Tests of He/D_2 discrimination via mass spectroscopy for the ITER Diagnostic RGA system.

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Abstract

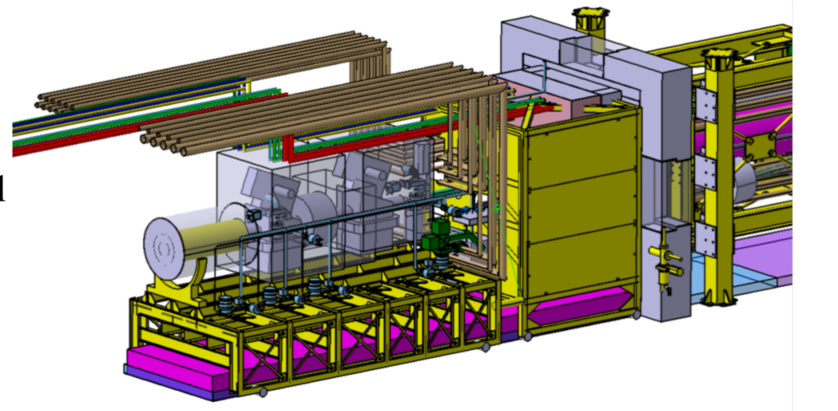
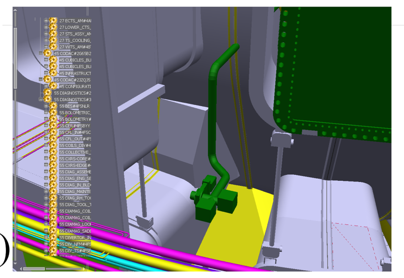
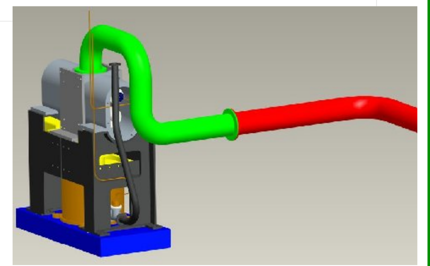
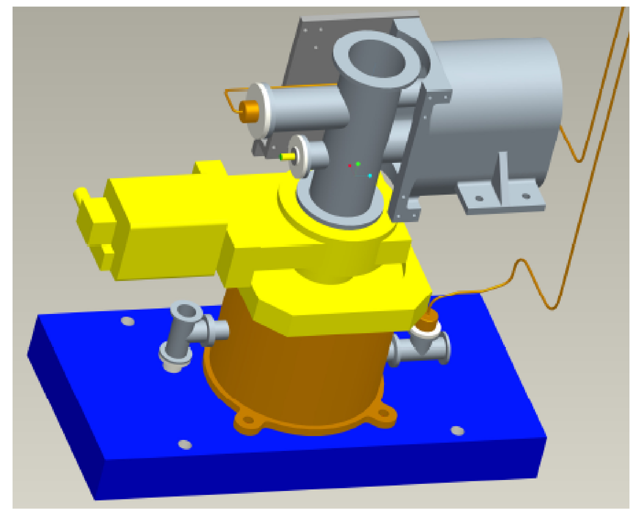
Among the ITER tasks awarded to the US ITER Domestic Agency, and subsequently to the ORNL Fusion Energy Division, is the design and fabrication of the Diagnostic Residual Gas Analyzer (DRGA) system. The DRGA is expected to be a key "first plasma" diagnostic for the commissioning of ITER, which is estimated to begin operation in 2020. The ORNL design for the DRGA system is currently in the Preliminary Design phase, and active R&D is being carried out to address key issues. In particular, the ITER DRGA system requirements specify that the diagnostic must provide gas concentration data for the 1-100 amu range with a time response of 10 s or better. Moreover the system should be able to resolve the concentration of He and molecular D_2, which are separated by only 0.0245 amu. The detection of He, as a D-T fusion byproduct, in low concentrations in the gas effluent is especially relevant to the performance of the DRGA. To this end the prototype Cryogenic Viscous Compressor (CVC, also being developed for ITER at ORNL) is used to carefully control the He/D_2 concentration in a gas stream, and various RGA technologies have been assessed, including a traditional quadropole mass spectrometer (QMS) and a new ion-trap mass spectrometer (ITMS). The ITMS is capable of resolving the presence of He in a D_2 gas stream at concentrations as low as 1%, within the 10 s time constraint, while concurrently scanning a 1-100 amu range. A detailed evaluation of the tested ITMS technology, as it pertains to this ITER task, will be given. Additionally, an overview of the design of the DRGA system for ITER will be presented, along with the current status of R&D into outstanding design issues and concerns.

