UP8.020 Status of the design of the Diagnostic Residual Gas Analyzer System for ITER first plasma

Presented at the
55th APS Division of Plasma Physics Meeting

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Denver, CO, USA

November 11th - 15th, 2013

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Abstract

Among the ITER procurements awarded to the US ITER Domestic Agency, and subsequently to the ORNL Fusion & Materials for Nuclear Systems Division, is the design and fabrication of the Diagnostic Residual Gas Analyzer (DRGA) system. The DRGA system reached the Preliminary Design Review (PDR) in Spring 2013, and has transitioned into the Final Design phase. As a result of the PDR, and ITER systems design evolutions, several design changes have been incorporated into the DRGA system. The design effort has focused on the vacuum and mechanical interface of the DRGA gas sampling tube with the ITER vacuum vessel and cryostat. Moreover, R&D tasks to demonstrate the 3-sensor instrumentation design (quadrupole mass spectrometer, ion-trap mass spectrometer, and optical Penning gauge) are maturing through the construction and testing of a DRGA prototype at ORNL. Results will be presented at this poster along with the DRGA design overview.

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Thanks to ITER DRGA team

- ITER International Organization
  - Philip Andrew (Technical Responsible Officer)
- US ITER (Domestic Agency of the US)
  - Dave Johnson (WBS manager), Bill DeVan, Emil Nassar
- ORNL FMNS Division (subcontract to US ITER)
  - Ted Biewer, Chris Klepper (project managers); Van Graves, Chris Marcus, Tim Younkin
- DeNuke Inc. (subcontract to ORNL, scheduling)
  - Mike Morris

Outline

- Introduction: PDR and Diagnostic Goals
- DRGA System Overview
  - Equitorial Port 11 Concept
  - Divertor Port 12 Design
- Harsh environment: Magnetic Field and Radiation
  - Shielding and separation of sensitive electronics
- 3 Sensor DRGA Design: QMS, OPG, ITMS
- Project evolution towards FDR and Installation

Introduction

- The ITER Diagnostic Residual Gas Analyzer system (PA 5.5.P1.US.01) was defended at a Preliminary Design Review on April 9-10, 2013 at the "new" ITER building in France.
- This was the "first US-credited diagnostic to reach PDR."
- Provisionally passed; Cat. 1 Chits currently being resolved.
- The DRGA is expected to be installed for "first plasma".

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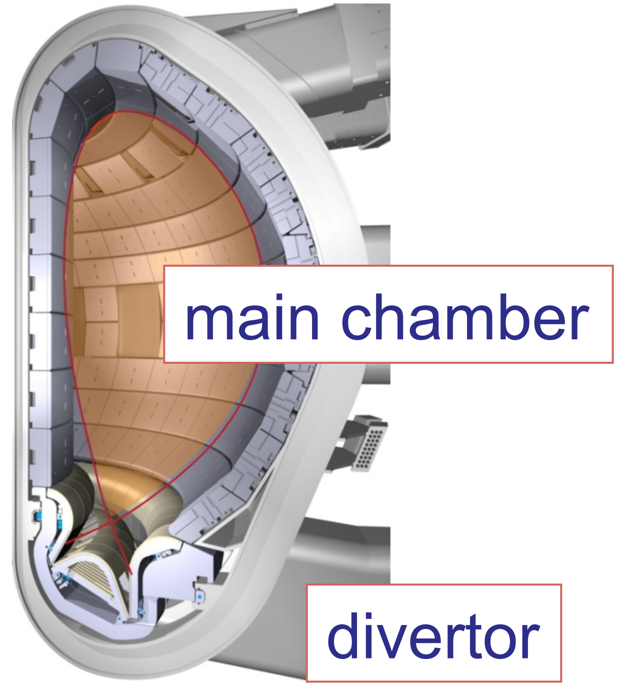
Diagnostic Objectives



- Physics understanding
  - Divertor impurity compression
  - Particle balance (fuel, helium)
  - Wall retention
- Assistance to T inventory measurement
  - Back-up
  - This system is NOT responsible for T inventory measurement
- Not responsible for measurement at Massive Gas Injection
- ITER vacuum pumping section (PBS 31) also provide RGA to monitor vacuum condition (operational aspects)
  - Detection of air leak
  - Wall condition monitor
  - Readiness for operation
  - Breakdown

Measurement Requirements for DRGA

G.04	Measurement role: 1a1: Machine Protection	Diagnostic role:	Primary
Residual Gas Analyser	1a2: Basic Control		Backup
	1b: Advanced Control		Supplementary
	2: Physics		

Measurement	Parameter	Condition	Range	Meas. role	Resolution: time or freq	Resolution: spatial or wave number	accuracy
16. Divertor operational parameters	Gas composition. Fuel, He, impurities	A = 1 - 100, DA = 0.5Fuel vs. He & H20 vs. CxHy discrimination	(10-4 - 1) ·Pdiv	1a.2	1 s	several points	20% during pulse
18. Gas pressure and composition in main chamber	Gas composition. Fuel, He, impurities	A = 1-100, ΔA=0.5 Fuel vs. He & H20 vs. CxHy discrimination	(1E-4 - 1) ·Pmain	1a.2	10 s	several points	50% during pulse
19. Gas pressure and composition in vacuum ducts	Gas composition. Fuel, He, impurities	A = 1-100, ΔA=0.5. Fuel vs. He & H20 vs. CxHy discrimination	(10-4 - 1) ·Pduct	1a.2	1 s	several points	20% during pulse
39. Divertor Helium density	nHe		1E17 - 1E21 m-3	1a.2	1ms	-	20%
40. Fuel ratio in divertor	nH/nD		0.01 - 100	2	100ms	integral	20%
	nT/nD		0.01 - 10	2	100ms	integral	20%
18. Gas pressure and composition in main chamber	Gas pressure		1E-4 - 1 Pa	1a.2	1 s	several points	20% during pulse
19. Gas pressure and composition in vacuum ducts	Gas pressure		1·10-4 - 20 Pa	1a.2	100 ms	several points	20% during pulse
16. Divertor operational parameters	Gas pressure		1E-4 - 20 Pa	1a.2	50 ms	several points	20% during pulse

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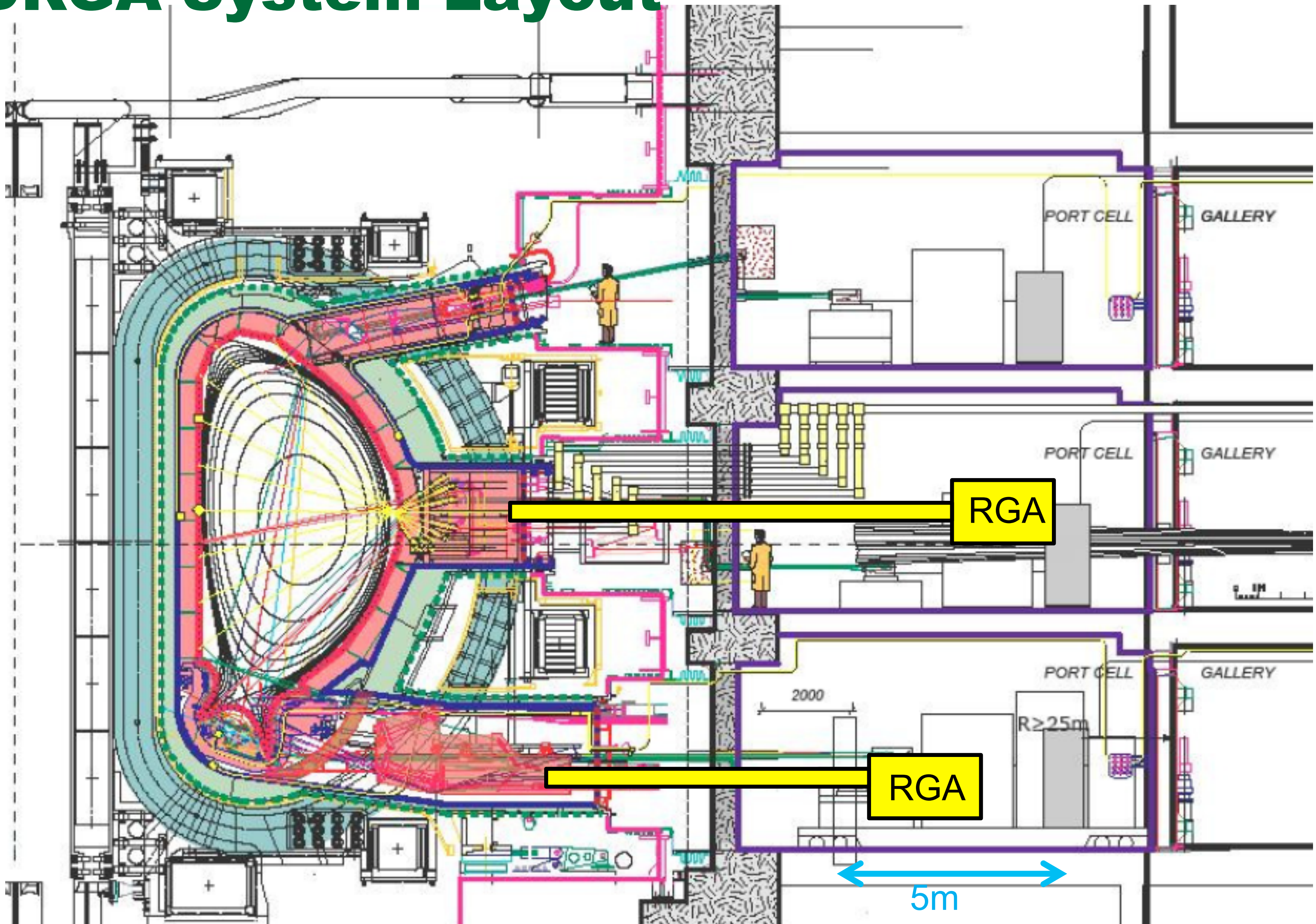
Measurement Requirement Summary

- DRGA measurement requirements
  - Group 1a2 measurements needed for basic machine control.
  - Goal: measure fuel ratios, He, and impurity concentrations
  - 1-100 amu range, with 0.5 amu or better
  - Time response: <1 s in divertor, <10 s at midplane
  - Accuracy (better than): 20% in divertor, 50% in main chamber
- Mass difference D_2 (4.0271 amu) - He (4.0026 amu) = 0.0245 amu
  - Not resolvable by conventional QMS (1-100 amu scan)
  - Utilize OPG (as on JET DT) to optically separate He, D
- Conjecture: "new" ITMS technology can scan 1-150 amu and resolve He/D_2

