The ITER Diagnostic RGA

C.C. Klepper

Oak Ridge National Laboratory

10th Meeting of RGA Users Group (*RGA-10*)
18 October 2011, Coventry, UK

In Collaboration with

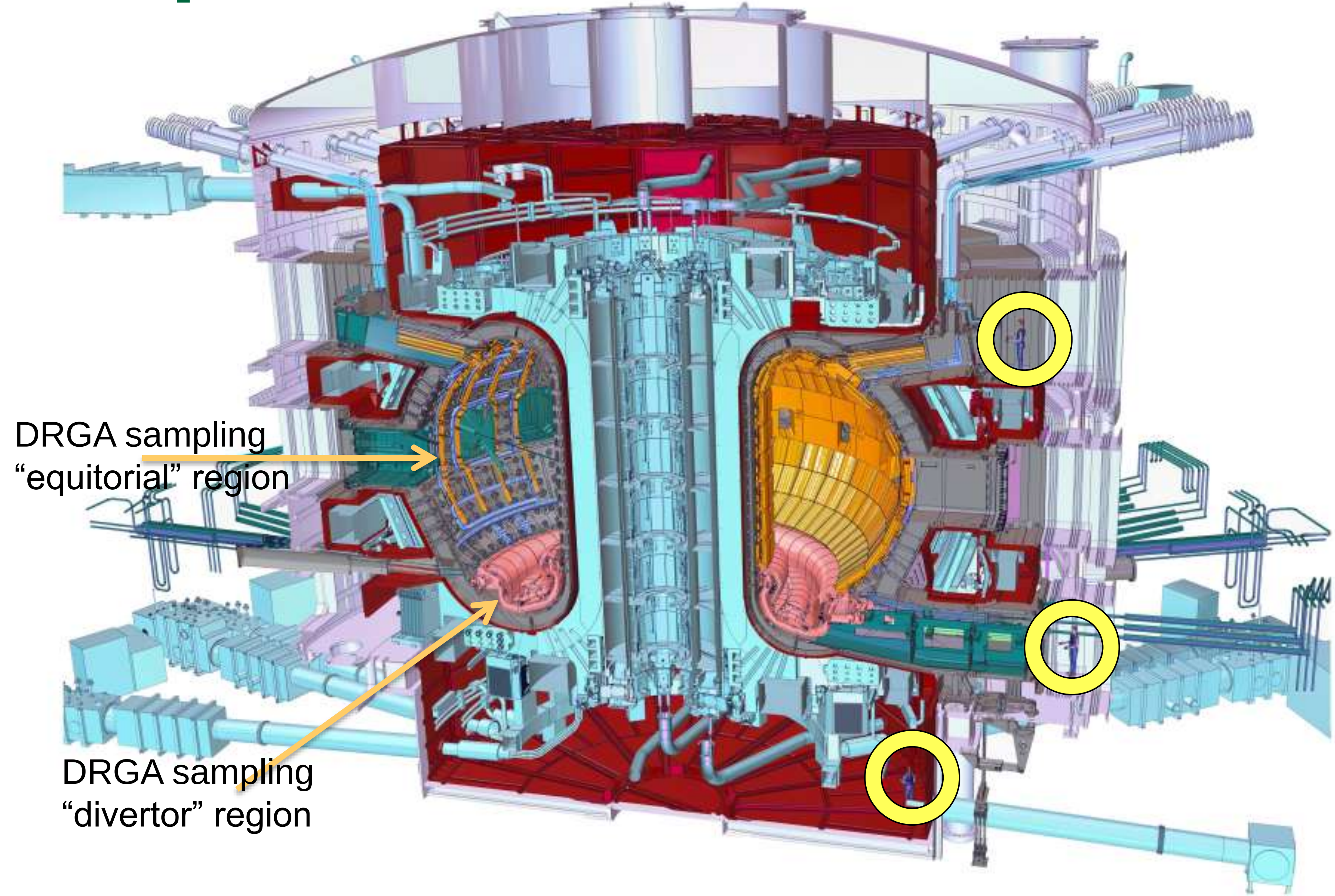
- Oak Ridge National Laboratory
  – T.M. Biewer, D.L. Hillis
- US ITER
  – W.L. Gardner **, David Johnson
- CEA-IRFM, France
  – Stéphane Vartanian, Jérôme Bucalossi
- ITER Organization
  – Philip Andrew, Shaun Hughes,
  – Bastien Boussier

** Also with ORNL

Outline

- ITER
- Diagnostic RGA system for ITER
  - Equatorial/Divertor sample tubes
  - RGA "head"
- Active areas of R&D
- Schedule/Plans

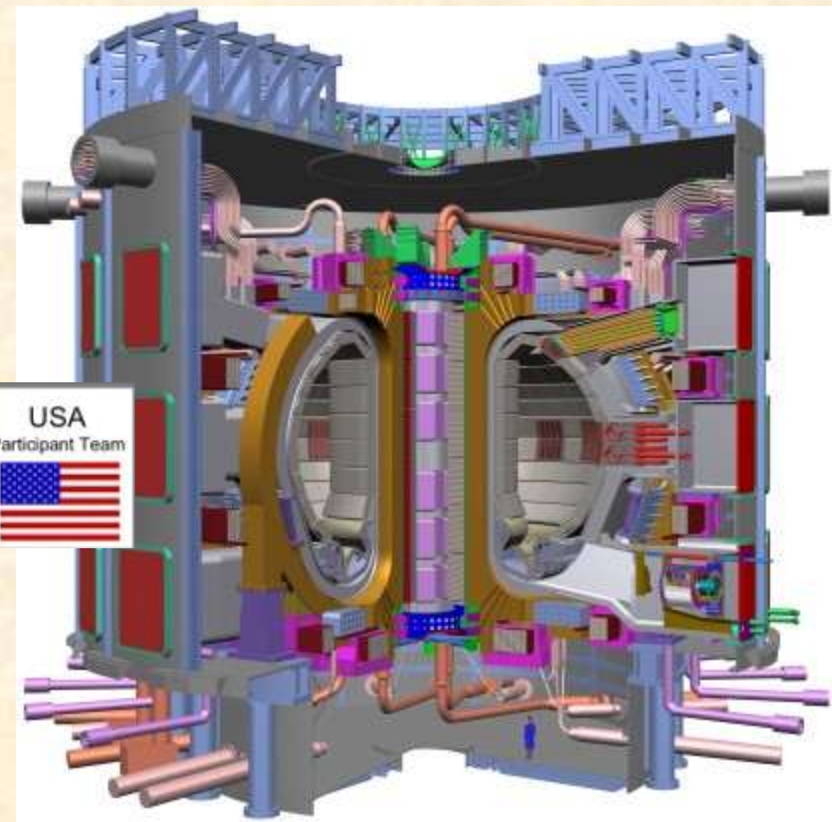
ITER: "International Tokamak Experimental Reactor"



Norbert Hotlkamp, SOFT Symposium, Warsaw 2006

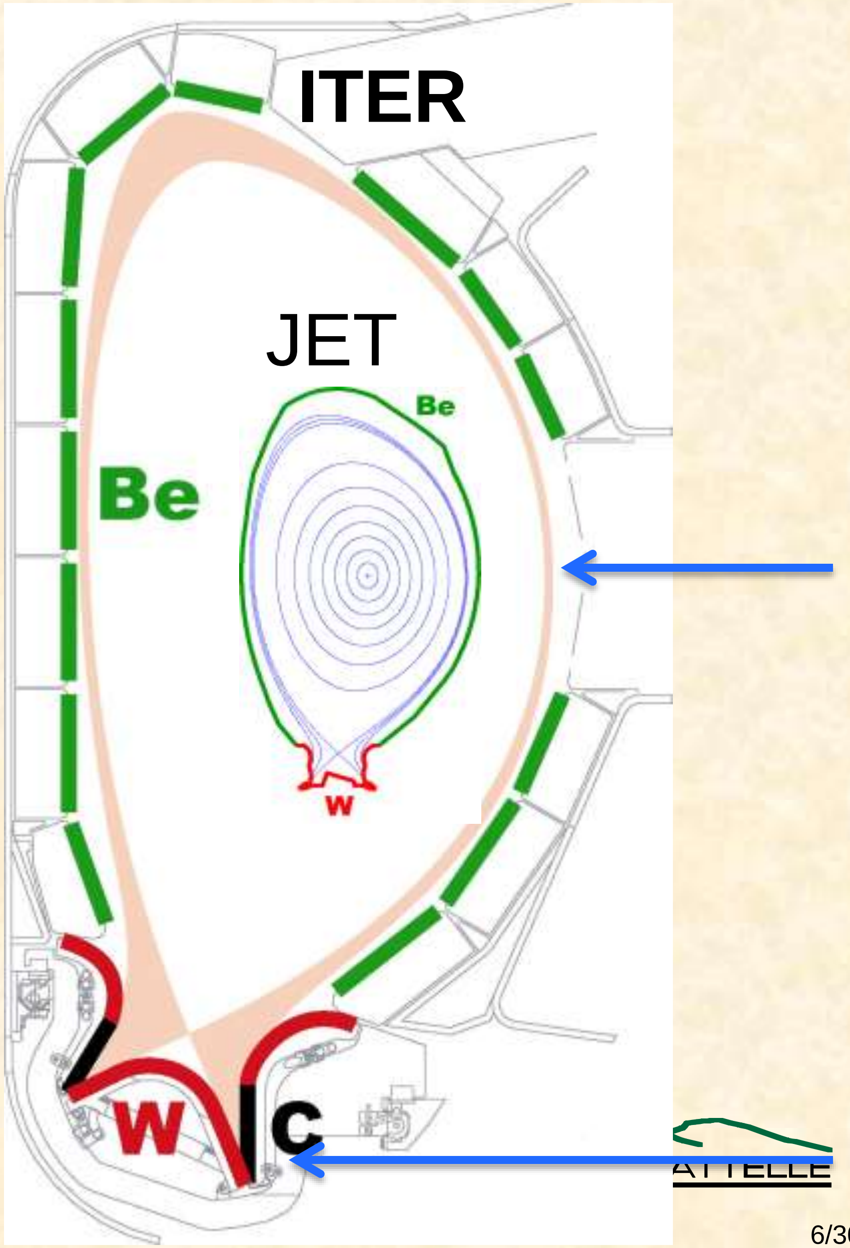
What is ITER Today?