Motivation

- A relatively new RGA technology, called Ion-Trap Mass Spectroscopy, is being evaluated for inclusion in the ITER Diagnostic RGA system.
- If acceptable, this technology could replace or compliment established RGA technologies, such as Quadropole Mass Spectroscopy and/or Penning Optical Gas Analysis, as has been presented at the ITER DRGA conceptual design review.
- A commercially available ITMS is being tested at ORNL and at Tore Supra, wrt ITER measurement requirements.

Overview of the ITER DRGA

- The Diagnostic RGAs are Group 1a2 ITER diagnostics[1]:
  - "Group 1a2 includes those measurements needed for basic machine control."
- Sample gas in pumping duct (divertor exhaust) and main vessel (equitorial midplane): 2 complete, independent systems.
  - Measure fuel ratios, He, and impurities.
- Mass range: 1-100 amu
  - Resolution: 0.5 amu or better
- Pressure Range: (1 to 10^{-4})xP_{max}
  - P_{max} ~ 20 Pa in divertor; P_{max} ~ 0.2 Pa in main chamber
- Time response (sample aperture to RGA detector): <1 s for divertor; <10 s for main chamber
  - Accuracy: 20% in divertor; 50% in main chamber (or better)
- Environment of DRGA (Port Cell for sensors, Gallery for CODAC):
  - ~150 mT vertical magnetic field
  - [TBD] GY radiation dose
- Multi-sensor design meets these requirements and provides flexibility
  - QMS: P~10^{-3} Pa, 1 – 100 amu range at ~1 amu resolution
  - OPG: P~1 Pa, optical discrimination of He, D, H, T
  - ITMS: P~10^{-3} Pa, 1—100 amu range at ~0.02amu resolution
    - New technology, needs proving in tokamak environment

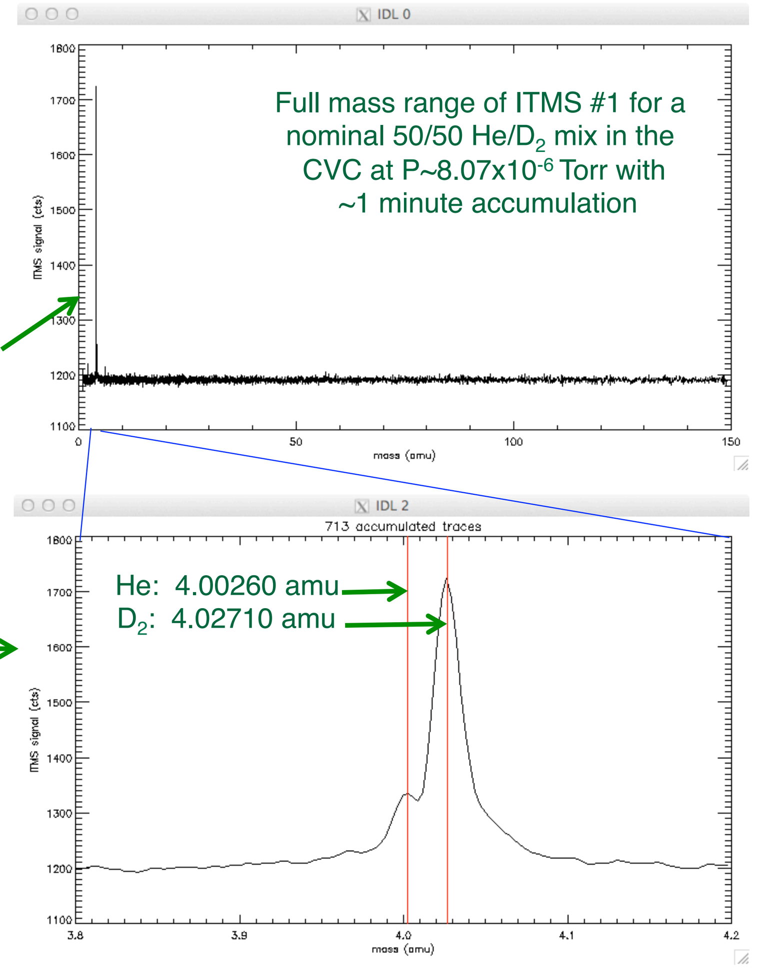
Mechanical design of the ITER DRGA systems.

