The ITER Diagnostic RGA

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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”

DRGA sampling “equitorial” region

DRGA sampling “divertor” region
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.
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

- RGA “chamber”
- Sampling tube
- Branch duct
- Main Torus Cryopump housing
- Aperture
- Pumping duct
Configuration in divertor ports

Sample gas at junction between \textit{branch pump} and \textit{main pump}

Main pump: on
Branch pump: off

Philip Andrew
Configuration in divertor ports

Sample gas at junction between branch pump and main pump

Main pump: off
Branch pump: on
Divertor level

Vacuum vessel & cryostat penetration
Same as divertor cooling water pipes

RGA pipe 1 rigid piece
Bellows between cryostat vacuum extensions
Configuration at equatorial port

Port plug

Interspace

Port
Configuration at equatorial port

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

RGA pipe
Port
Port plug
Interspace

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)

Philip Andrew
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 (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

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/N₂, CD₄/D₂O
    OGA resolves He/D₂ and can provide more direct H₂/D₂/T₂ measurement
Types of Mass Spec Analyzers

- Magnetic Sector
- Quadrupole Mass Spec
- Electrostatic Ion Trap

Currently Testing ITMS-Tokamak Compatibility

http://www.brooks.com/pages/4074_simplicity_solutions_partial_pressure_instrumentation.cfm
Precedent of Continuous, Shielded, QMS Mass-Spec DRGA on a Tokamak

- 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

Uses commercial Balzers QMG-421 Mass-Spec

** C.C. Klepper et al, REVIEW OF SCIENTIFIC INSTRUMENTS 81, 10E104 2010
OGA Concept and Current Use

- Neutral gas is excited by a local plasma discharge
- 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\textsubscript{2} (both M = 4)
  - On DIII-D it also measures Ne/D\textsubscript{2} and Ar/D\textsubscript{2}
  - On JET it measures H\textsubscript{2}/D\textsubscript{2} and T\textsubscript{2}/D\textsubscript{2}
  - On Tore Supra it measures He/D\textsubscript{2}
Penning-OGA at JET with Tritium Shots*

OGA T₂/D₂ 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


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Chris Klepper
A-10, UK, Oct 18th 2011
ITER DRGA Component Diagram

Analyzer Shield
rf Lines - Shielded
RF Supply Shield
Signal lines (Shielded?)
Control Unit

TMP 2-Stage
Optical Gas Analyzer (OGA)**

Optical Fiber Bundle
- 3 or 7 Fibers
(600μm core; Fused Silica)

2 - 4 Optical Fibers - to Filterscope (H I, He I, Ar I, Ne I ?)
1 - 3 Optical Fibers; to (Optional) High Resolution Spectrometer (to resolve H I / D I / T I)

**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
  - $P(\text{MS}) \sim 1 \times 10^{-3}$ Pa
  - $5 \times 10^{-2}$ Pa < $P(\text{OGA}) \sim 1$ 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

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

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

Calibration Gas System
- Gas Source
  - Vent
  - Pressure Gauge
  - Turbodrag Pump
  - MS - Mass Spectrometer
  - OPG - Optical Penning Gauge
  - SVS - Service Vacuum System

SVS Distribution Box
- Containment Interspace monitoring
- Aperture
  - Torus Vacuum Boundary
  - Cryostat Vacuum Boundary

Optical Bench
- Signal Cabling
- Equipment Rack

Fiber optic cable

Baking and magnetic shielding not shown

MS – Mass Spectrometer
OPG – Optical Penning Gauge
SVS – Service Vacuum System
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 $10 \times nT_E$

• Achieved $nT_E \approx 1/2$ required for fusion, but needs $10 \times T_i$

• 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.

Courtesy of D. Meade
ITER site, CEA Cadarache, France
Divertor level

- Bio shield
- Main pumping duct
- Branch pumping duct
Divertor Design Concept Model

Isolation Valves

Turbopump with magnetic shielding

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\textsubscript{2} critical for ITER’s OGA

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

Calibration System: Integral Part of Each DRGA System

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

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C.C. Klepper, RGA-10, UK, Oct 18th 2011