- 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**
  - **Equatorial System**
  - **Divertor System**
    - **~100x higher pressure**
- **Similar DRGA's in use on JET & Tore Supra**



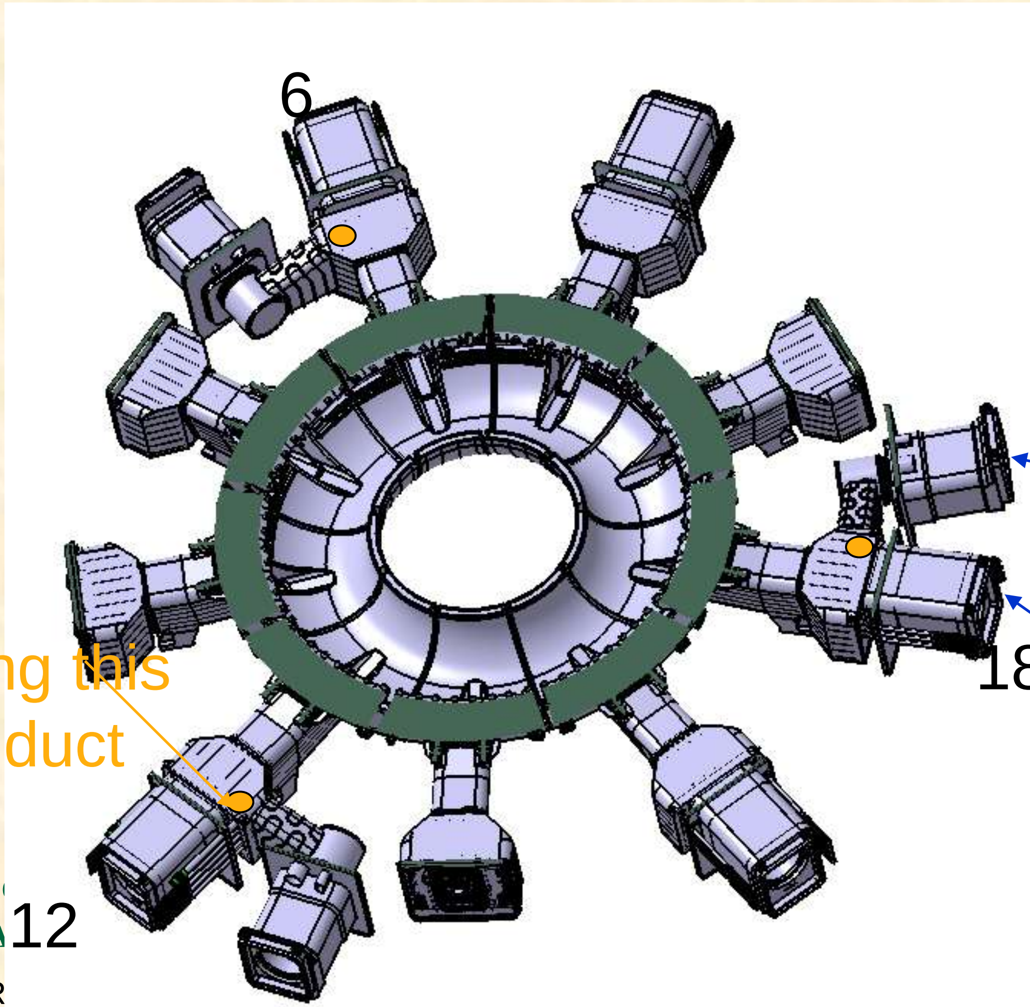
Recent **Procurement Arrangement** Signing

"US ITER Project Director, Ned Sauthoff, and Director-General Motojima signing the Residual Gas Analyzer Procurement Arrangement. The RGA diagnostic will have responsibility for "deciphering" the composition of neutral gases in ITER." **

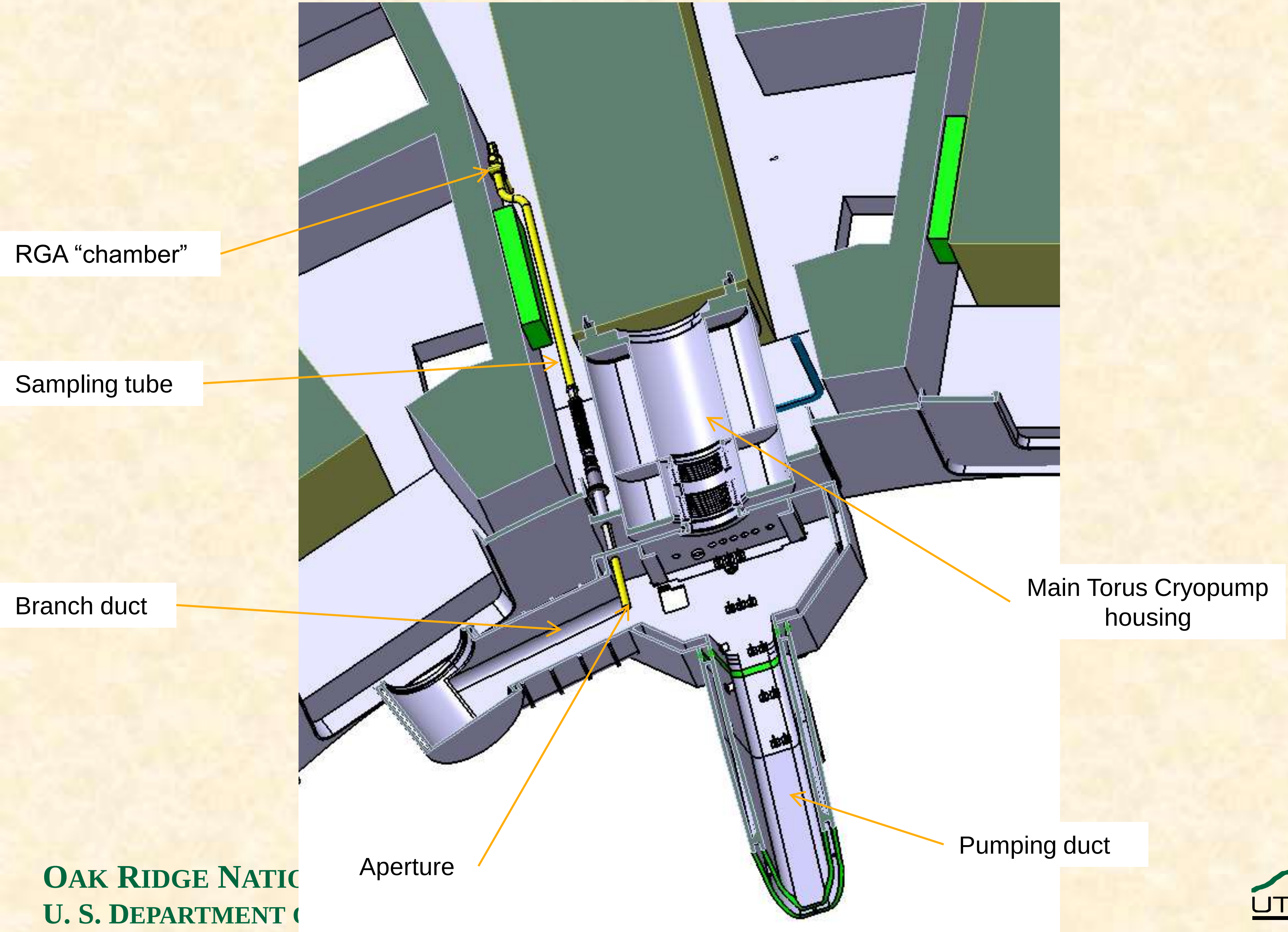
** **http://www.iter.org/newsline/192/885**