1) ITER Project Requirements document, IDB 27ZRW8

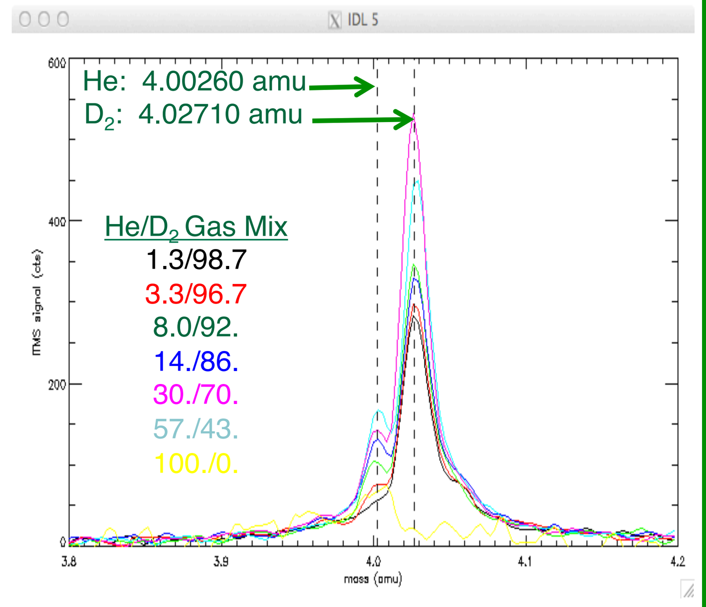
He/D_2 Discrimination Tests with the ITMS

Test Set-Up

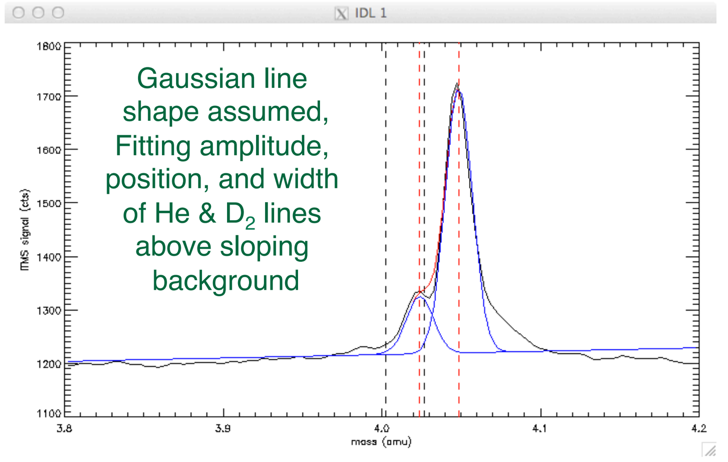
- Tested 2 different ITMS gauges from Brooks Automation: Vacuum Quality Monitor (VQM) 830 gauges
  - #1 "off the shelf" VQM 830, owned by ORNL FED
  - #2 "high resolution" VQM 830 on loan from Brooks
- Testing was carried out on the Cryogenic Viscous Compressor (CVC) prototype at ORNL FED (see details box below)
- VQM 830 ITMS acquires a complete mass scan (1 – 150 amu) every 85 ms
- SNR is improved by averaging or accumulating multiple full-mass scans
- Effectively increases the total time for a "full range" measurement
- Mass resolution is inherent to the device
- Data acquisition utilizing "Simplicity Solutions" software provided with VQM 830
- Raw data (every ~85 ms) was logged to file for ~1 minute
- Data was post-processed in IDL