DRGA System Layout



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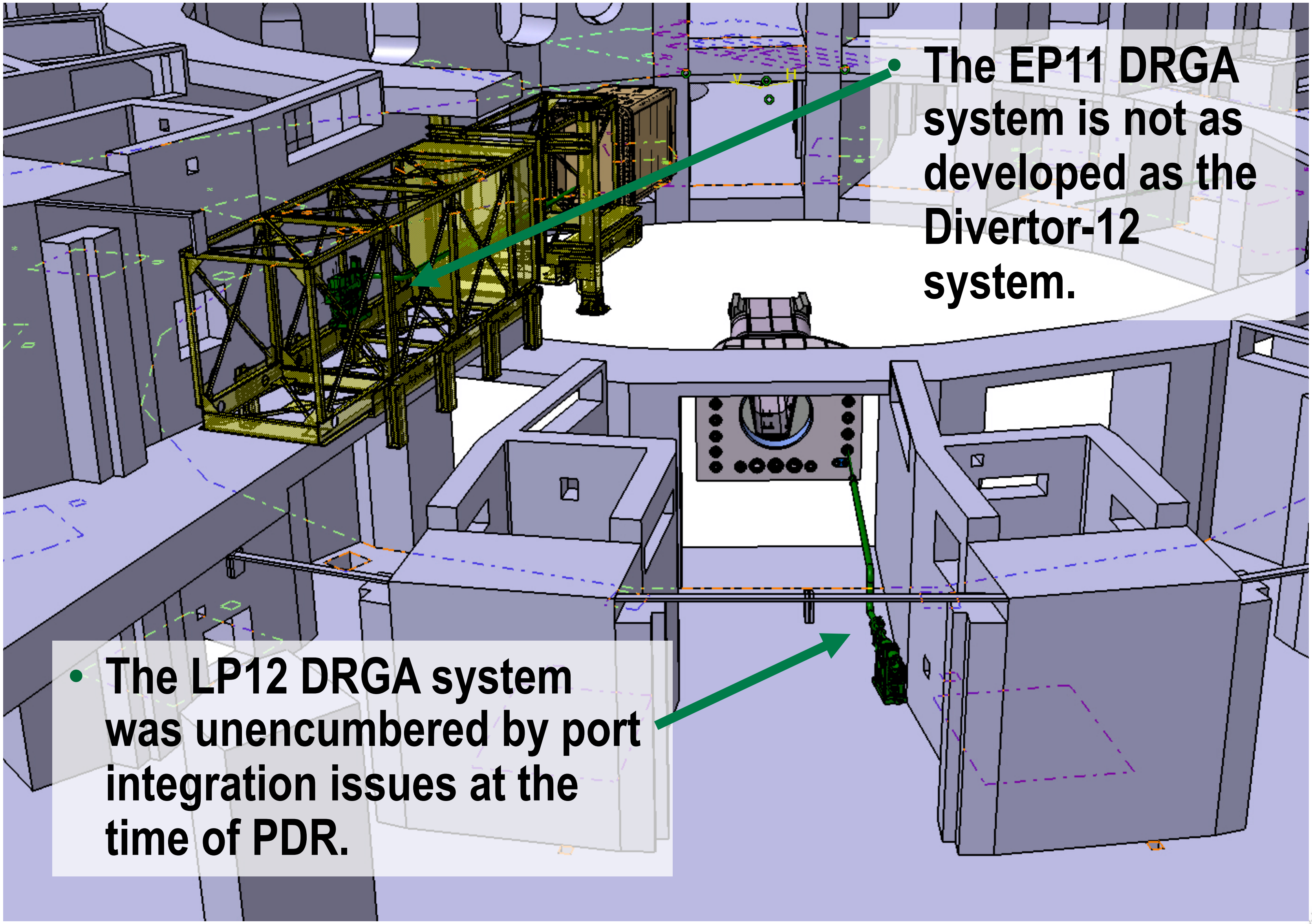
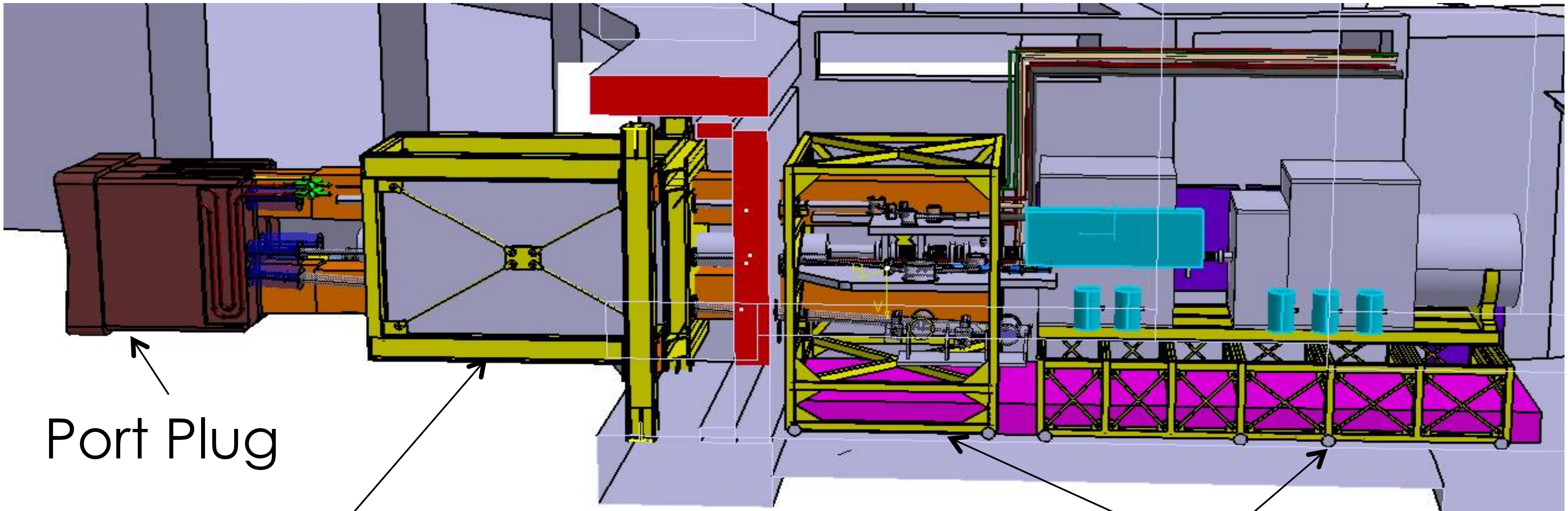
PDR baseline DRGA configuration



- The EP11 DRGA system is not as developed as the Divertor-12 system.
- The LP12 DRGA system was unencumbered by port integration issues at the time of PDR.

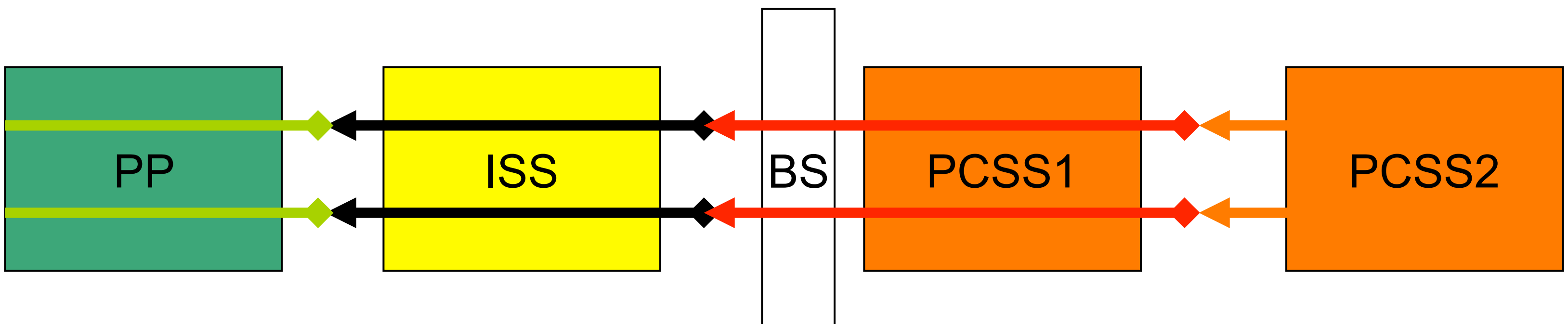
Equatorial Port 11 integration is ongoing



Port Plug

Interspace structure (ISS)

Port Cell structures (PCSs)



