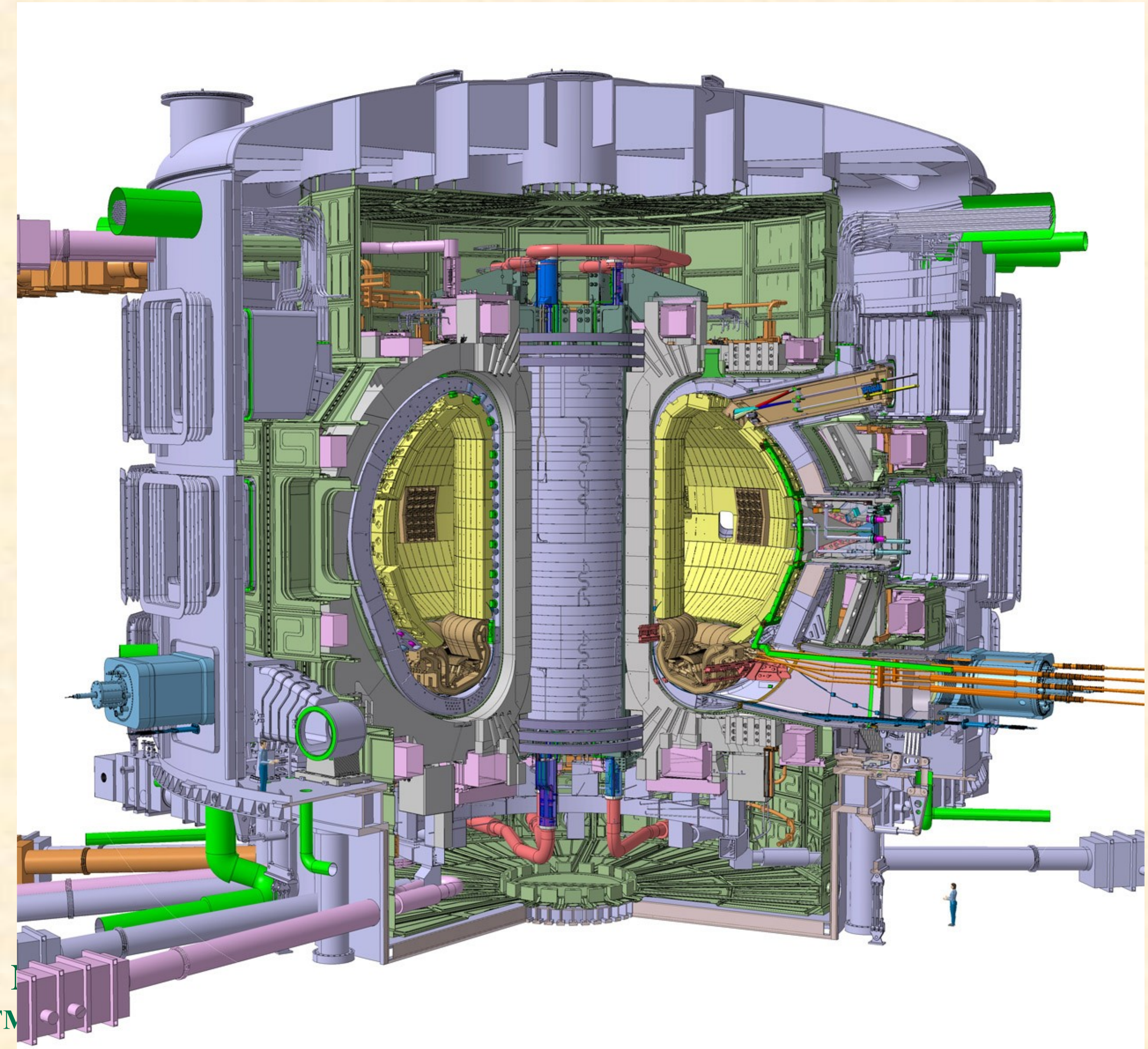
- Conceptual Design completed July 2010
- Active areas of R&D
  - ITMS tests at Tore Supra as replacement for QMS
  - Inter-turbo pumping port for OGA tests at Tore Supra
  - Magnetic shielding tests at Tore Supra and ORNL
  - Swappable apertures engineering design at ORNL
- Preliminary Design Review in Nov. 2012
- Final Design Review in Summer 2013
- Fabrication w/ delivery goal of Summer 2016
- ITER first plasma . . . ?