Design Basis - Locations

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



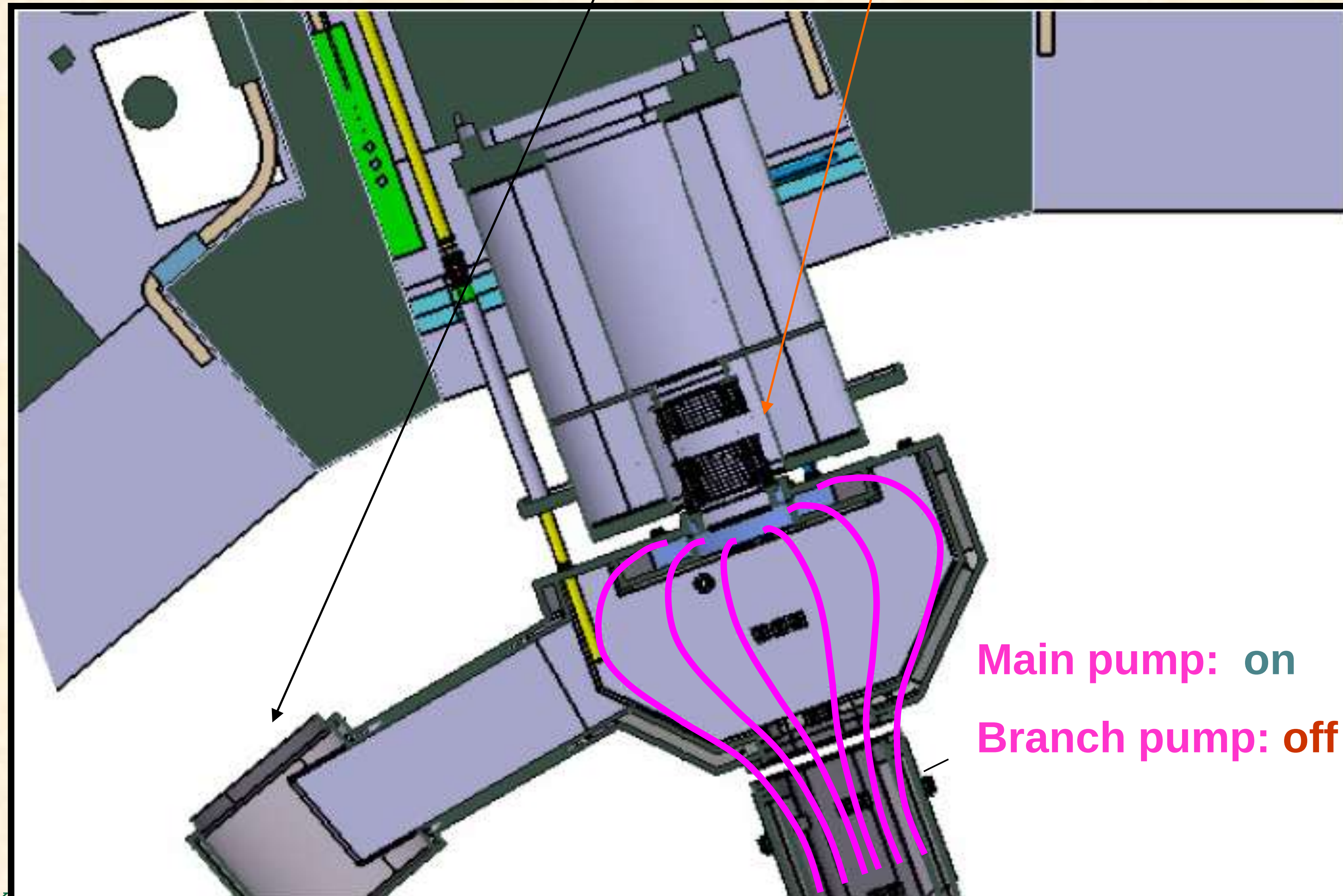
Divertor Design Concept Model



Walt Gardner

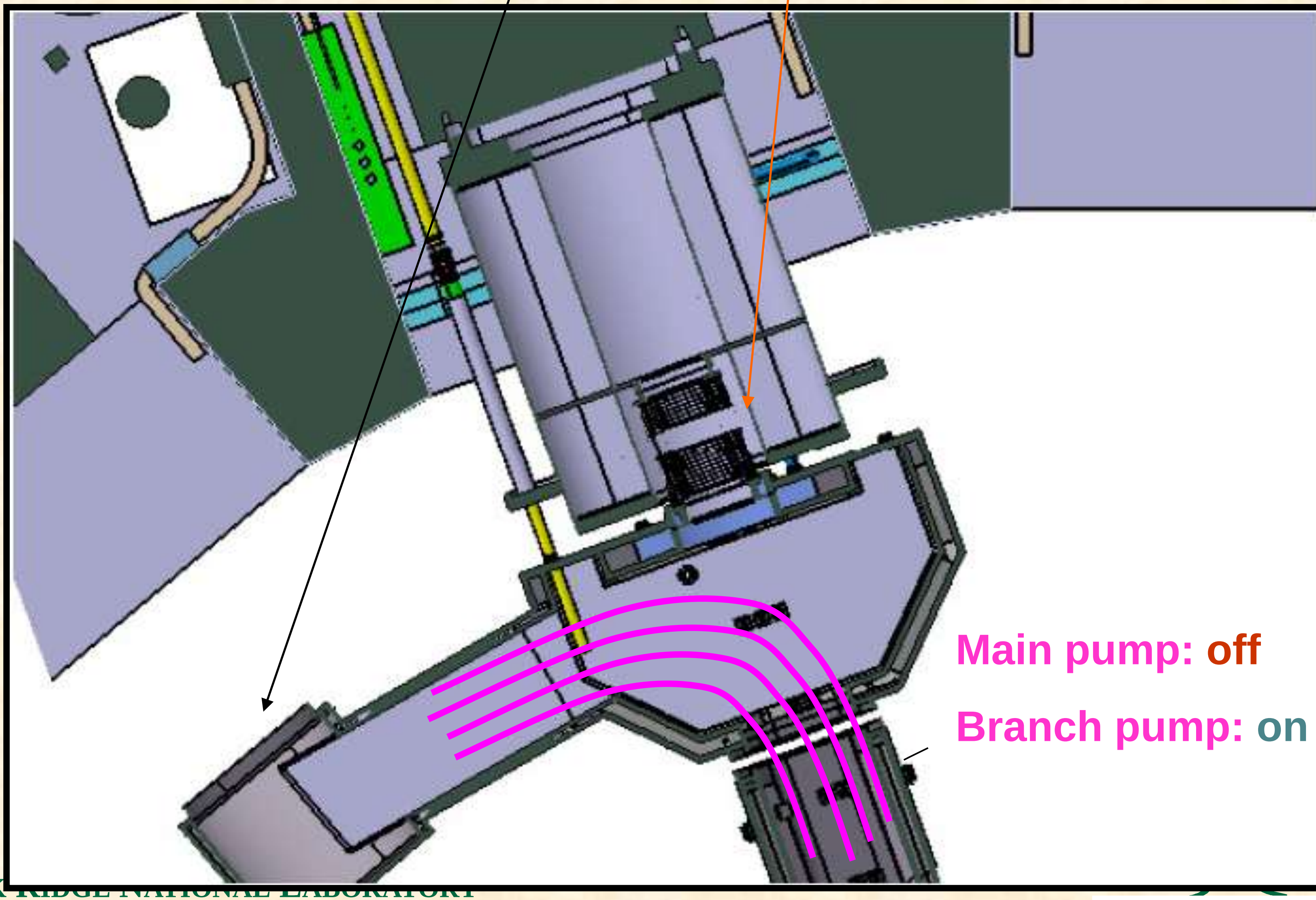
Configuration in divertor ports

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

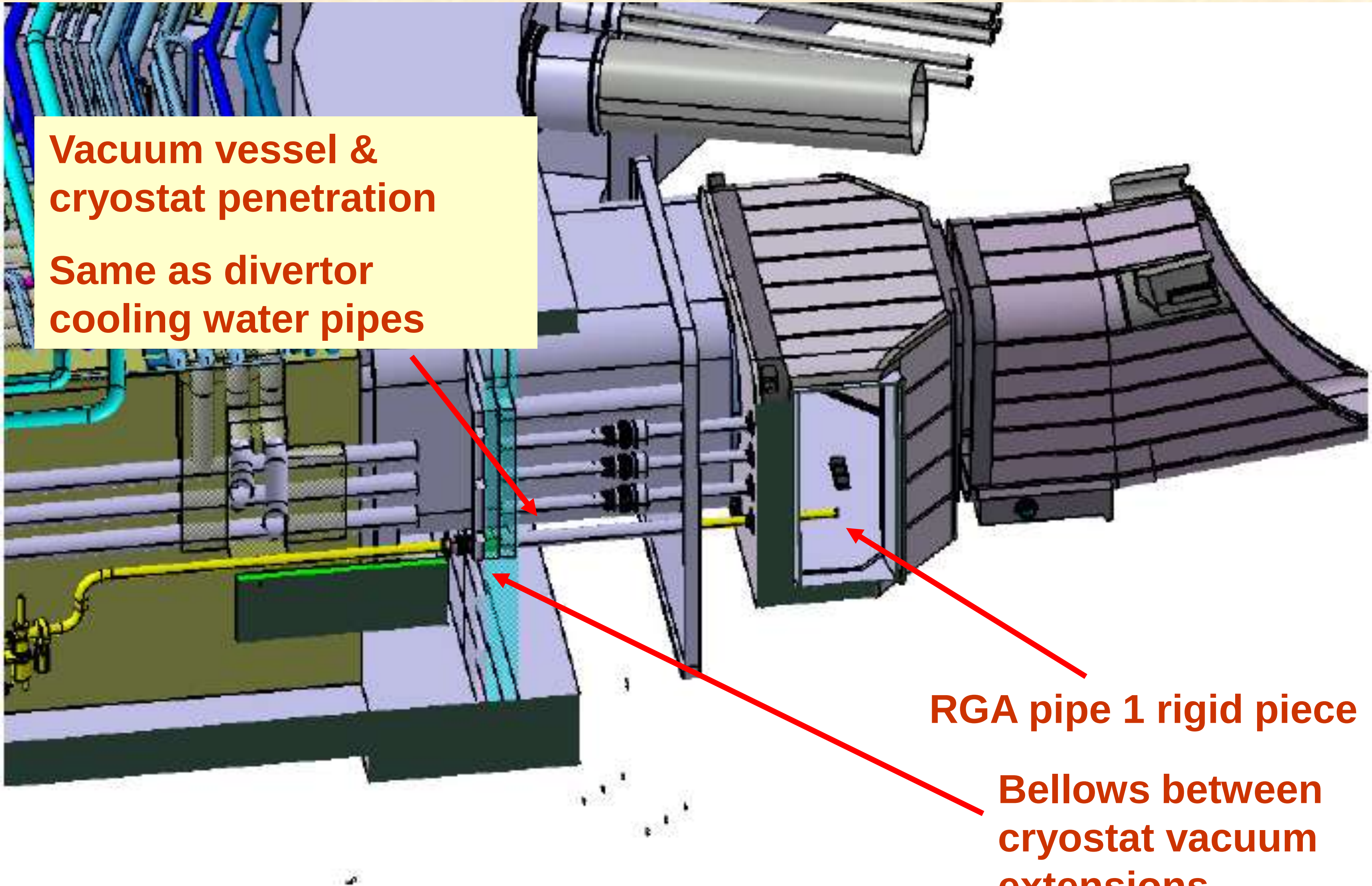


Configuration in divertor ports

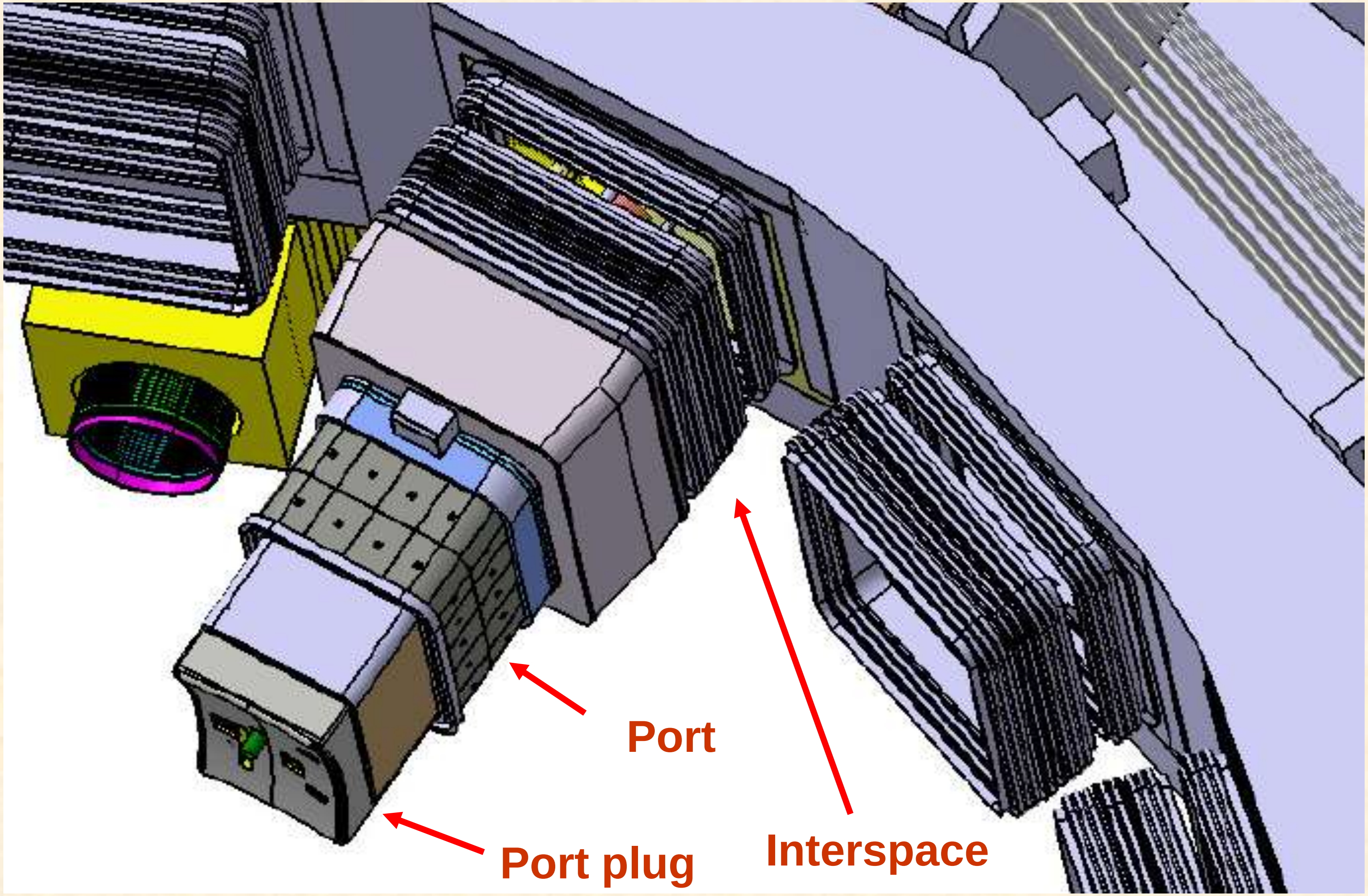
Sample gas at junction between branch pump and main pump