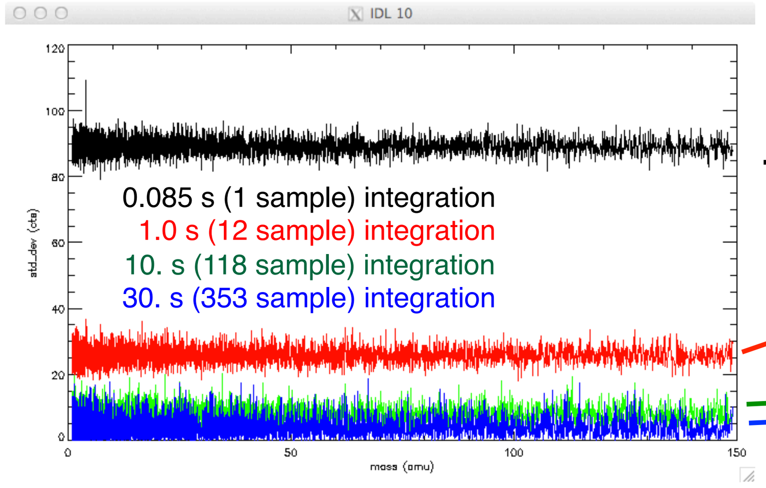
He variation in D_2 gas

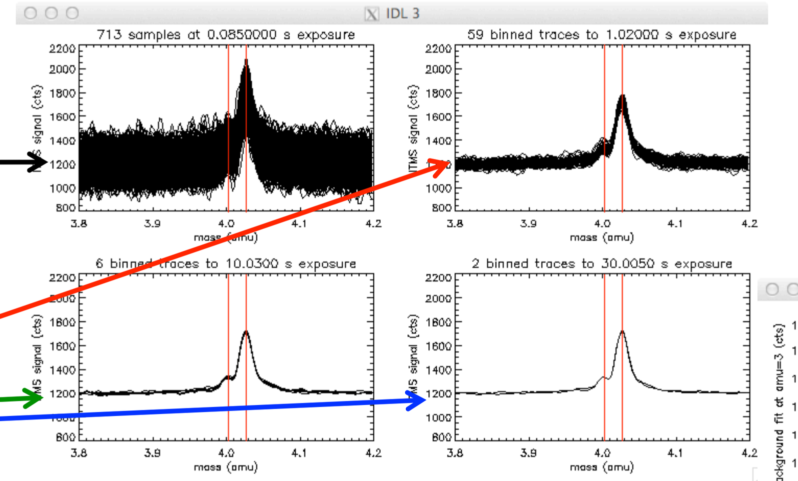


Mass Spectrum Fitting



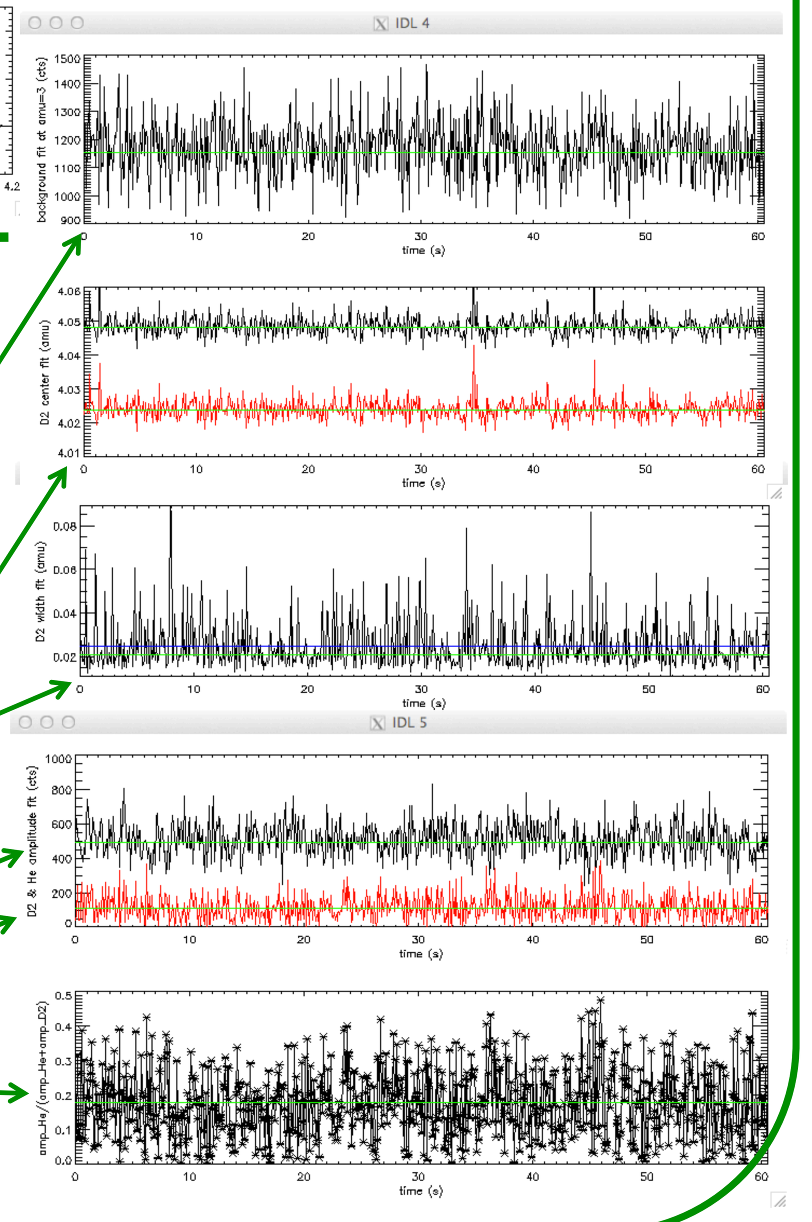
ITMS Characterization





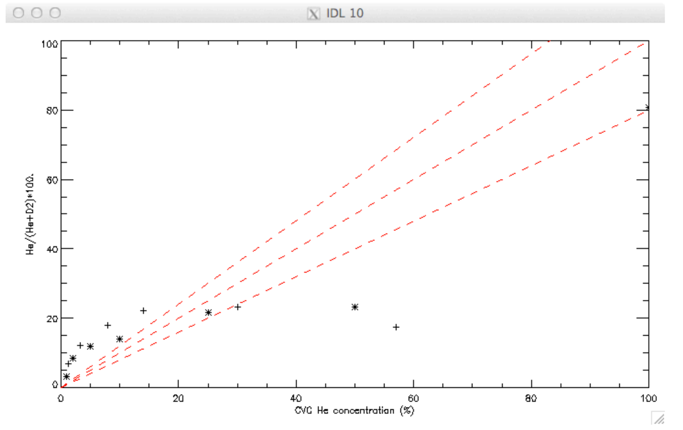
- ~1 minute of data acquisition at ~85 ms/sample yields a 713 sample data set
- The sample-to-sample variation (standard deviation from the mean) partially characterizes the read-noise of the data
  - The noise level is ~ constant at all masses
- This noise is "reduced" by averaging over multiple samples in post-processing
- The height of a given mass peak (above the background count rate) should be higher than the read noise
  - Desire for SNR > 1
- Small amplitude peaks require greater number of samples (longer effective integration) to discriminate from background.
- Mass resolution is determined by the FWHM of a given mass peak: R=(Mass)/FWHM
  - Desire FWHM < 0.0245 amu (D_2 – He)
  - R>164 at M_{D2} to "resolve" He from D_2

- Gaussian line shapes are fit to the raw data for each sample (black=D_2, red=He) and compared to fits to the entire data set averaged data (green)
- Background variation shows no secular trend, variation consistent with read noise