Questions?

Supplemental Slides

Supplemental Slides

ITER: “International Tokamak Experimental Reactor”



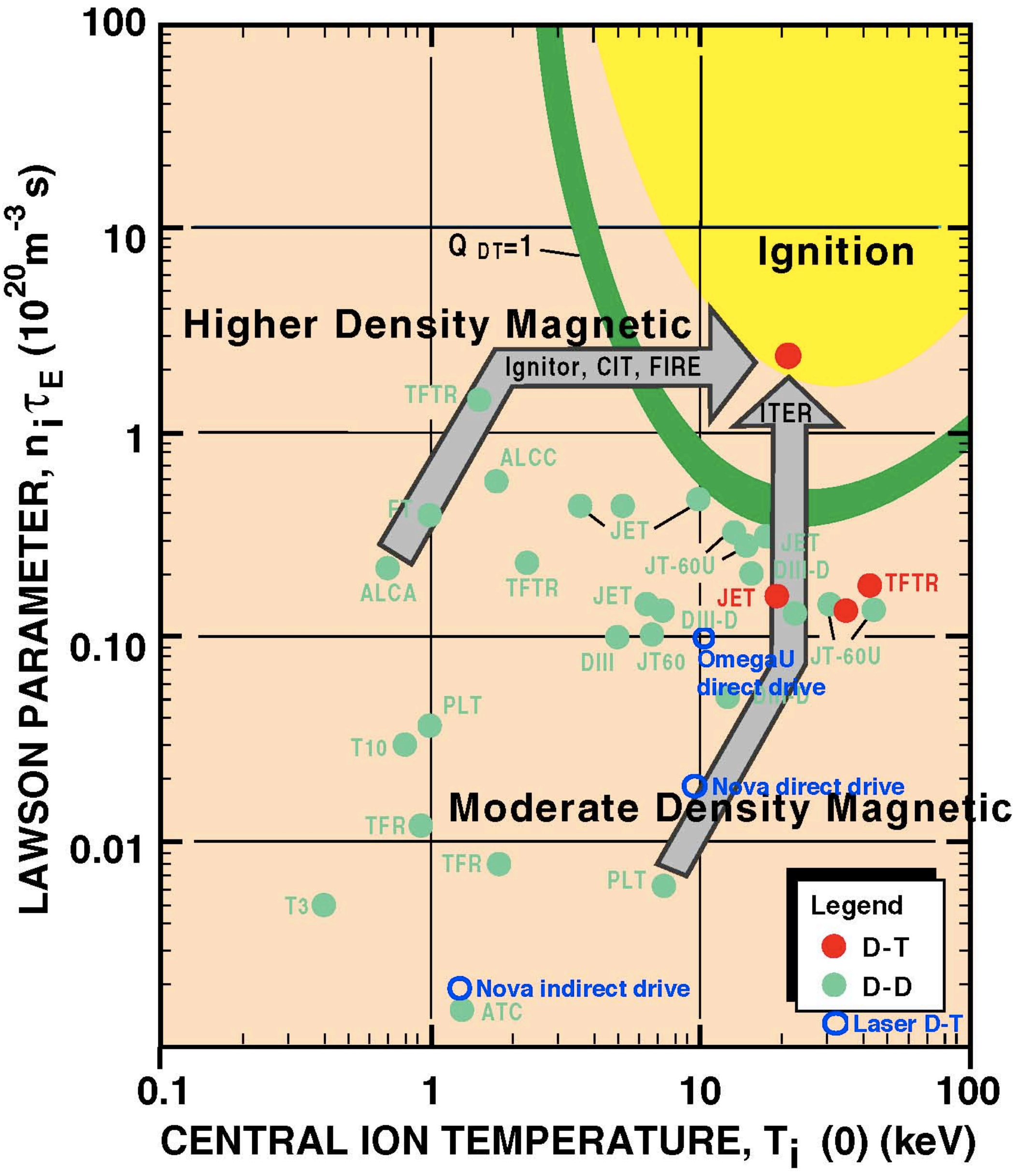
Norbert Hotlkamp, SOFT Symposium, Warsaw 2006