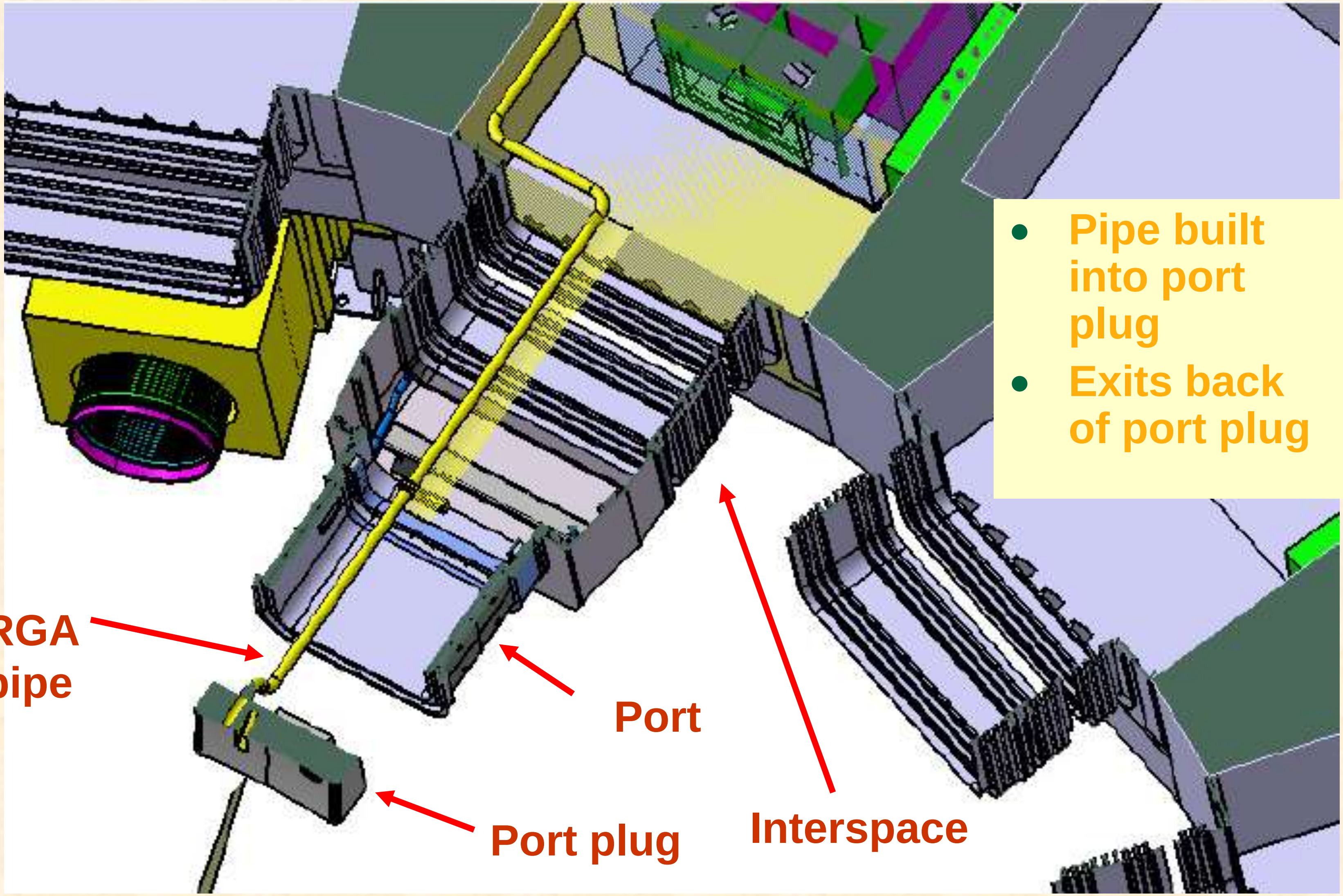
Divertor level



Configuration at equatorial port



Configuration at equatorial port



- Pipe built into port plug
- Exits back of port plug

Philip Andrew

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)

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

Philip Andrew

UT-BATTELLE

Environmental Conditions

- **The main conditions affecting Diagnostic RGA equipment operation:**
  - **<u>Magnetic field</u>: 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.**
  - **<u>Radiation field</u>: 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 (equatorial 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**

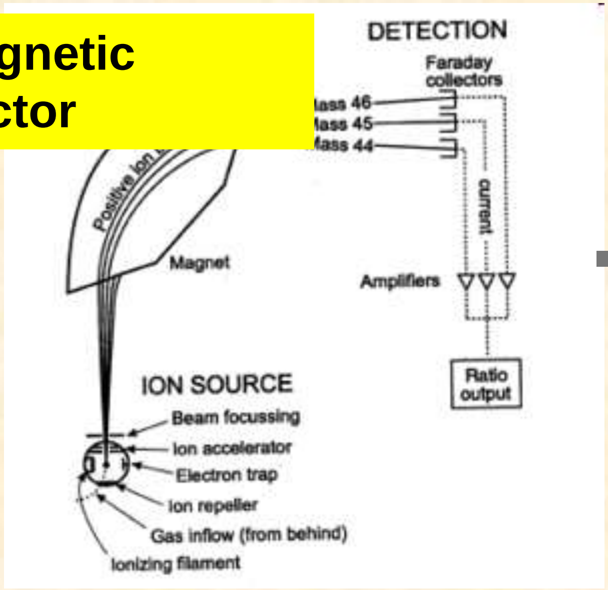
* D. L. Hillis, et al., Rev. Sci. Instrum., Vol. 70, No. 1, January 1999

Dual Sensor Design
(Mass Spectrometer and Optical Gas Analyzer)

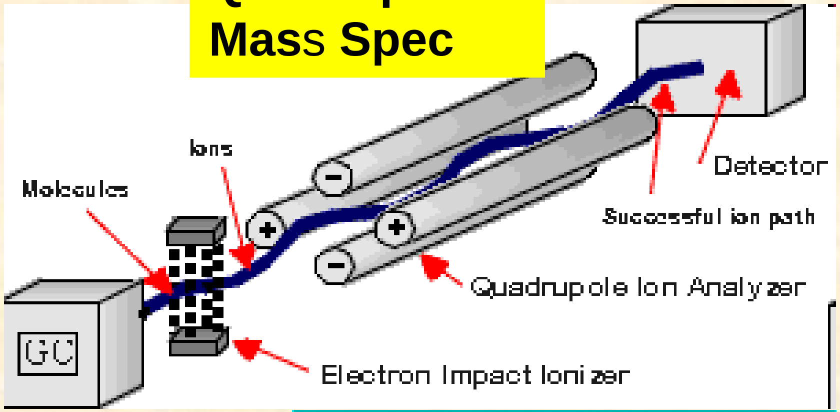
- **The Dual Sensor design (MS + OGA) allows each DRGA system to meet the measurement requirements**
  - **MS provides 50 to 100 atomic/molecular masses to be acquired simultaneously**
    - **Existing models can be applied to the spectra to resolve CO/N_2, CD_4/D_2O**
  - **OGA resolves He/D_2 and can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

Types of Mass Spec Analyzers

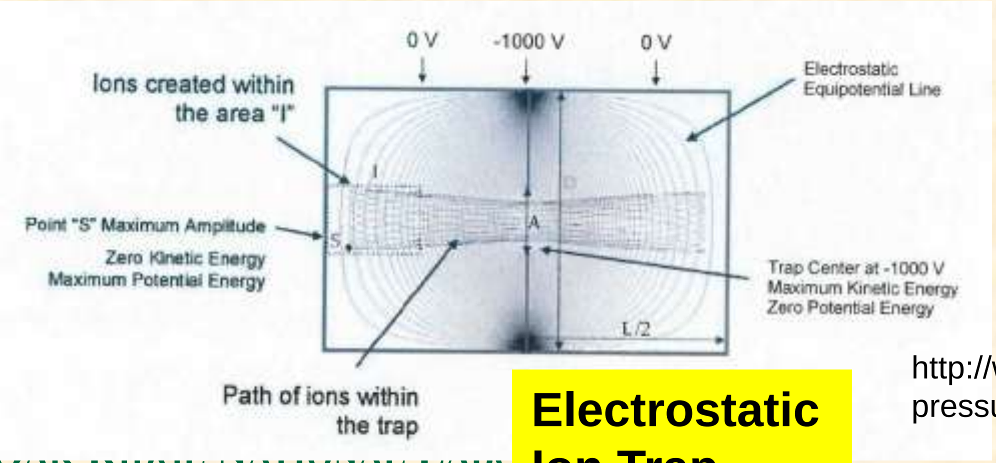
Magnetic Sector



Quadrupole Mass Spec



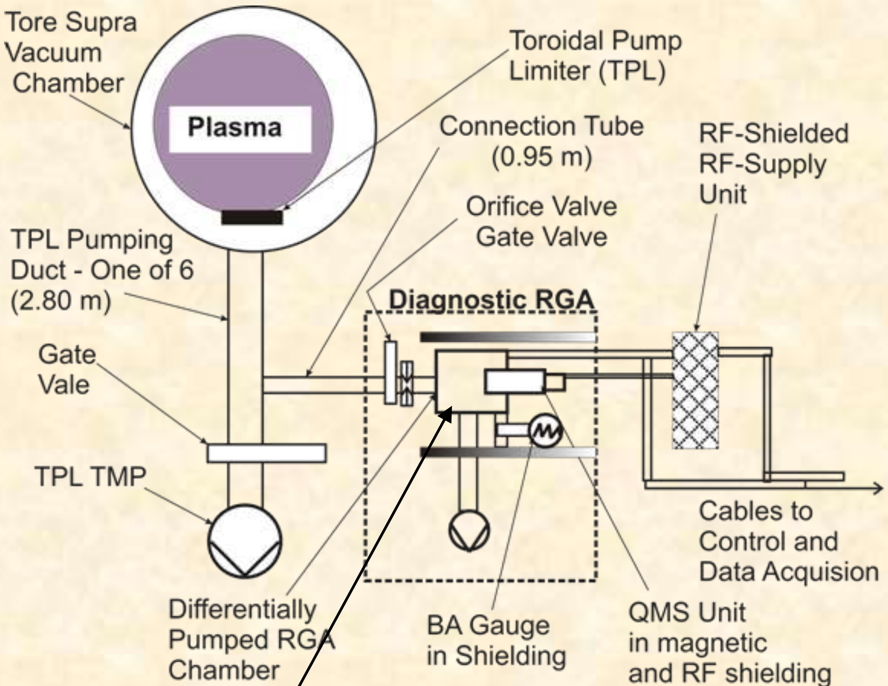
Currently Testing ITMS-Tokamak Compatibility