Biological Shield

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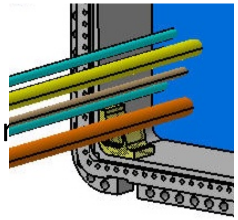
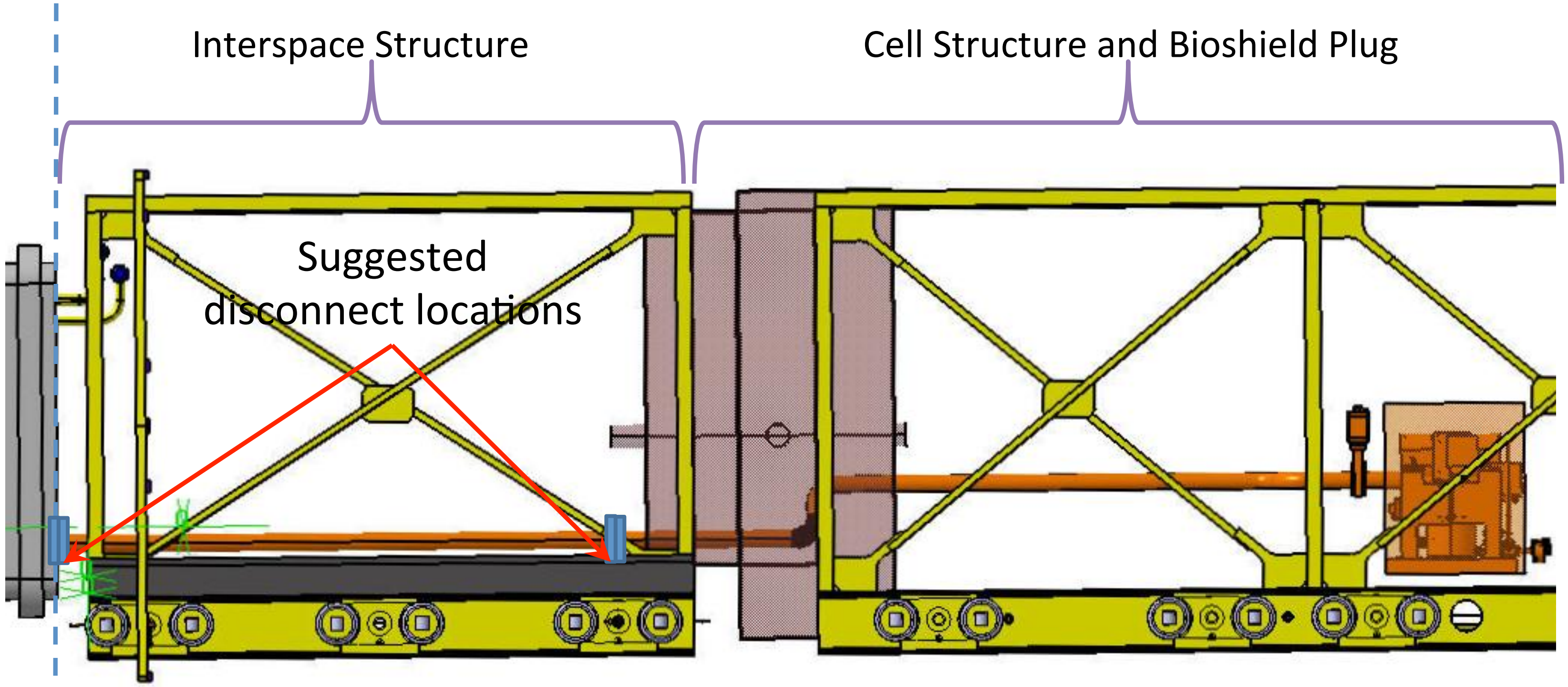
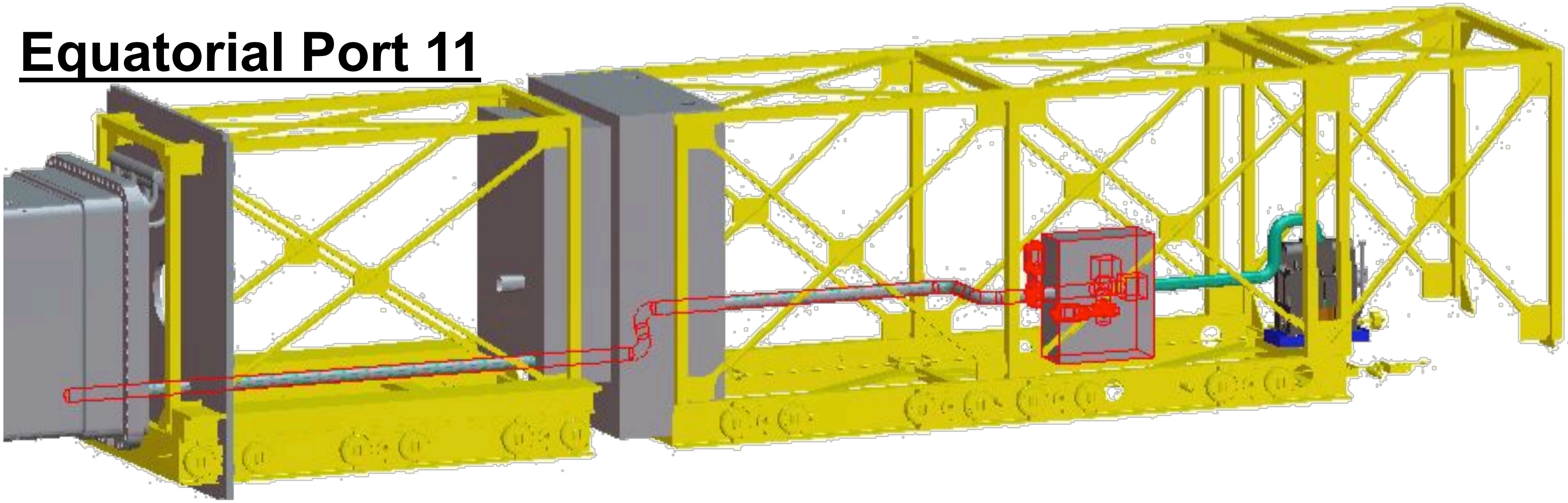
Equatorial Port DRGA

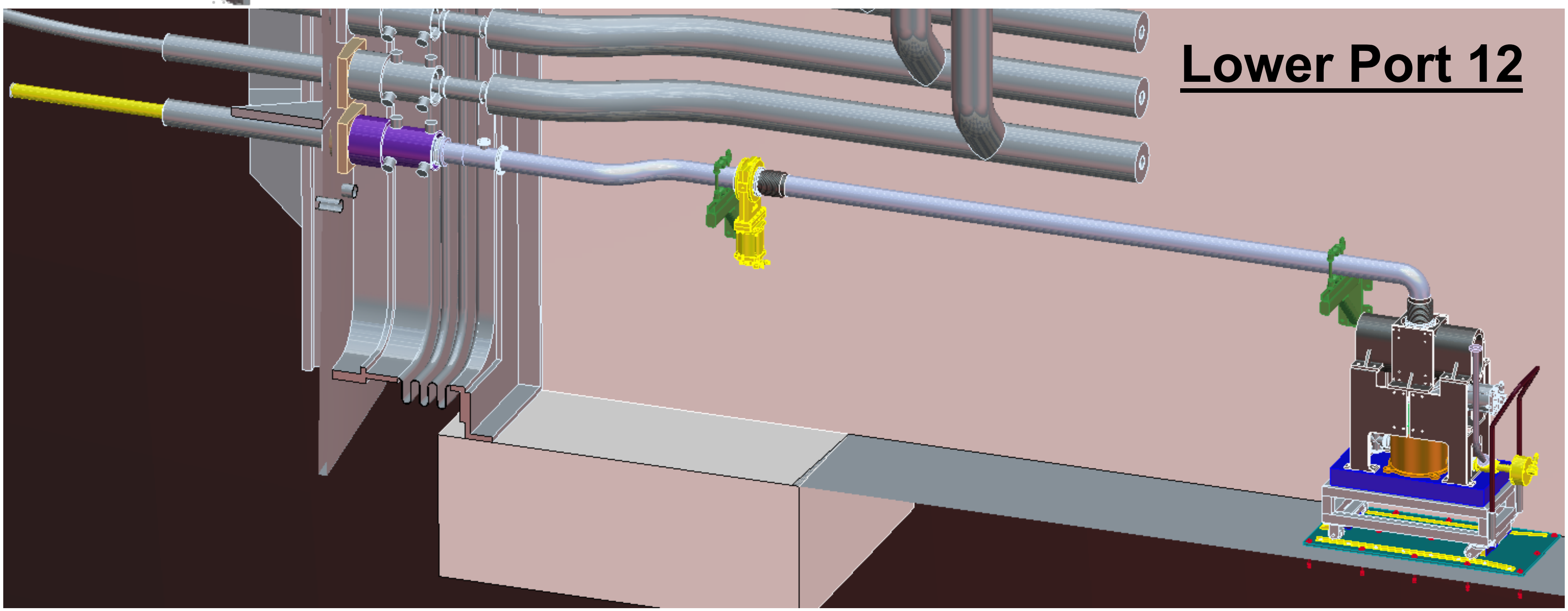




- **The EP11 DRGA system is not as developed as the Divertor-12 system**
  - **EP11 environment evolved substantially during the PD phase, as a result of EP11 Integration Process & PCSS CD activity.**
- **Preliminary Design includes a <u>concept</u> for DRGA in EP11.**