ITER Collaboration

- **For its size and cost and the involvement of virtually all the most developed countries, representing over half of today world's population ITER will become a new reference term for big science projects.**

- **The ITER project is one of the world's biggest scientific collaboration.**

Status of Laboratory Experiments - Lawson Diagram



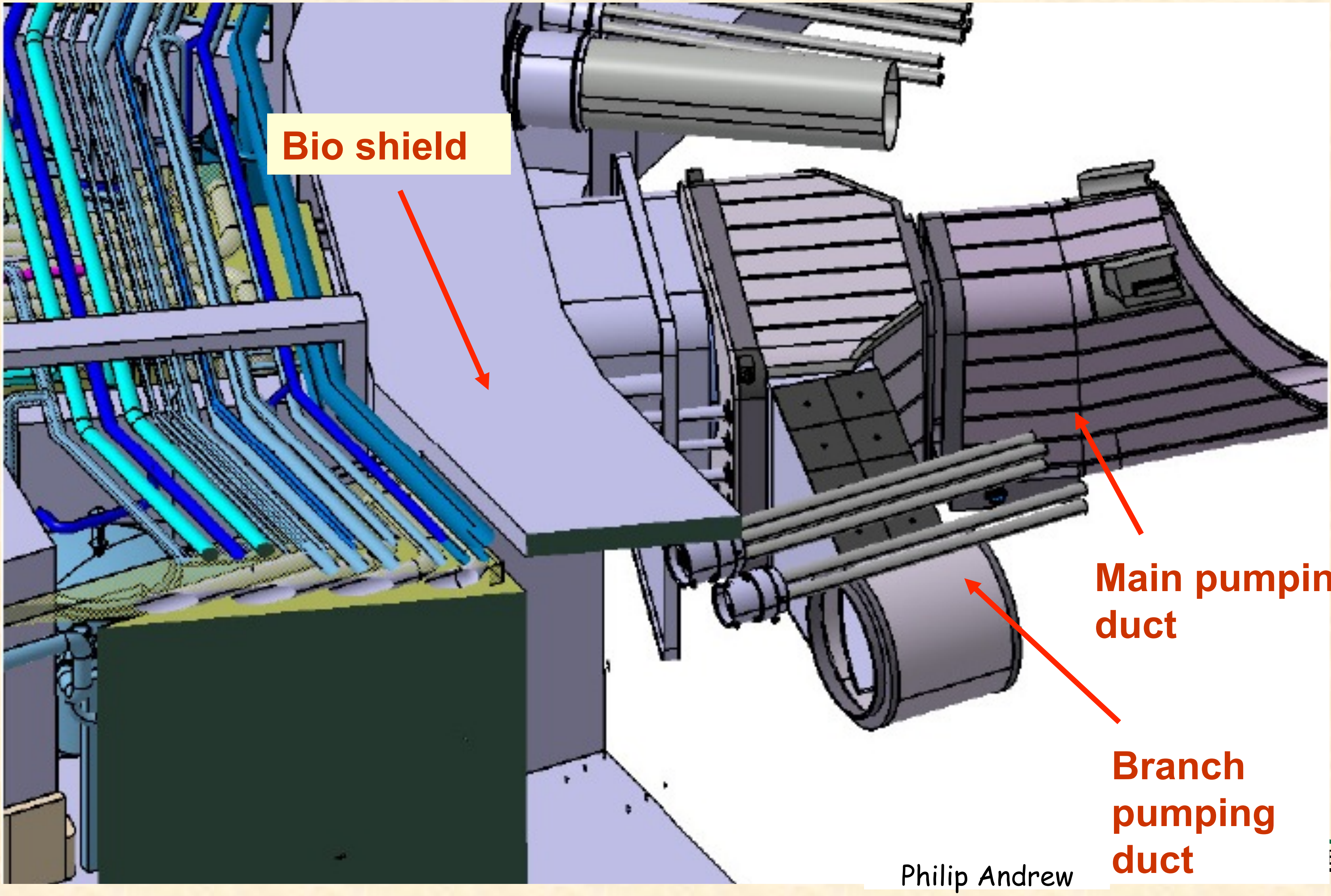
- T_i required for fusion has been achieved, but needs 10x $n\tau_E$
- Achieved $n\tau_E \approx$ 1/2 required for fusion, but needs 10xT_i
- After 50 years, MFE is 10% of the way.
- Requirements depend on plasma profiles, impurities, synchrotron radiation, etc
- Similar curves for ICF but some bremsstrahlung absorption.