Electrostatic Ion Trap

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

Precedent of Continuous, Shielded, QMS Mass-Spec DRGA on a Tokamak

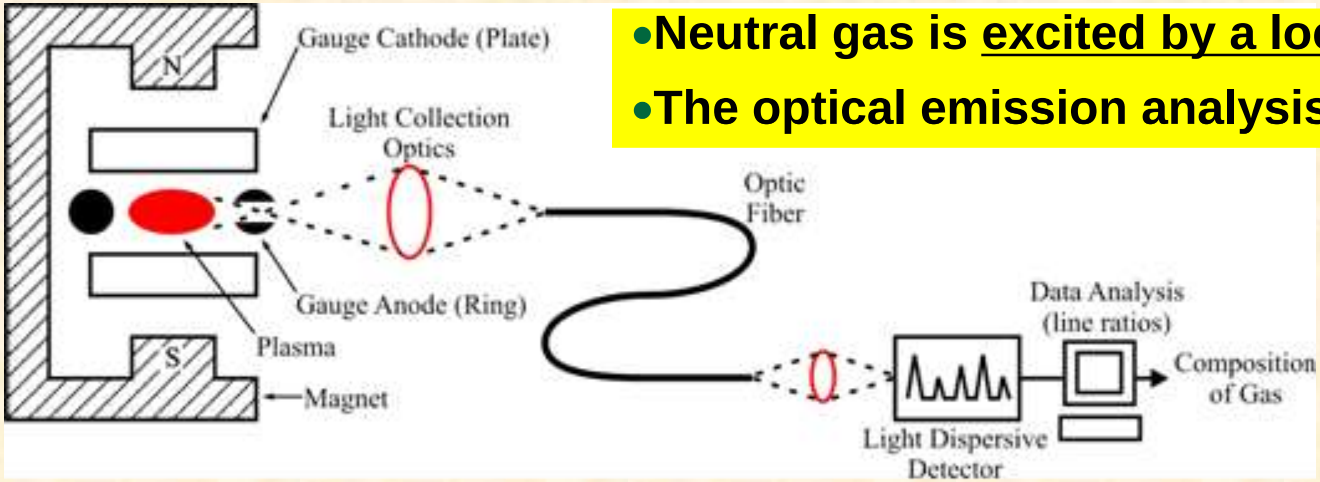


Uses commercial Balzers QMG-421 Mass-Spec

- **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 ****

** C.C. Klepper et al, REVIEW OF SCIENTIFIC INSTRUMENTS 81, 10E104 2010

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 Tritium Shots*

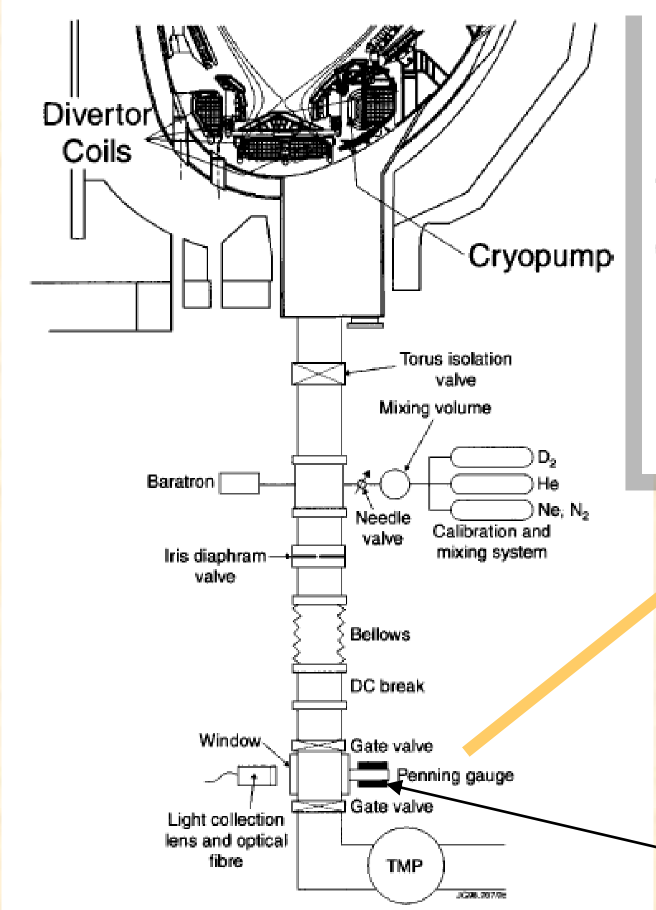
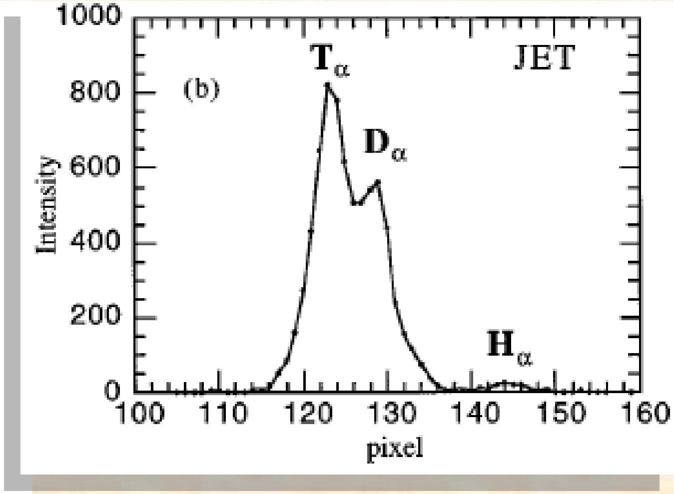
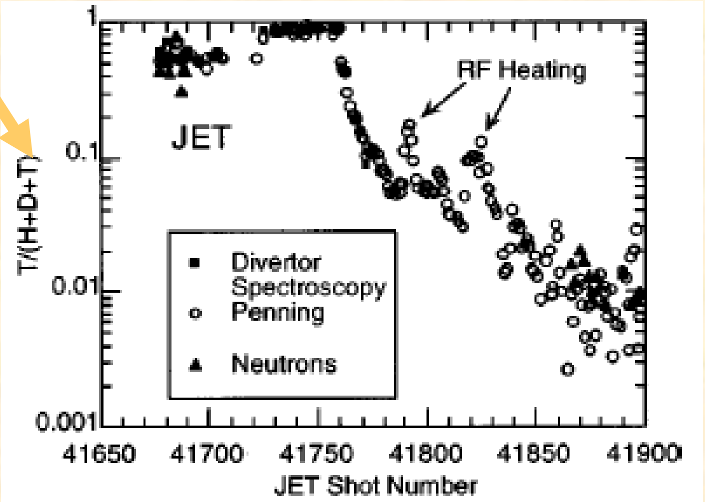


FIG. 1. Penning gauge diagnostic system for the measurement of the tritium concentration in the divertor of JET.



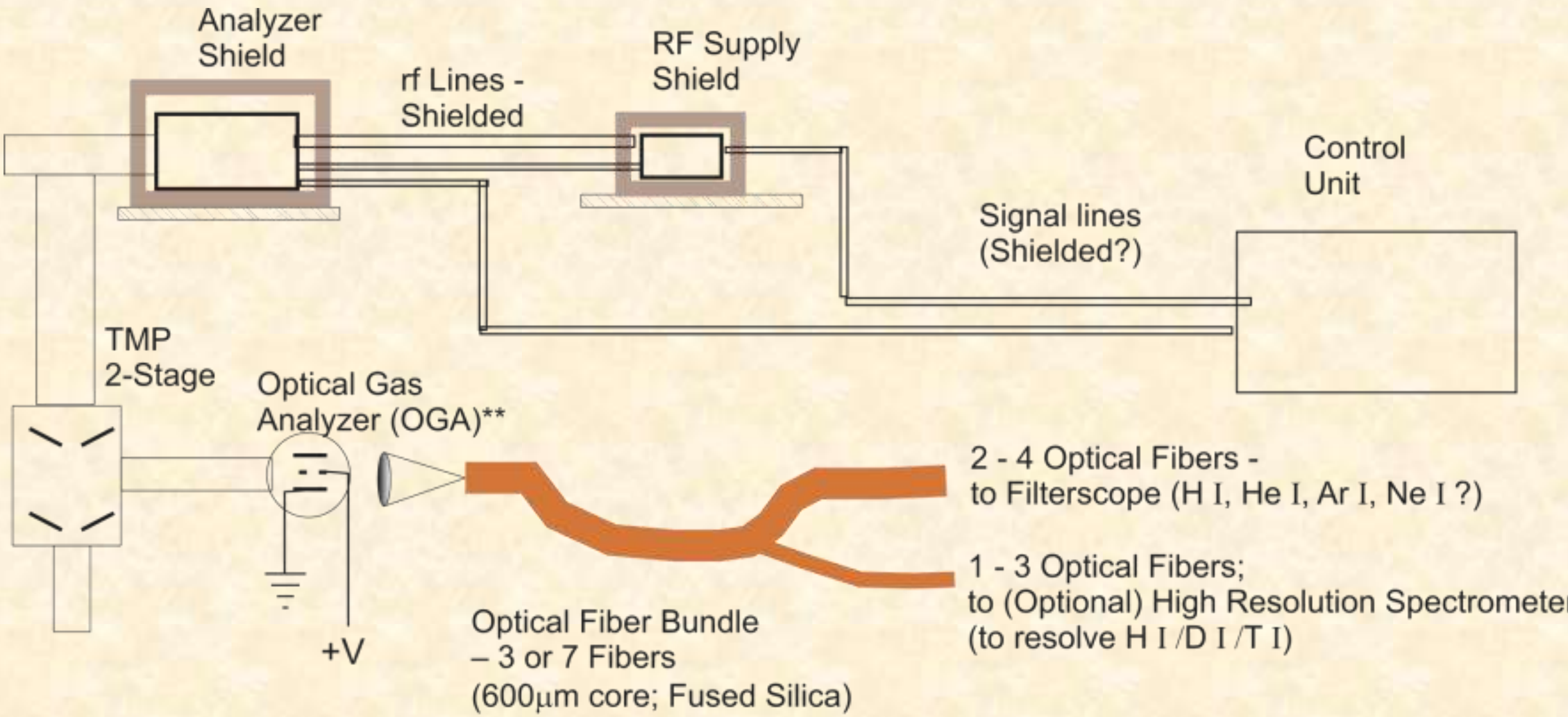
- **OGA T_2/D_2 measurement is "self-calibrating"!**
- **JET study is best proof-of-principle for OGA on ITER**