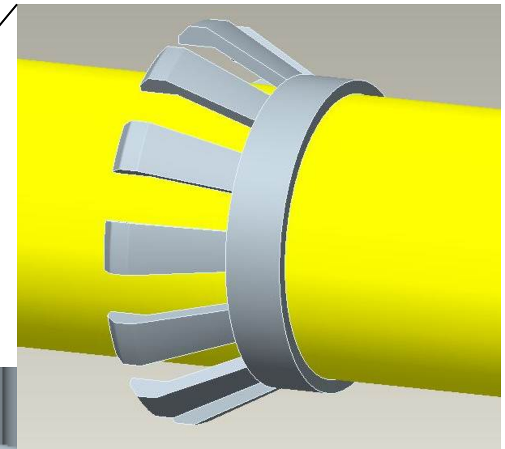
PDR design focused on LP12 DRGA system

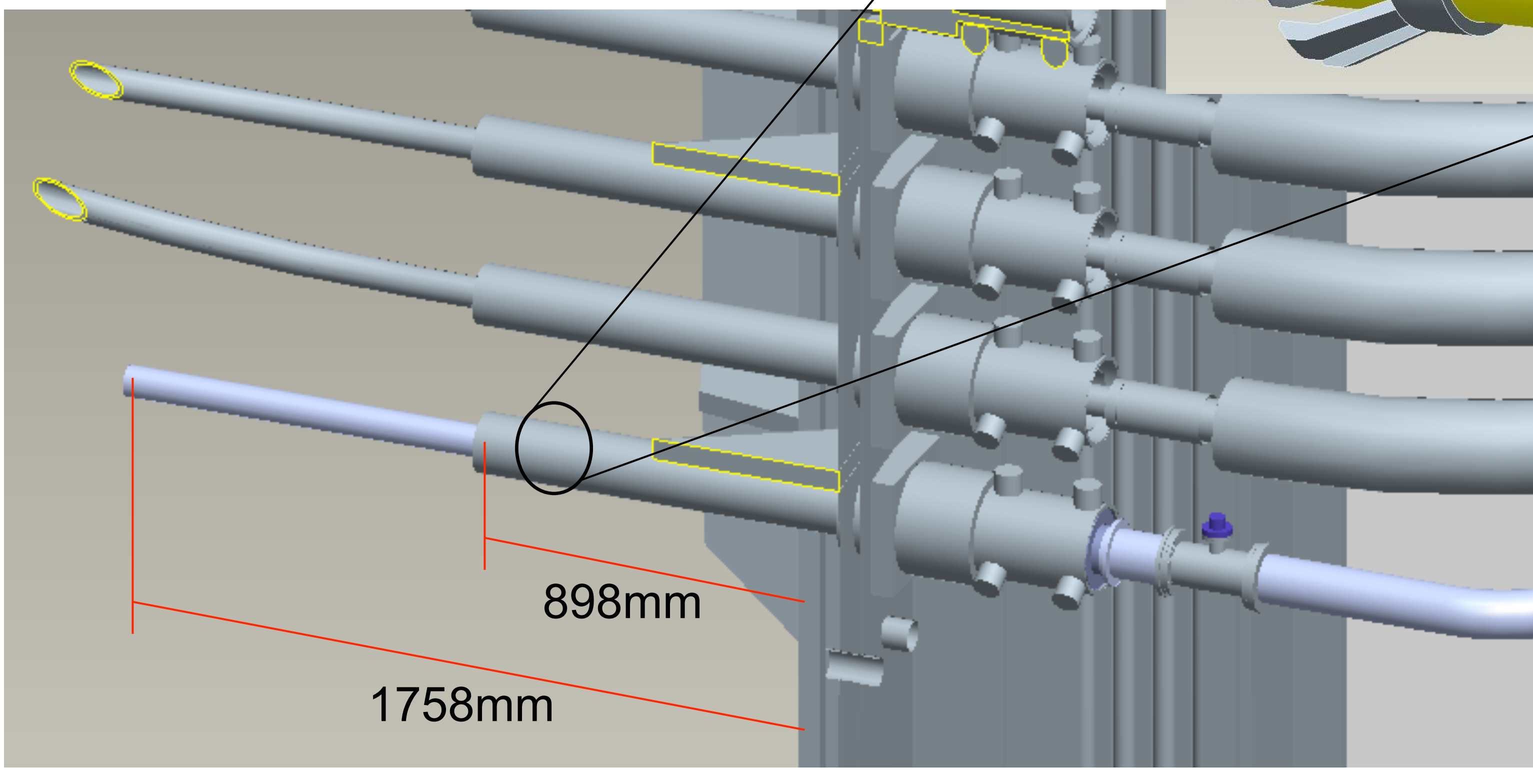




Gas sample tube inside cryostat

- Sample Pipe extends 1.7 meters inside bioshield.
- Thick Wall pipe is sufficient to support its own weight.
- Centering feature provides support from outer pipe.
  - Last 86 cm would still be self-supported.





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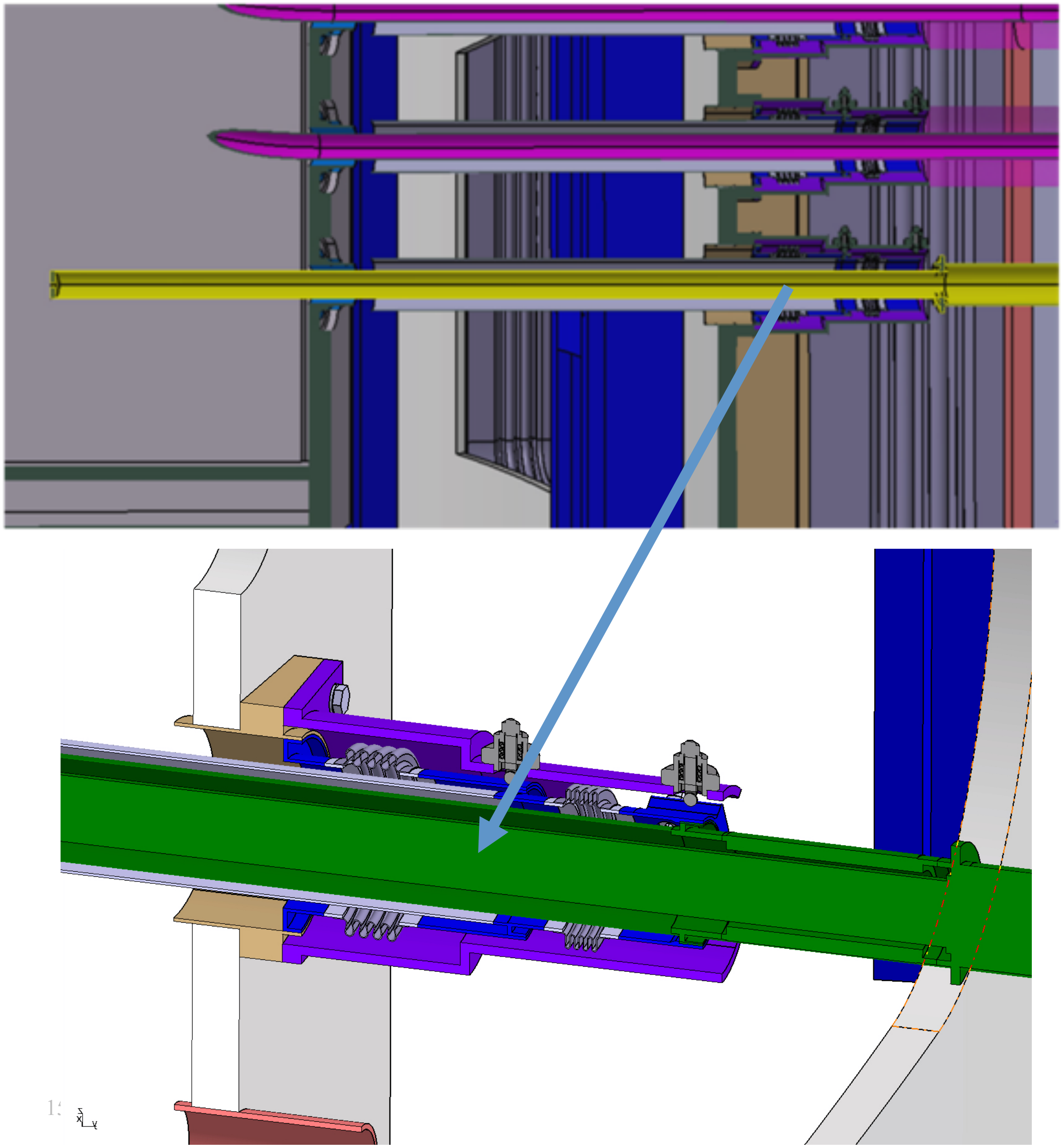
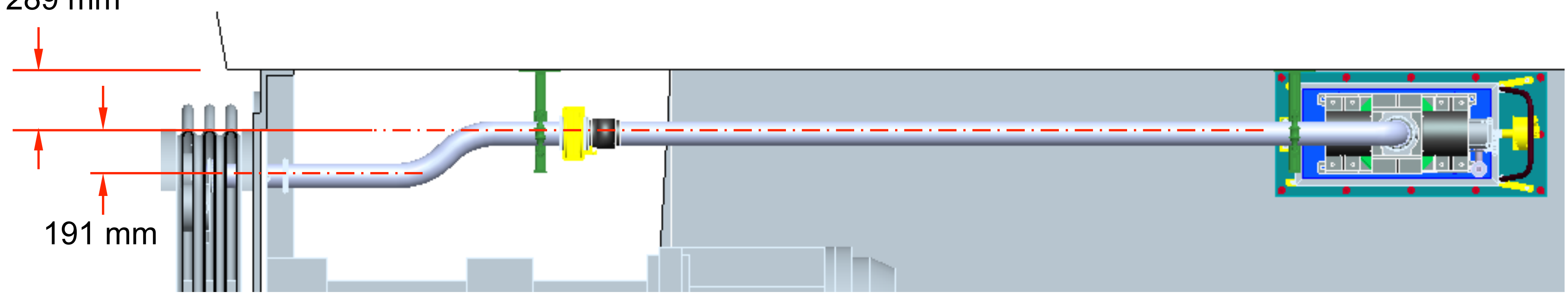
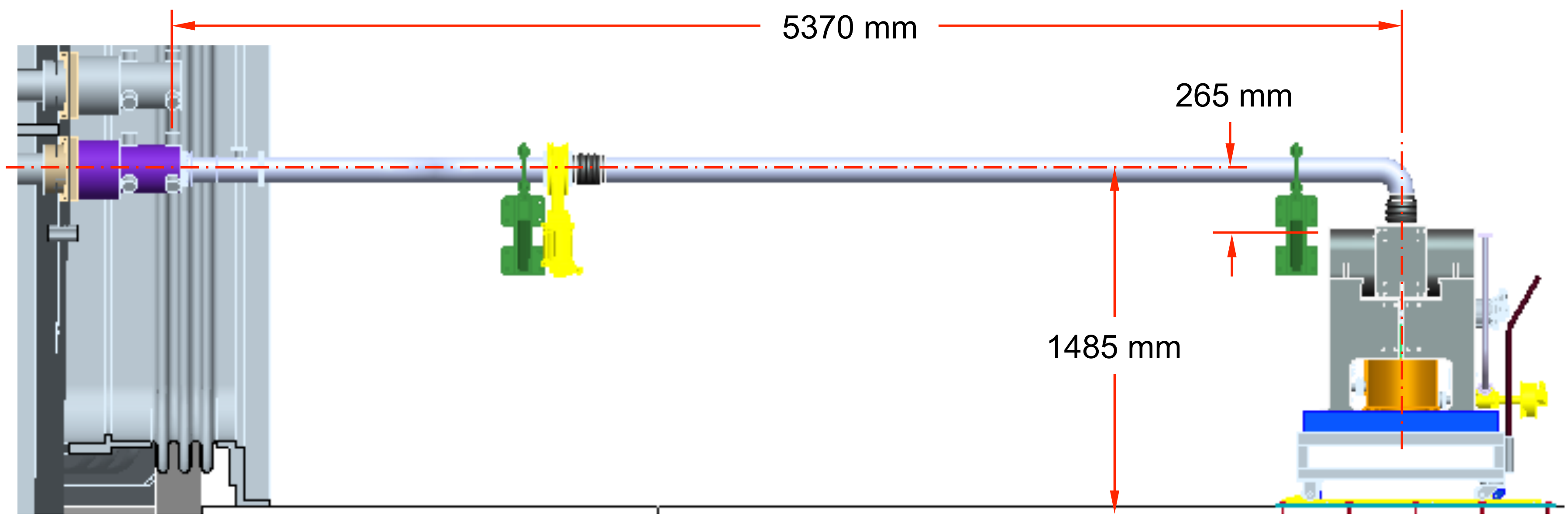
Cryostat Pass-through



- One of the PD challenges, for the Divertor DRGA, was the cryostat pass-through
  - Essential to access the divertor region
- Preliminary Design includes a CONCEPT for
  - Aperture Replacement
  - External heating of the pass-through section of the sampling pipe.