UT-BATTELLE

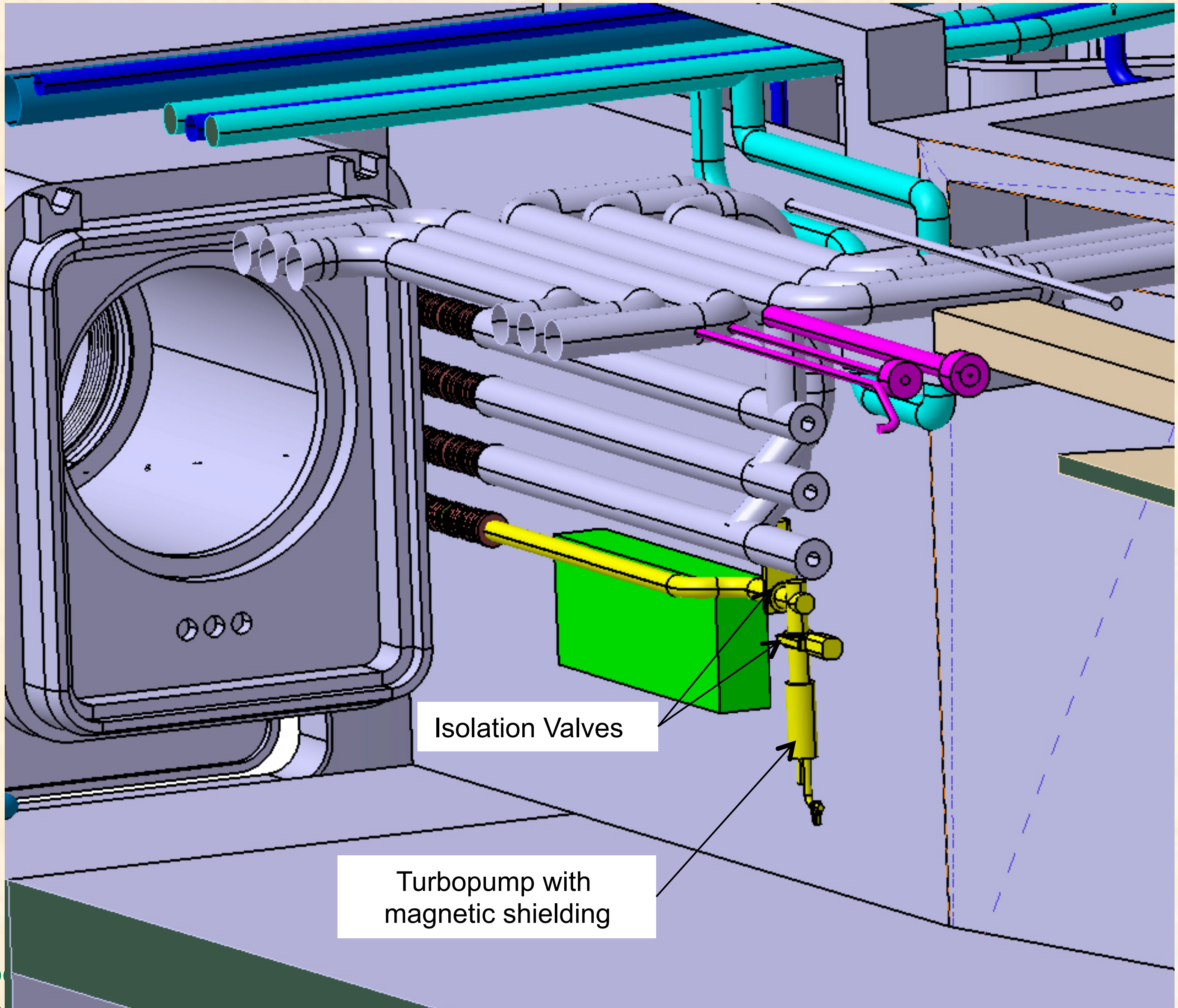
Courtesy of D. Meade

ITER site, CEA Cadarache, France

Divertor level

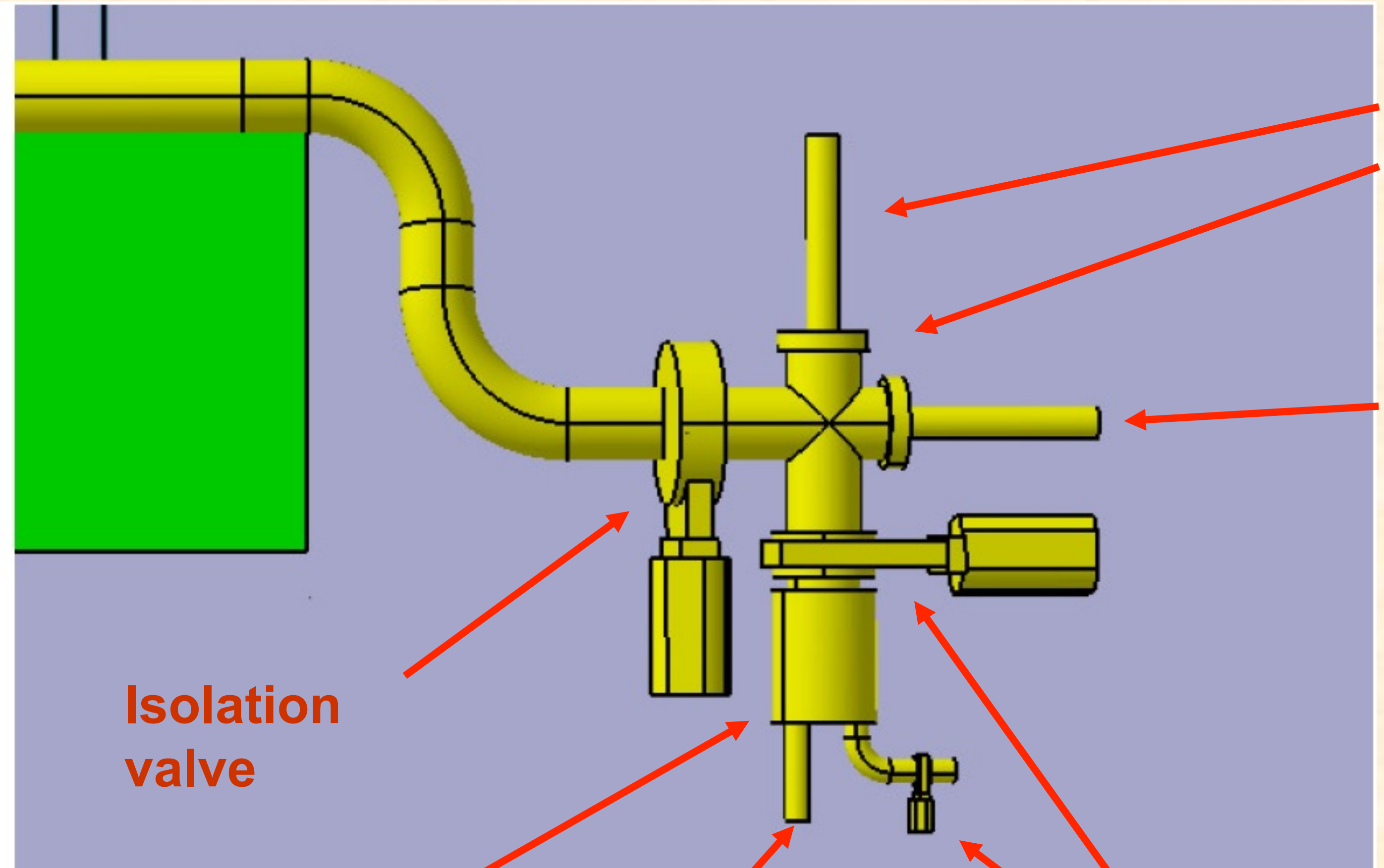