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

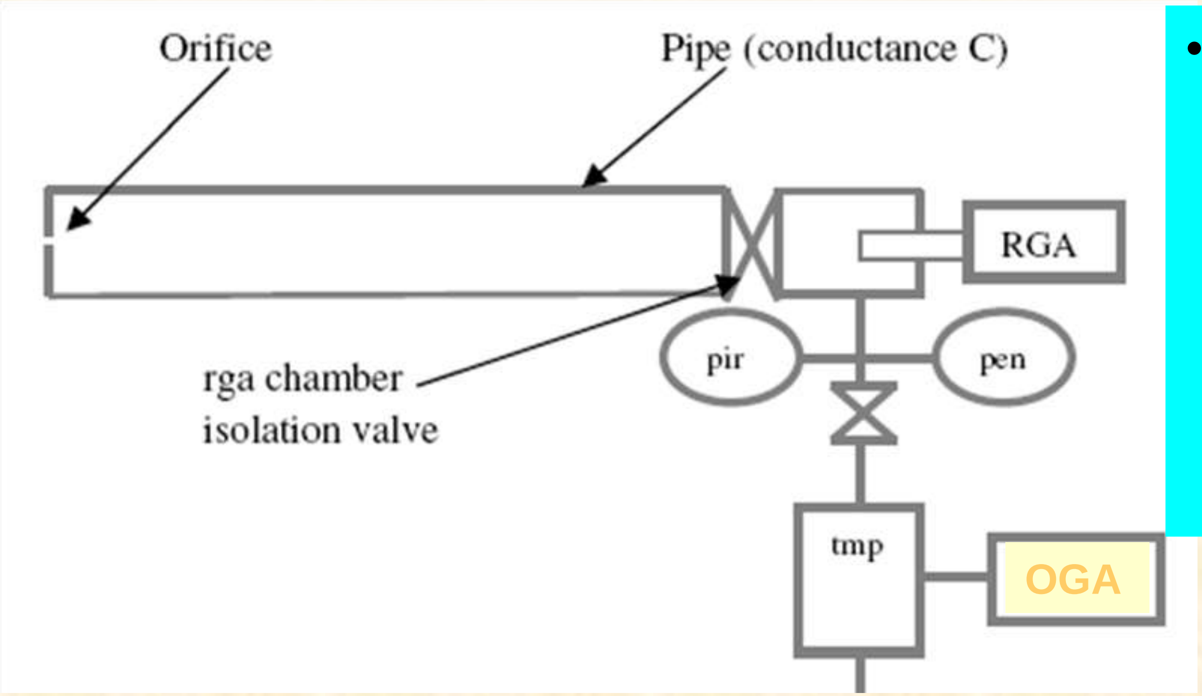


**Initially based on Penning-discharge excitation; RF solutions expected in future

Innovative Vacuum Interface

- **MS and OGA sensors require different base pressures for optimal operation**
  - **P(MS) <~ $1x10^{-3}$ Pa**
  - **$5x10^{-2}$ 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**

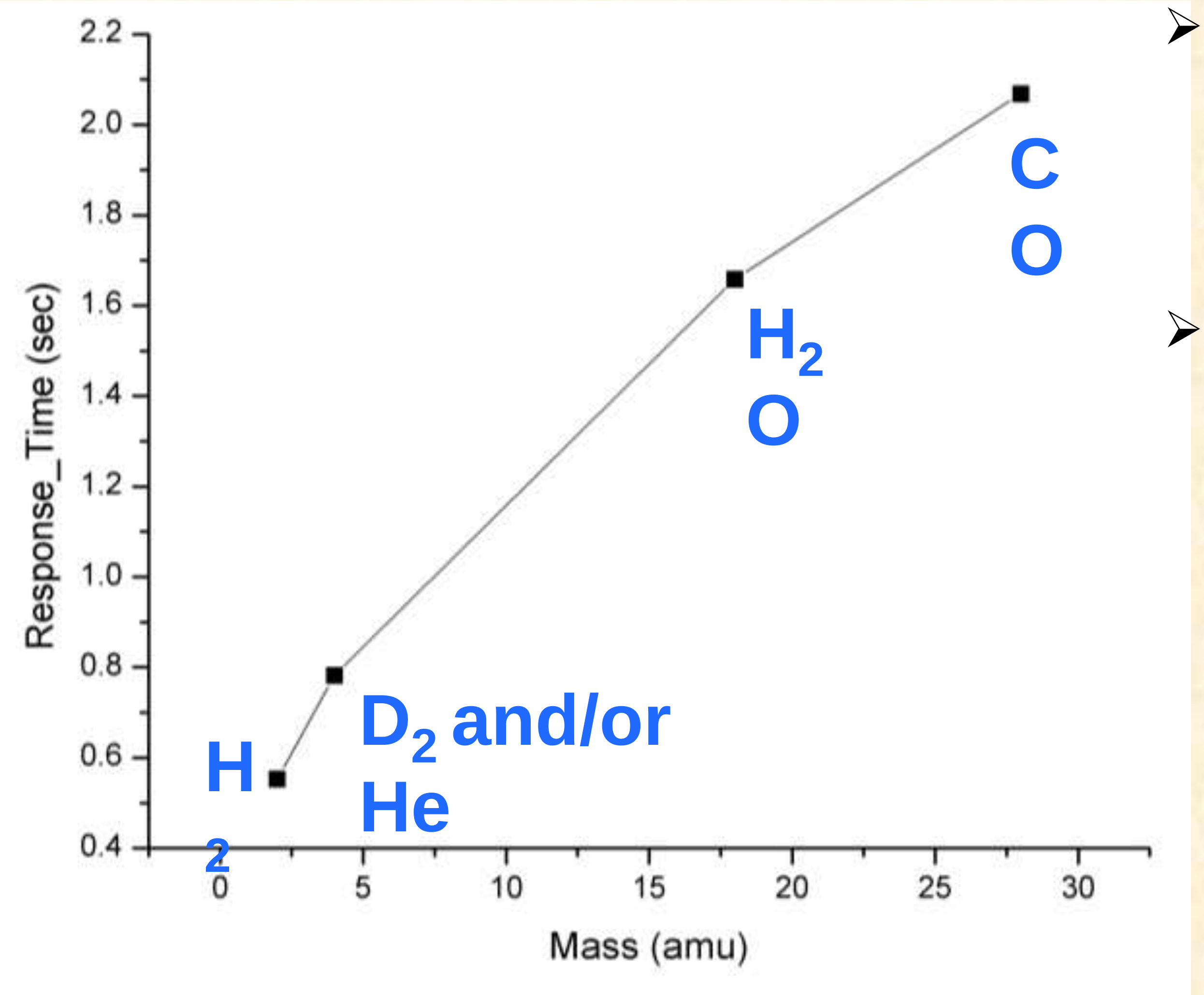
Innovative Vacuum Interface



- 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

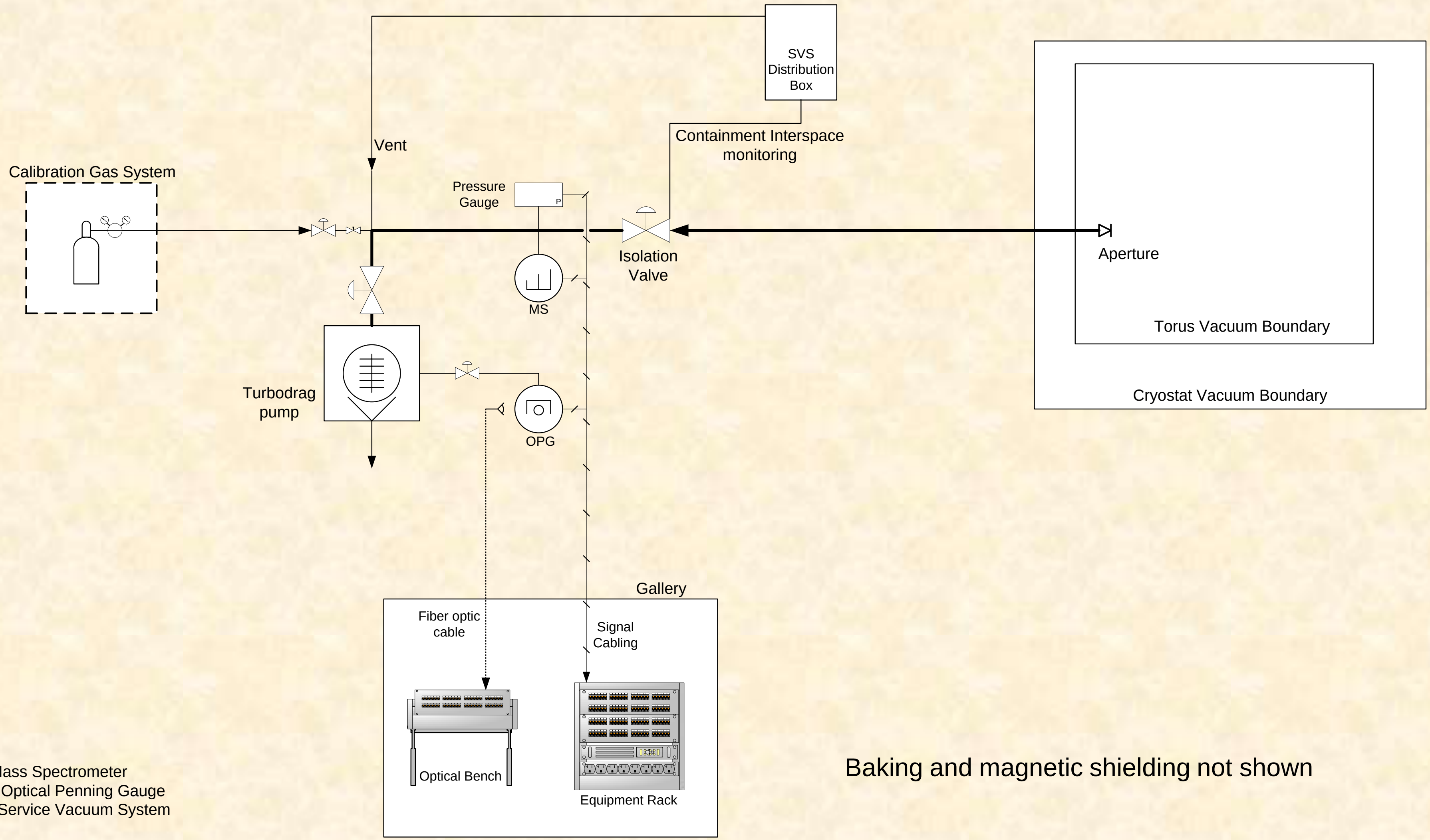


- ➢ Present design is compatible with ~1s response time requirement
- ➢ For the mid-plane RGA, ~identical design will provide same ~1s response time
  - ➔ 10x better than requirement.