- Position of He/D_2 peaks is ~stable in time, 0.0028 variation << 0.0245 amu mass difference (D_2-He)
- FWHM line width
  - 0.0246 +/- 0.0113 amu, indiv. fits
  - 0.0207 +/- 0.0001 amu, avg data set fit
- Amplitude of D_2 and He above background shows no secular trend
- He amplitude implies ~1s integration needed for SNR~3 at this mix
- He/(He+D) ~0.2 (shouldn't it be 0.5?)



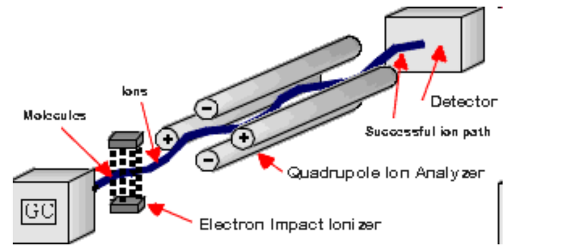
Summary and Future Work

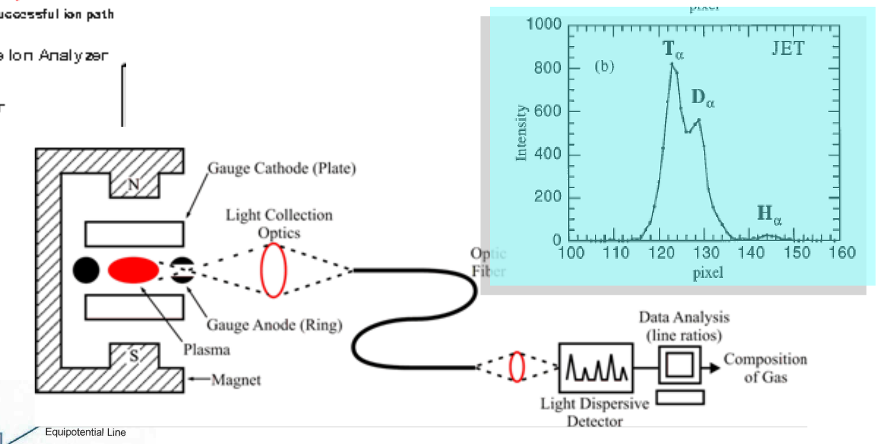
- Brooks VQM 830, ITMS gauge was tested with varying relative concentrations of He and D_2 from the Cryogenic Viscous Compressor prototype.
- "Read Noise" is manageable at 1s to 10 s time frame of measurement requirement.
- Position of He/D_2 peaks is ~stable in time, 0.0028 variation << 0.0245 amu mass difference (D_2-He)
- FWHM line width from VQM 830
  - 0.0246 +/- 0.0113 amu, individual fits: R~164
  - 0.0207 +/- 0.0001 amu, avg data set fit: R~195
- Concentration doesn't follow "mass flow" concentrations?
- A VQM 830 has been shown operational in a tokamak environment
  - Ongoing work at Tore Supra, CEA Cadarache, France
- Magnetic & radiation shielding requirements for ITER environment?
- Could this technology be improved/extended to resolve T from HD
  - Would need R~500