Divertor Design Concept Model



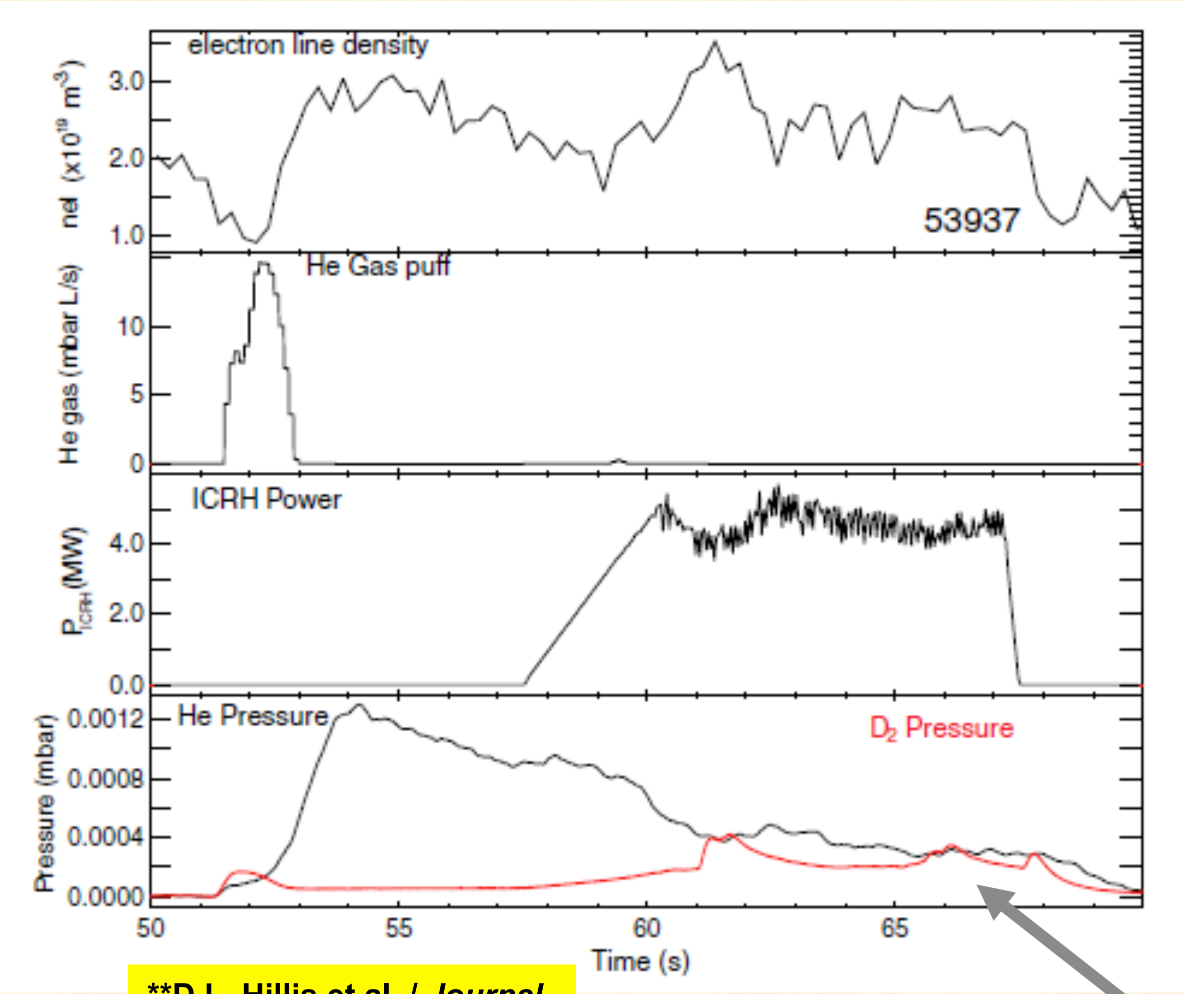
Walt Gardner

Contents of RGA vacuum chamber



Philip Andrew

He/D_2 critical for ITER's OGA