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**
  - Looking into a New Rad-Hard MS model with RF source + control electronics 15m away (MKS MicroVision2).
  - MS analyzer unit accessible for replacement
  - Spectrally resolved detection of OGA signals can overcome any scintillation issues in the optical fibers.

DRGA System Schematic



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

Baking and magnetic shielding not shown

Schedule/Summary

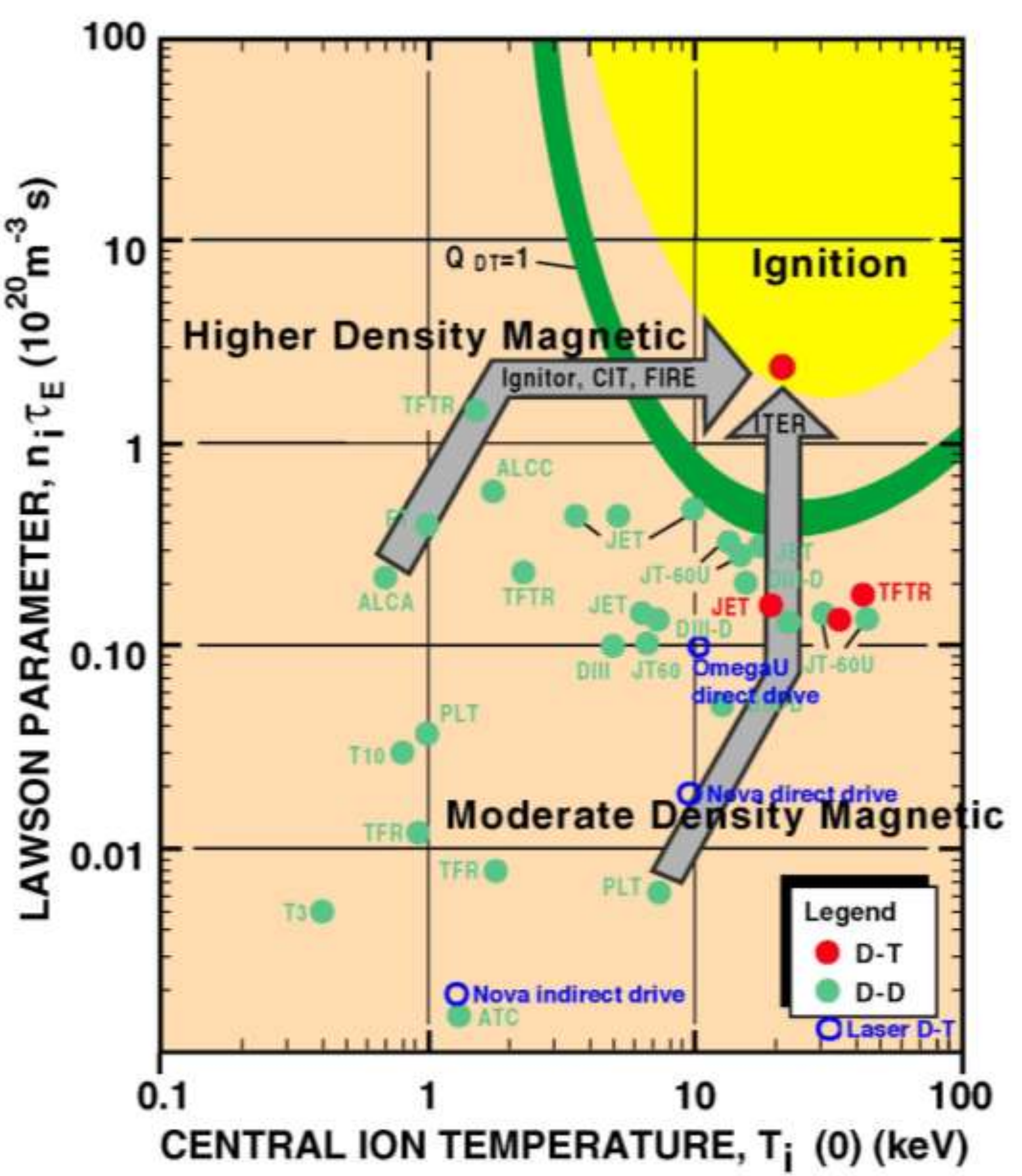
- Conceptual Design completed July 2010
- Active areas of R&D
  - ITMS tests at Tore Supra as replacement for QMS
  - Test OGA on TMP inter-stage port at Tore Supra
  - Test 2 commercial, RadHard TMPs on Tore Supra
  - Magnetic shielding tests at Tore Supra and ORNL
  - Swappable apertures engineering 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 . . . Recently delayed to 2020

Questions?

Supplemental Slides

Supplemental Slides

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.

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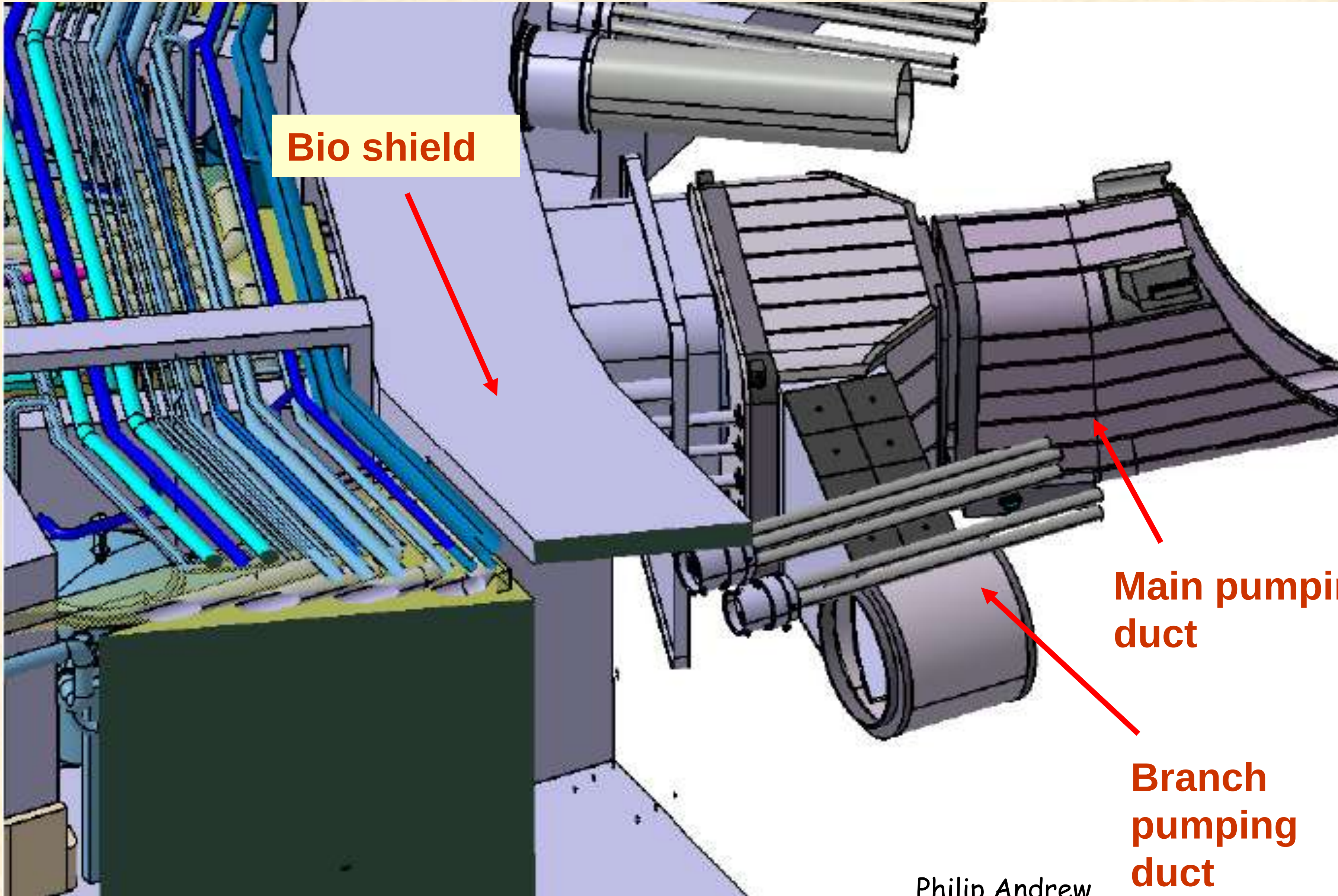
Courtesy of D. Meade