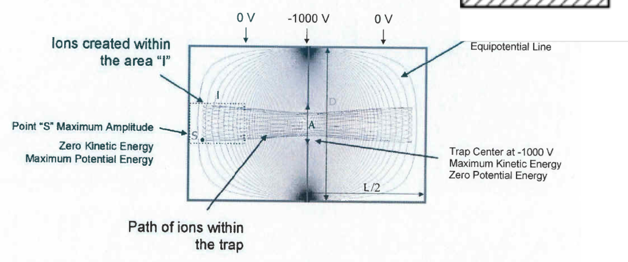


Comparison of RGA technologies

- Quadropole Mass Spectrometers
  - Full mass range
  - Poor D_2/He resolution
  - Slow time response, >10 s
- Penning Optical Gas Analysers[1]
  - Neutral gas excited by a local gas discharge
  - Optical emission is used to analyze gas composition
  - Originally developed to distinguish He from D_2
  - Improved to also distinguish H/D/T
- Ion Trap Mass Spectrometers
  - Full mass range
  - Good D_2/He resolution
  - High time response



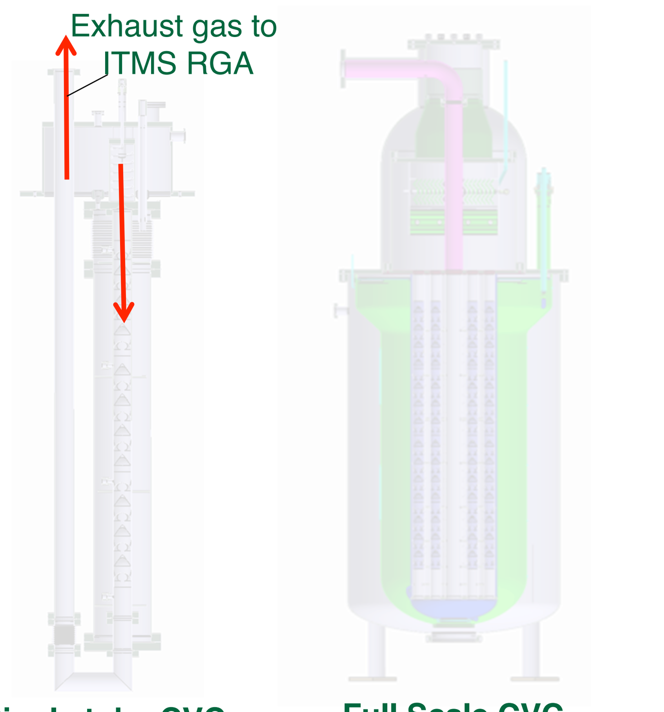




1) Hillis, et al., Rev. Sci. Instrum. **70** (1), 1999

The Cryogenic Viscous Compressor & Single Tube CVC Prototype

- The Cryogenic Viscous Compressor (CVC) will be deployed at ITER to help remove H/D/T from the vacuum exhaust stream and regenerate it at higher pressures to be processed more efficiently within the Tokamak Exhaust Processing (TEP) system.
- Single tube CVC test system developed to determine optimum configuration for freezing H/D gas in full scale prototype design.
- The ITMS RGA test system samples the exhaust gas from the single tube CVC through a limiting aperture (to reduce the pressure in the sample region) with differential pumping.
- Flow of He and D into single tube CVC prototype is regulated by mass flow controllers: vary concentration and total gas flow rate that is sampled by ITMS RGA test system.
- Tests were done when system was at ambient to baseline sensitivity of ITMS RGA and then compared to results at test conditions (5K to 10 K)



Single tube CVC Prototype

Full Scale CVC Prototype