Gas sample pipework in port cell LP12





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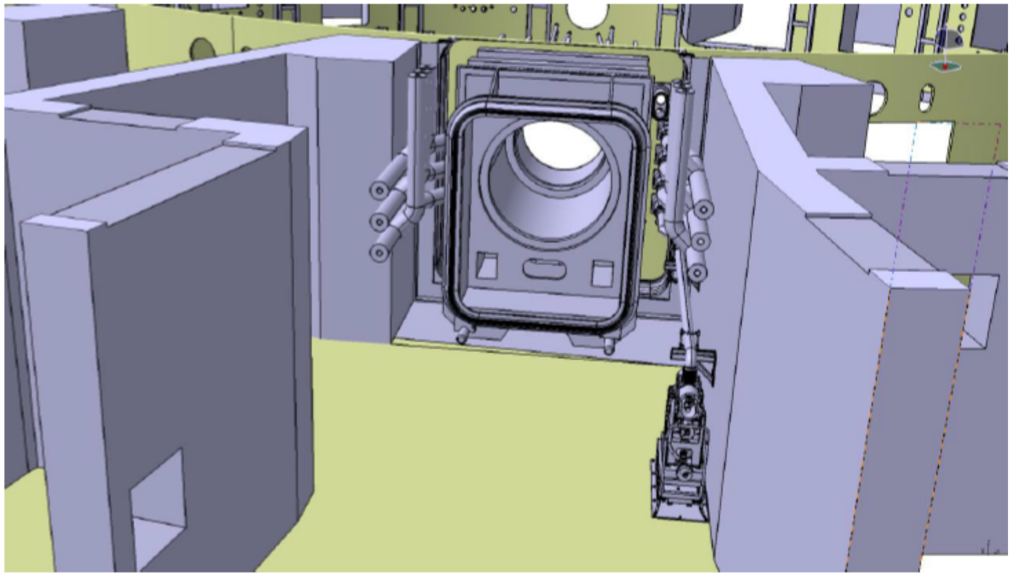
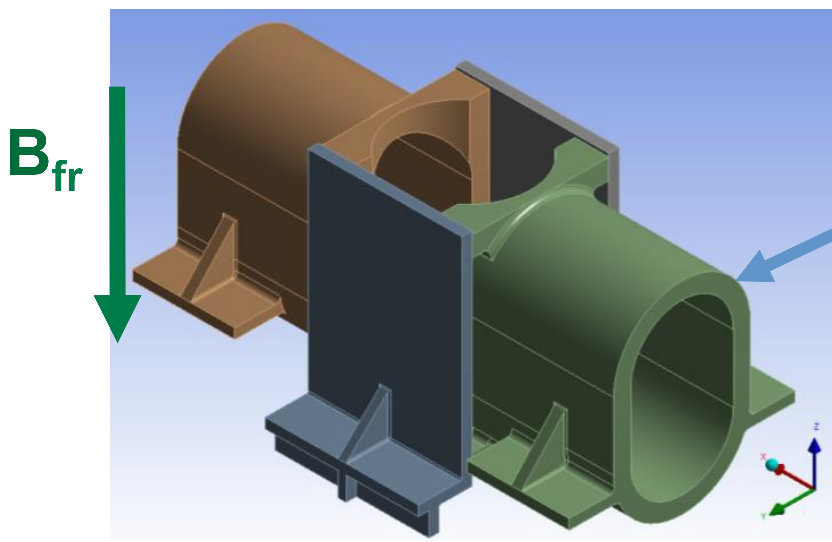
Harsh Environment: Fringing B-fields



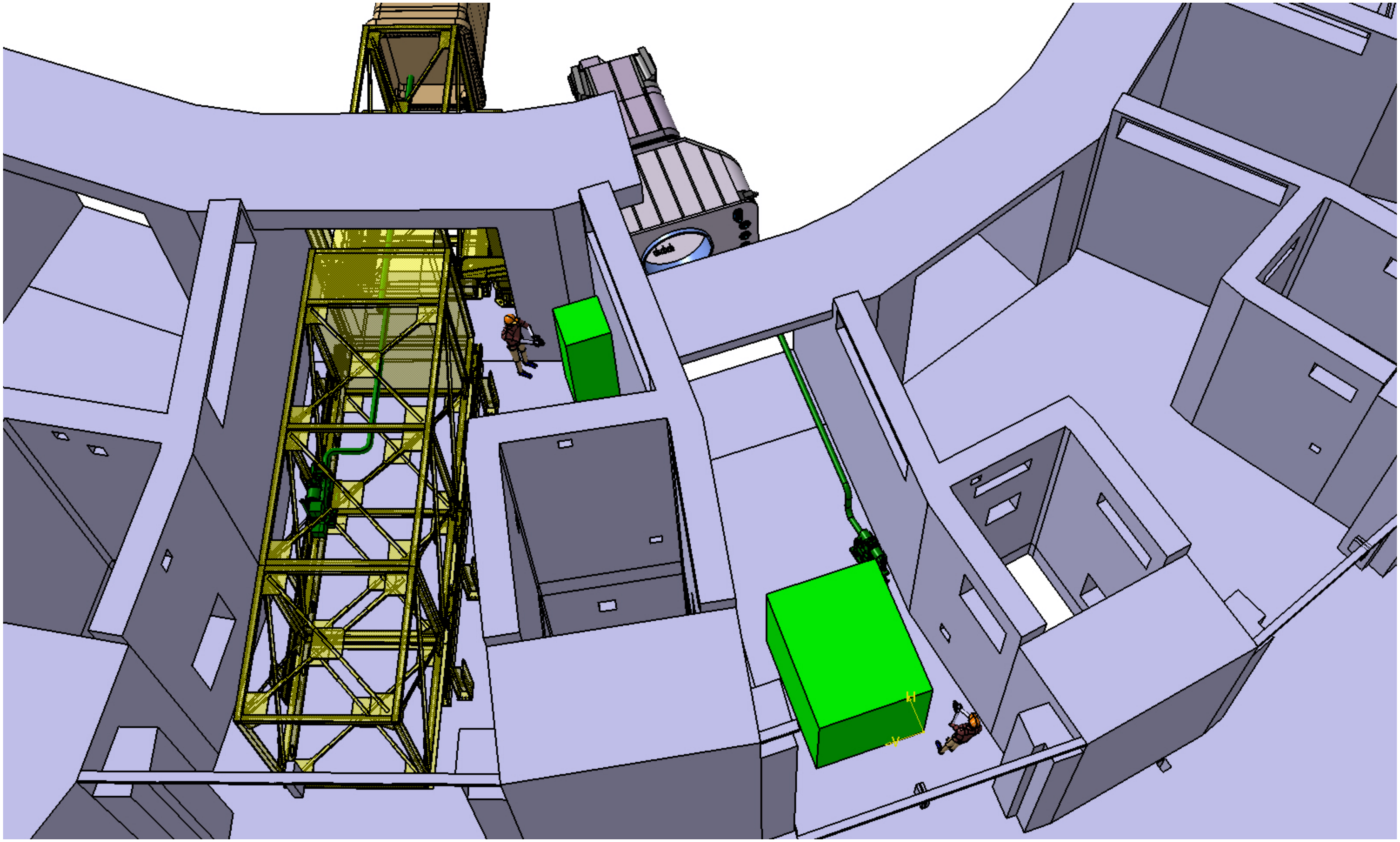


- During operation, instruments in the port-cell are also exposed to fringing magnetic
  - Estimated ~100mT; designing for 150mT
- Most RGA sensors will only tolerate up to 5mT
  - ➔Magnetic Shielding is essential
  - Good news: Substantial experience already (Tore Supra, JET)
  - See Magnetic Effects R&D Report for validation of present concept

Loughlin model estimates for the port-cell radiation dose

- Assuming then ~5,000 hours of operation for ITER, one can estimate a total, accumulated dose in the range of 0.5MGy or 5×10^5 Gy for the lifetime of the machine
- **Main impact for DRGA is lifetime of electronics:**
- Commercial electronics can only take up to 30 Gy (cumulative dose) before showing measurable deterioration.
  - **This still means that in the port-cell environment, we need ~10^5 attenuation or 28cm of lead (assuming N-16 γ' s).**
- **But RGA sensors need to be in the port-cell to meet measurement requirements!**