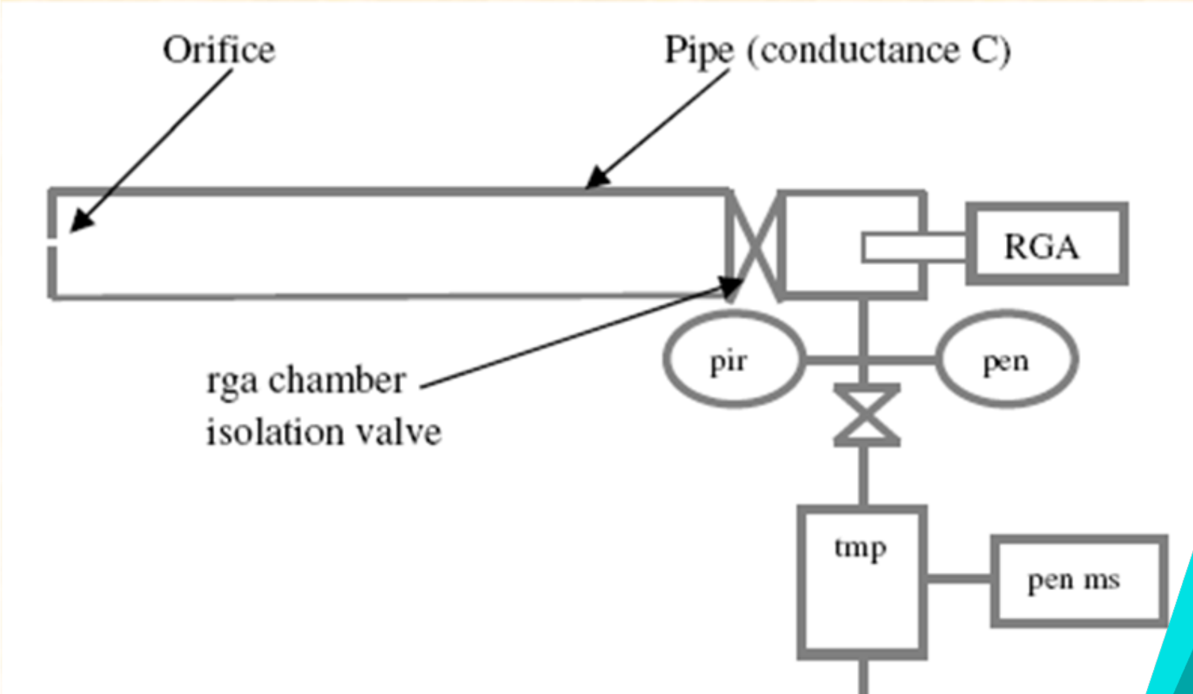


- This also from JET Divertor Penning-OGA
  - Earlier results with the Penning emission sampled with Dα and He I filtered detectors.
  - Change-over experiments with the the MkII-GB (gas box divertor configuration)**
- This measurement is not possible with present QMS sensors