ITER site, CEA Cadarache, France

Divertor level



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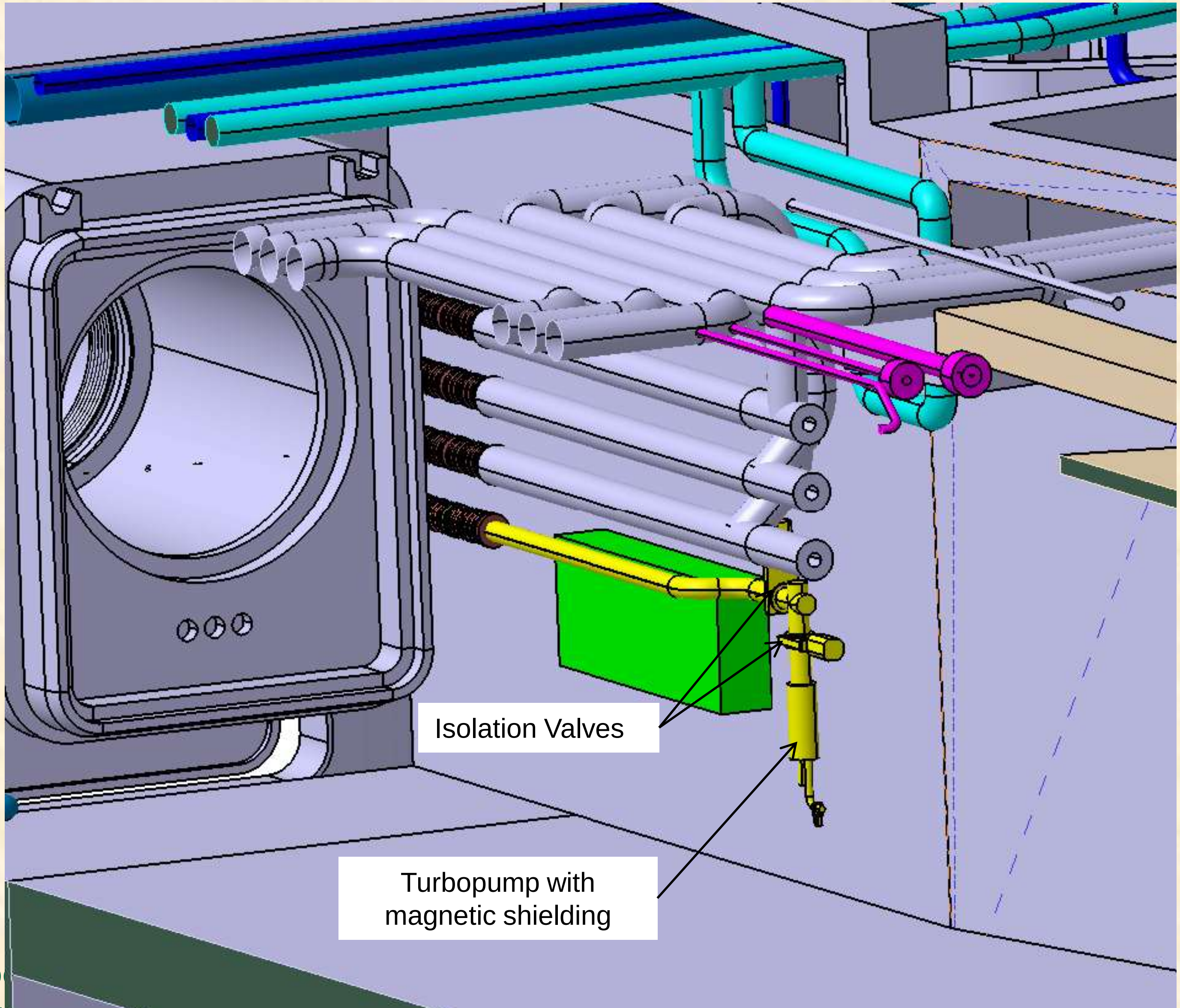
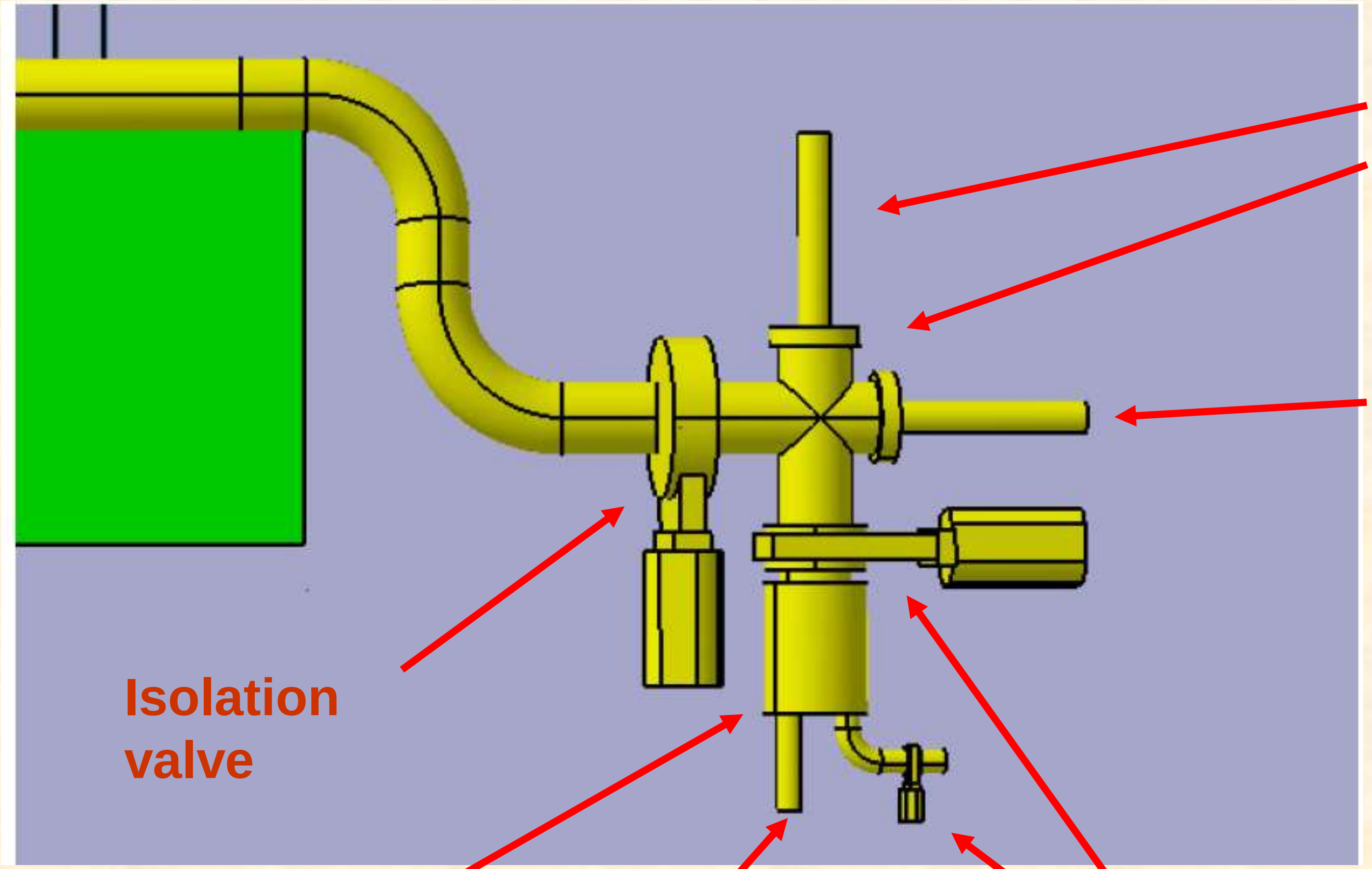


Walt Gardner

Contents of RGA vacuum chamber



RGA Chamber + pressure gauge

Mass Spectrometer

Isolation valve

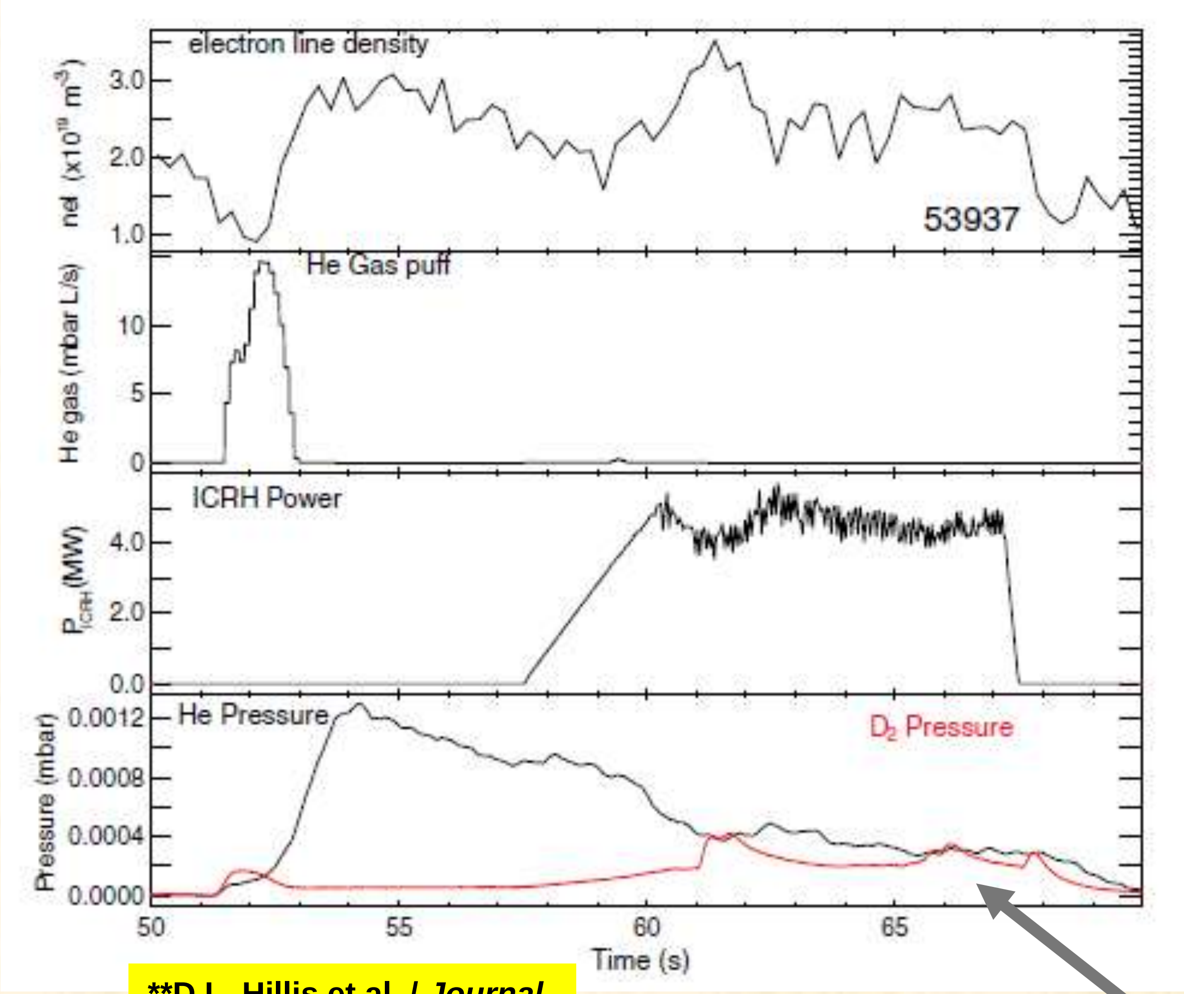
Turbo pump

Optical Penning Sensor

Isolation valves

Philip Andrew

He/D_2 critical for ITER's OGA



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

- **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**

Penning-OGA Data

Calibration System: Integral Part of Each DRGA System