Current cubicle allocation unacceptable



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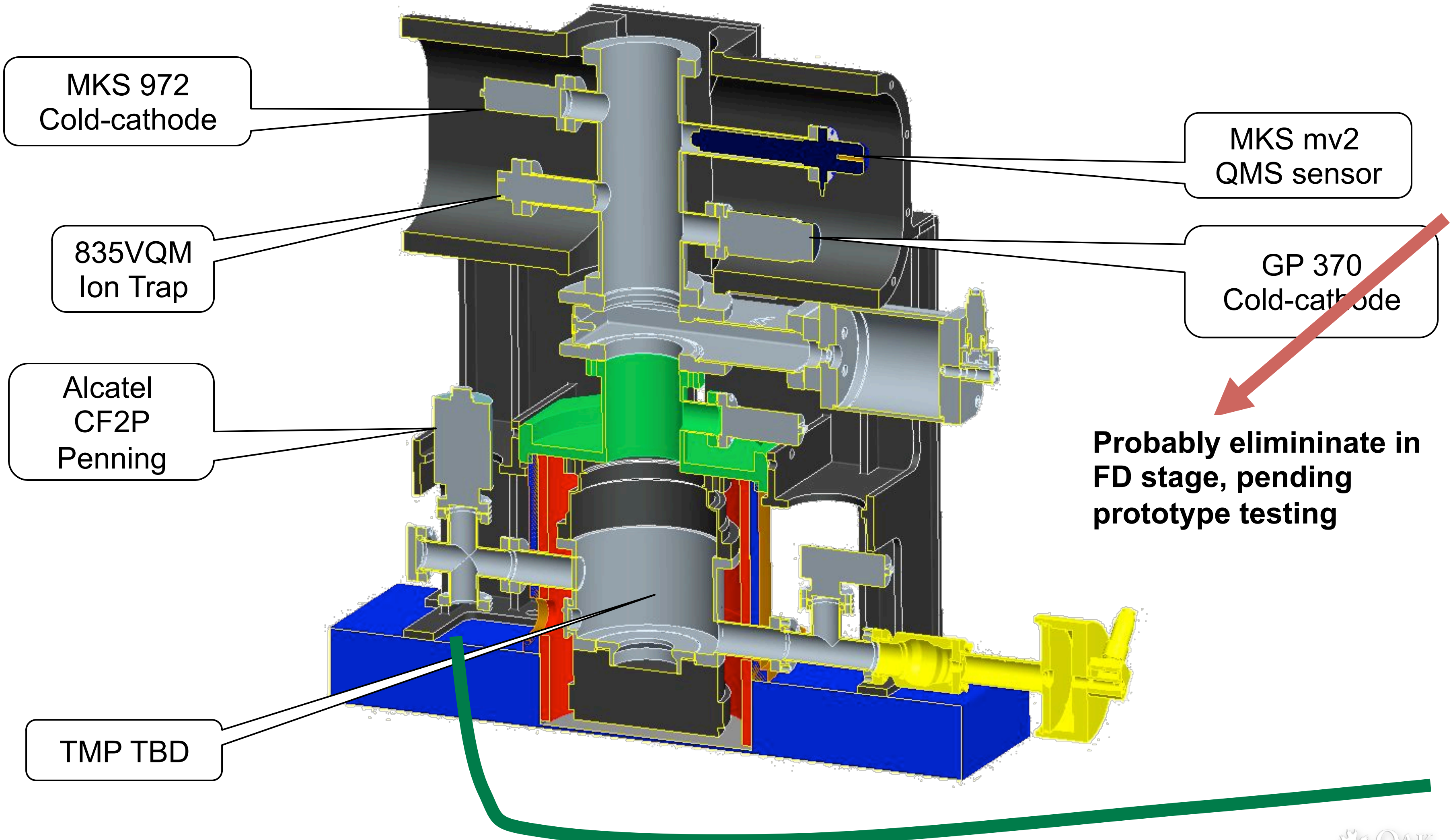
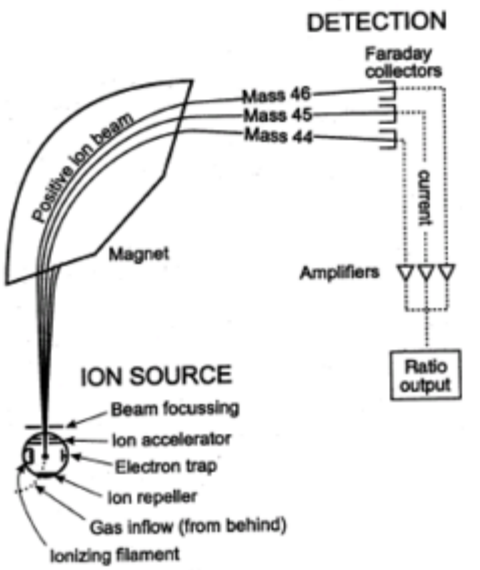
Sensor selection will be further validated by prototype testing

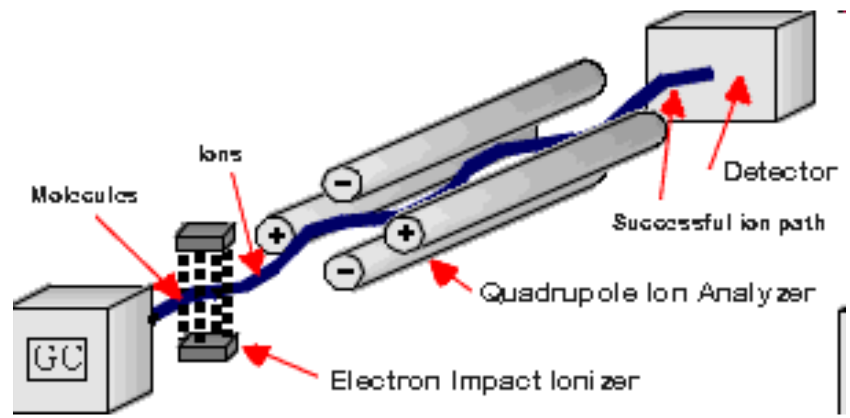


Mass Spectrometer Variations

Magnetic Sector

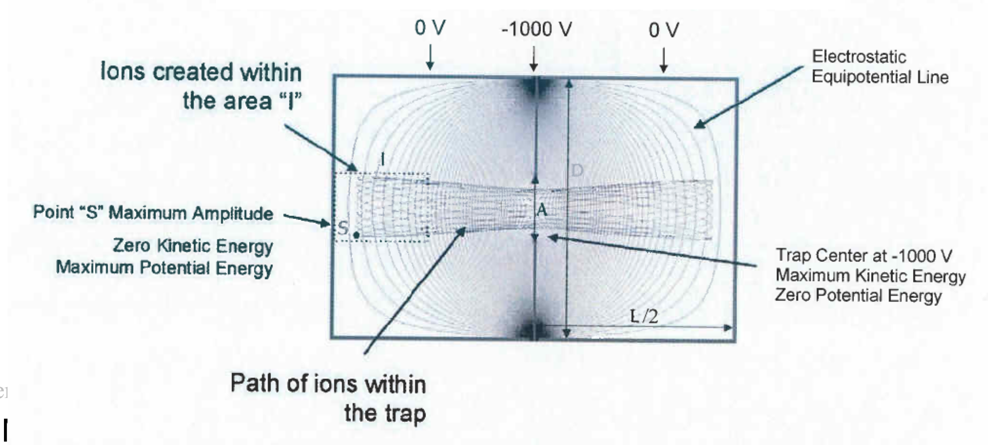


Quadropole Mass Spec.

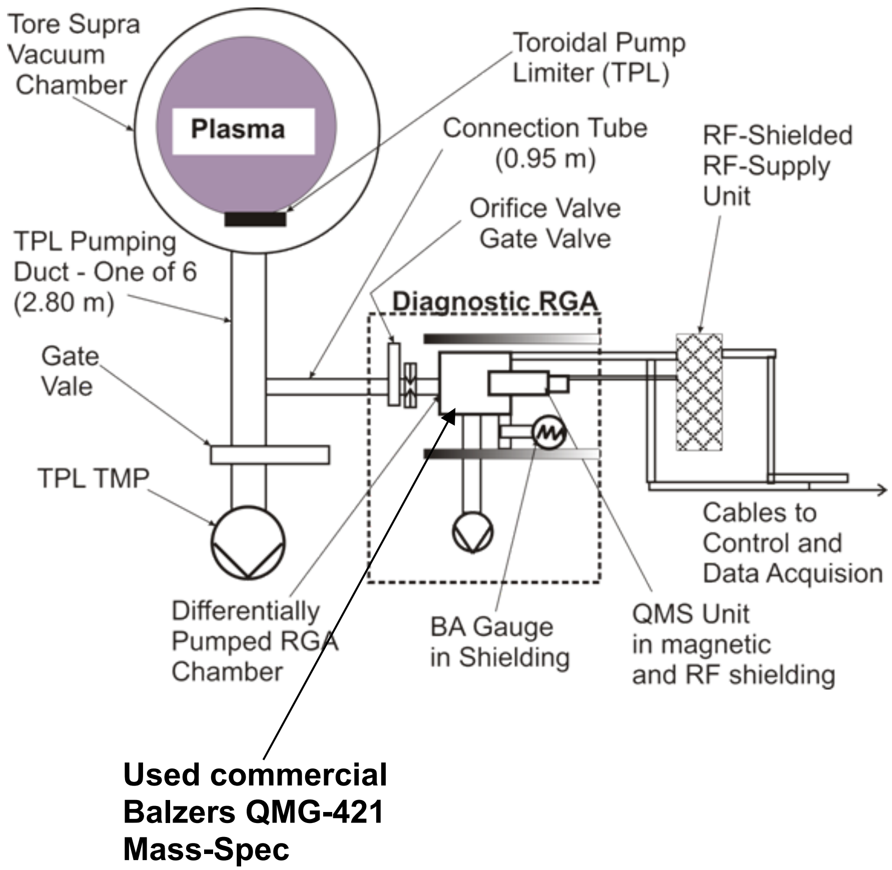


Ion Trap Mass Spec.

(Emerging Technology)



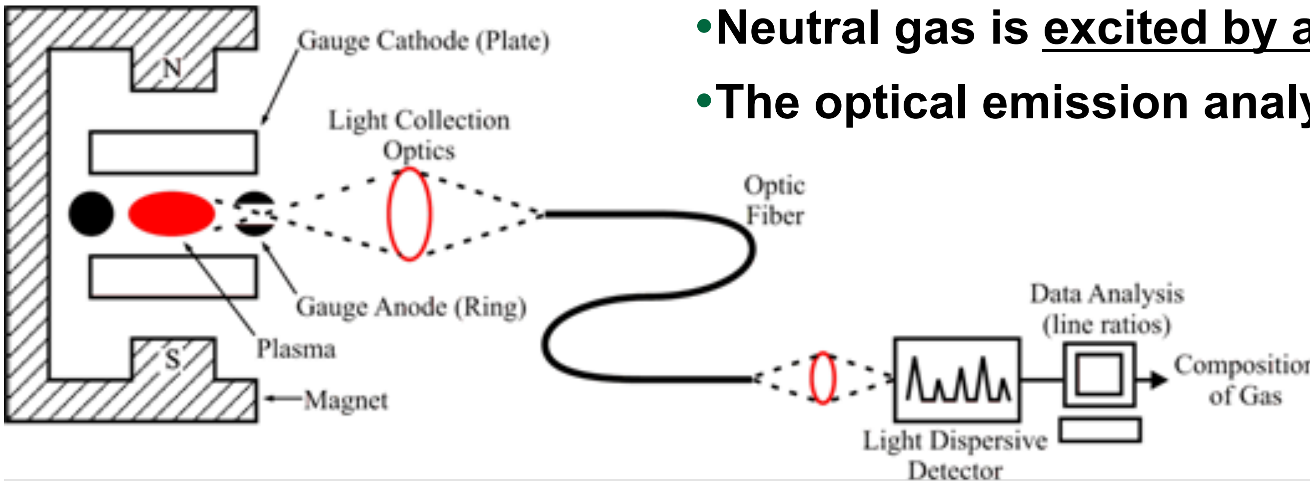
Precedent of Continuous Mass-Spec DRGA on a Tokamak