**D.L. Hillis et al. / *Journal of Nuclear Materials* 313–316 (2003) 1061–1065

Penning-OGA Data

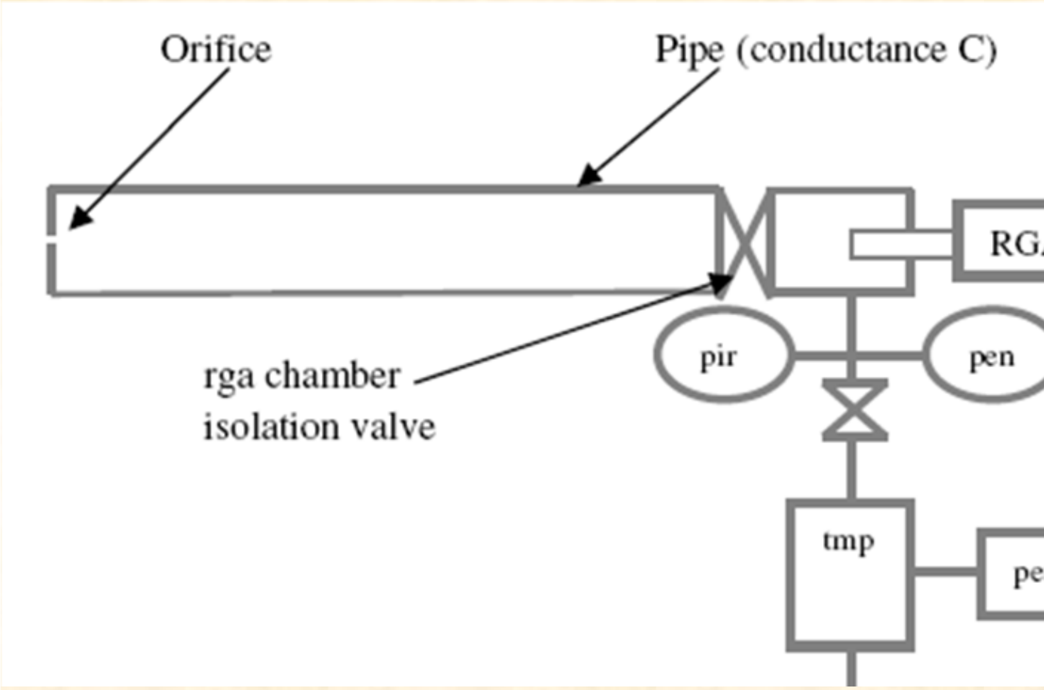
Innovative Vacuum Interface

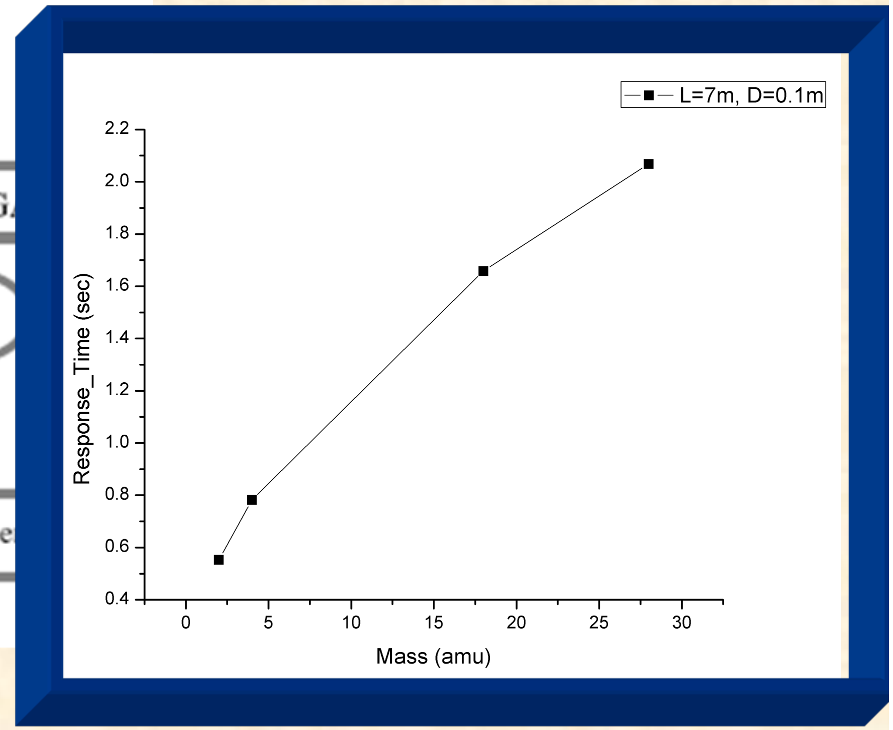


Optical Gas Analyzer Placed downstream from RGA chamber

- Having the primary RGA chamber at the lower pressures allowed for simpler (analytic) conductance calculations (molecular flow regime) and more certainty about meeting response time requirements.

Response Time





- **Present design allows for analytic calculations of response time (molecular flow regime)**

Accuracy and Calibration

- **Calibration Plan:**
  - Every RGA system will have its own calibration gas manifold
  - Gases injected directly into RGA chamber
  - Calibration procedures well documented in the published literature.
- **Accuracy:**
  - Mass Spectrometer
    - Expect 5-10% error in applying models to extract species concentration from multiple peaks
    - Expect up to 5-10% error in applying total pressure from Penning gauge to get actual partial pressures (not an issue for ratios)
    - Expect 5-10% error from interpolation between calibrations
    - ➔ Still consistent with 20-50% accuracy requirement
  - Optical Gas Analyzer
    - 10-20% error is consistent in most visible-range plasma spectroscopy experience.

Calibration System: Integral Part of Each DRGA System