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

- Tore Supra used a QMS DRGA (magnetically + EMI) shielded for operation during plasma operation**
  - Continuous data acquisition and data transfer (15 channels/ 32ms)
  - Successfully used with shots up to 6 min
- Similar system currently on JET

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*

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

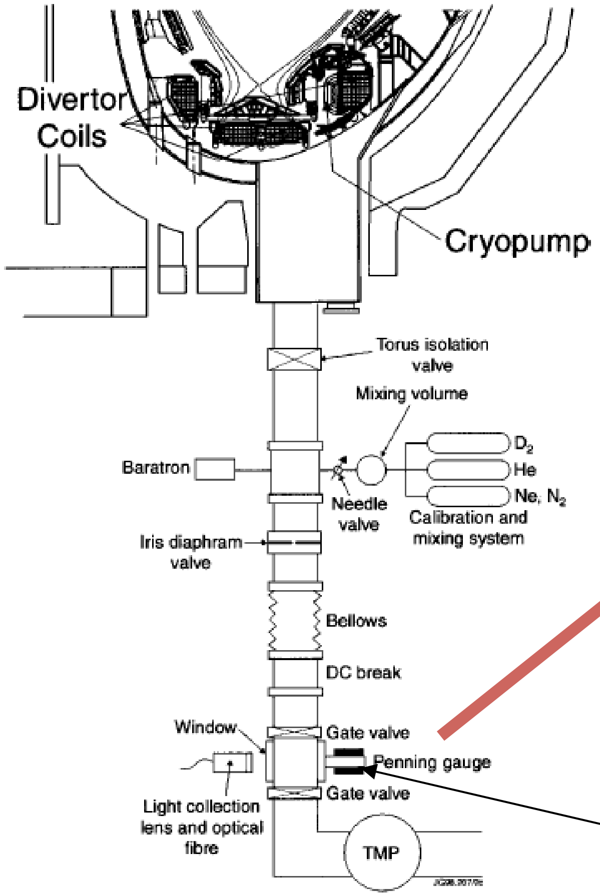
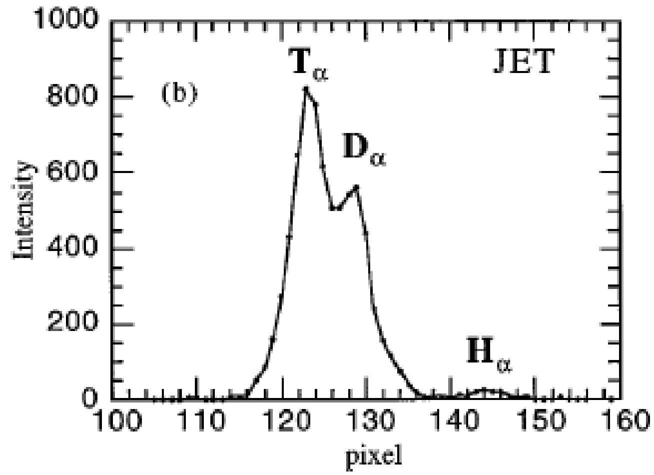
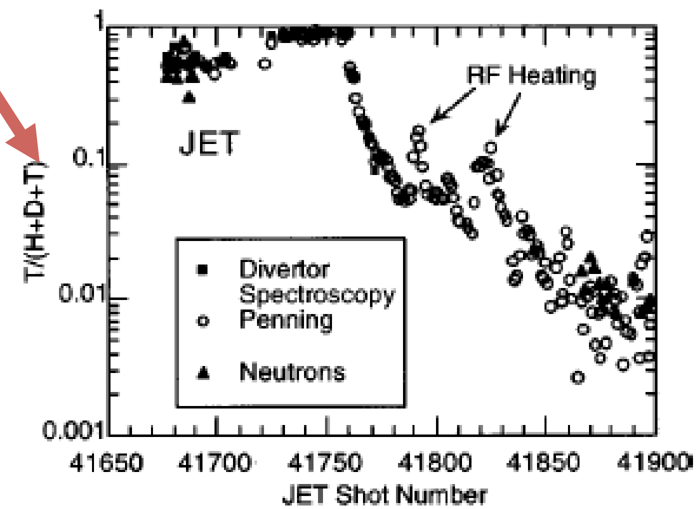


FIG. 1. Penning gauge diagnostic system for the measurement of the tritium concentration in the divertor of JET.



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

OGA: Uses commercial Alcatel CF2P Penning Gauge Tube**



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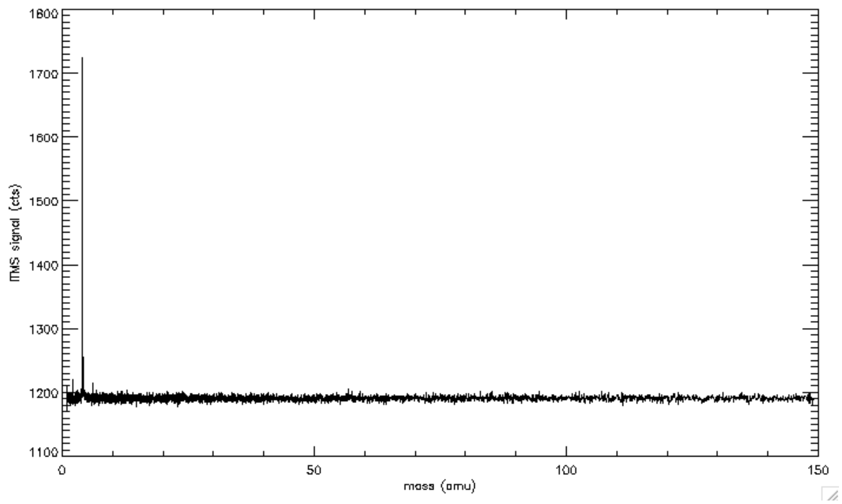
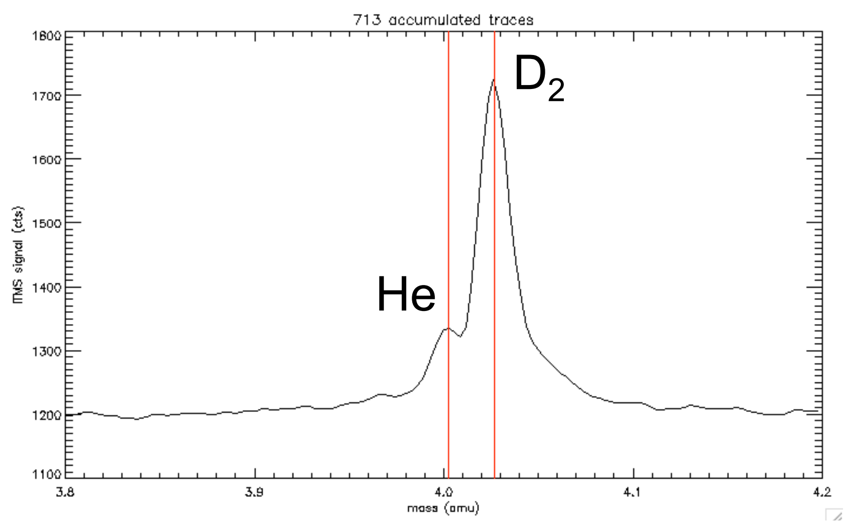
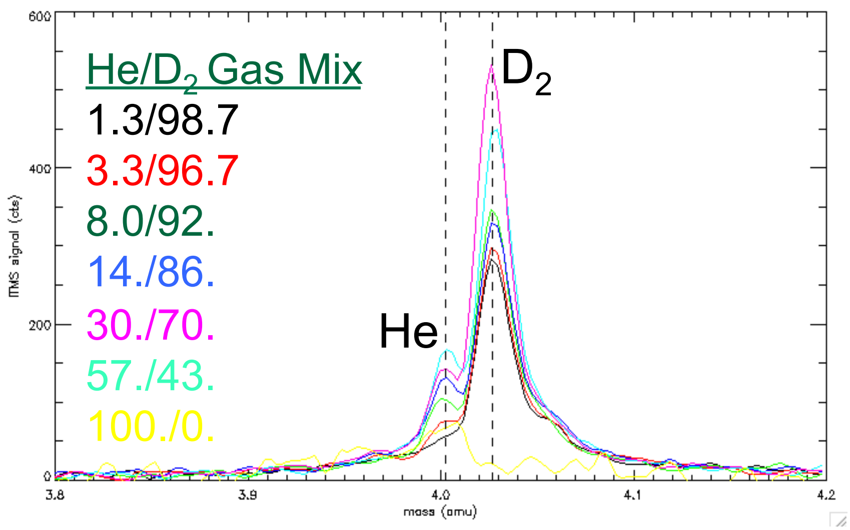
Sample mass spectra from ITMS





- ITMS mass scan covers a full range from 1-150 amu
  - Exceeds ITER measurement requirement
- Single scan achieved in 85 ms
  - Noise reduced by ensembling multiple scans
  - Data shown is ~1 minute avg.
- Zoom in on "mass 4" region shows that He and D_2 mass peaks are resolved (50/50 mixture at P~$8x10^{-6}$ Torr)

He/D_2 discrimination possible at 1% He



- Percentage of He gas in D_2 gas stream was varied in CVC:
  - Target: 0, 1, 2, 5, 10, 20, 50, 100%
- If a SNR~1 can be tolerated, then even a ~1% concentration of He in D_2 can be measured within the 10 s measurement requirement for E11 DRGA.

Desire: ITMS to perform as well as OPG, and as well as conventional QMS

OPG & ITMS

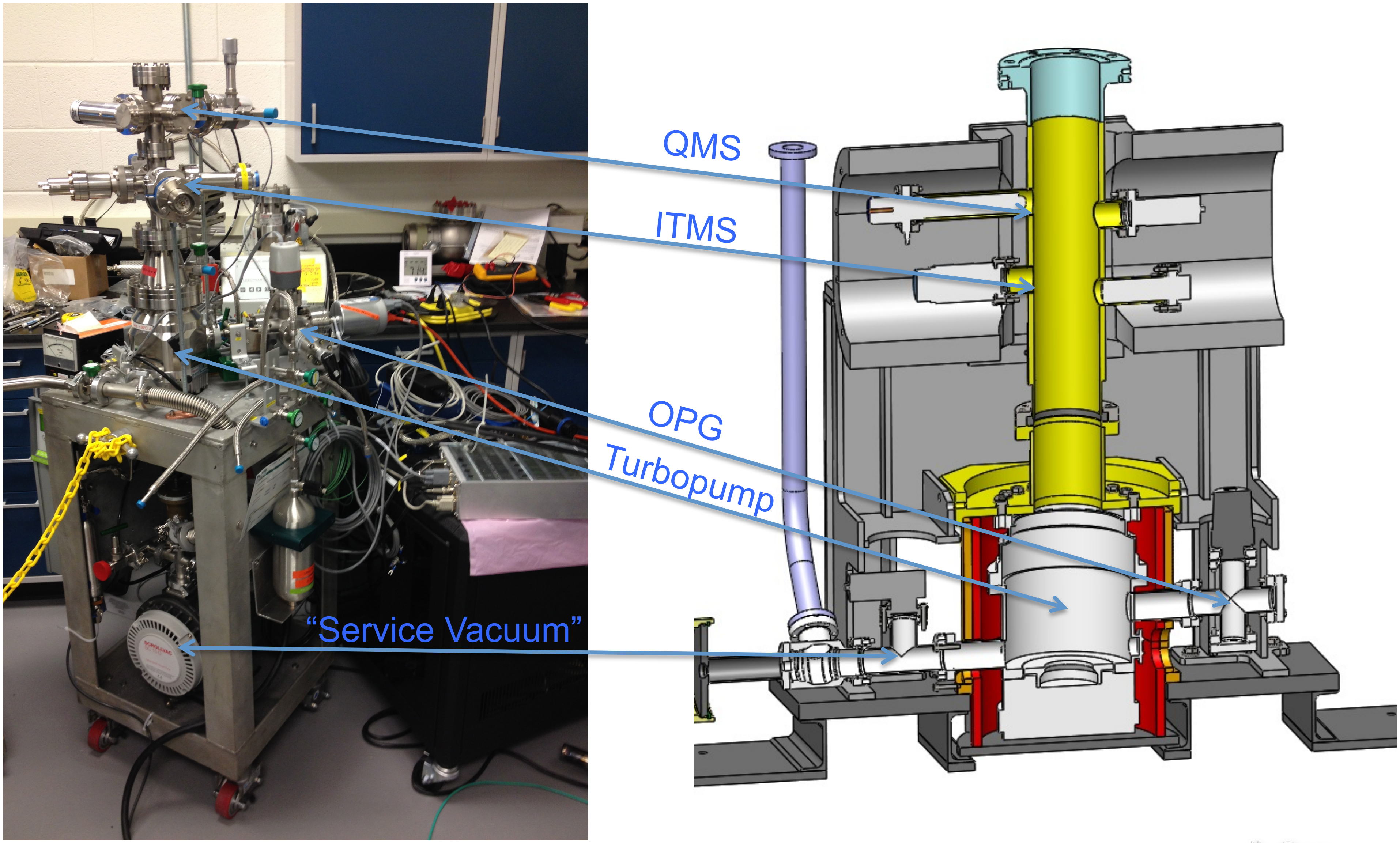
- Previous slide is example of OPG monitoring of relative concentration of He and D_2
- OPG was not calibrated for these tests
- OPG was not operated simultaneously with ITMS

QMS & ITMS

- Conventional QMS cannot resolve He/D_2 at full (1-100 amu) mass scan rates.
- ITMS also scans > 1-100 amu range
- Claim by MKS that MV-2 QMS can resolve He/D_2

- Cross-comparison tests of OPG & ITMS & QMS to be performed on fully calibrated prototype DRGA

DRGA prototype development



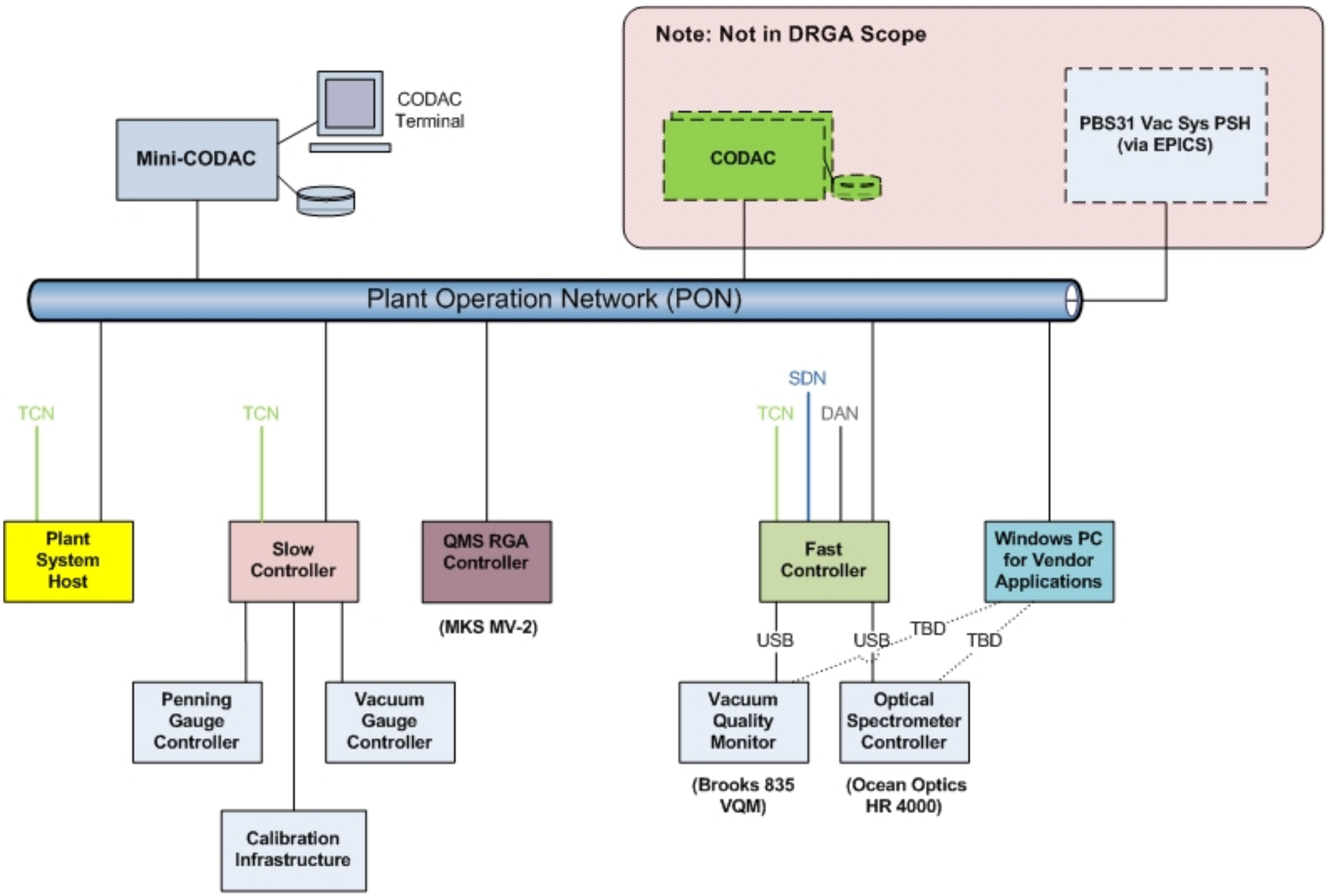
Documents Delivered

/ 55.G4 - RGA / Incoming Documentation (DA > IO) / Planned Documentation / PDR related documentation

Name	date	Date
2012.04_PA_R&D_Plan_5.5.P1.US.01_55.G4_RGA (ITER_D_7GH226 v1.0)	29 Mar 2013 17:43	23 Apr 2012
2013.03_PA_Risk and Mitigation Plan_5.5.P1.US.01.55.G4_RGA (ITER_D_DVVK6X v1.0)	02 Apr 2013 11:04	29 Mar 2013
Aperture Replacement Strategy Report (ITER_D_D3ZT7C v1.0)	01 Apr 2013 16:51	01 Apr 2013
Assessment of Penning OGA operation with the Penning tube mounted between stages of Turbo Pump (ITER_D_DW3FGU v1.0)	29 Mar 2013 09:52	28 Mar 2013
Chit_tracking_table_5.5.P1.US.01_55.G4_RGA (ITER_D_CUMGSG v0.0)	29 Mar 2013 11:42	29 Nov 2012
DDD for PD stage of diagnostic RGA (ITER_D_EH6N29 v1.0)	03 Apr 2013 20:44	28 Mar 2013
Design Compliance Matrix (ITER_D_F92TXM v1.0)	29 Mar 2013 11:08	29 Mar 2013
Diagrams and Drawings	19 Dec 2012 21:32	
DRGA I&C Integration Plan (FAT and SAT Scenarios) (ITER_D_FZTHXJ v1.0)	28 Mar 2013 22:27	28 Mar 2013
DRGA I&C Software Design Description (ITER_D_F933J9 v1.0)	28 Mar 2013 22:17	28 Mar 2013
DRGA Software Requirement Specification (ITER_D_F84LHC v1.0)	28 Mar 2013 22:10	28 Mar 2013
Electrical Power and Grounding Requirements (ITER_D_DWYMQY v1.0)	03 Apr 2013 20:36	28 Mar 2013
Electromagnetic Forces Analysis Report (ITER_D_EAUDY4 v1.0)	03 Apr 2013 20:25	28 Mar 2013
Interface documents	19 Dec 2012 21:35	
Ion-trap mass spectrometer testing for the ITER DRGA (ITER_D_DCNXTY v1.0)	01 Apr 2013 16:11	01 Apr 2013
ITER DRGA Calibration Procedure (ITER_D_DX8JZM v1.0)	03 Apr 2013 20:41	28 Mar 2013
Load Specification for PDR (ITER_D_EAYTDW v1.0)	03 Apr 2013 20:38	28 Mar 2013
Report on Magnetic Shielding Calculation for the ITER DRGA (ITER_D_DWYUUL v1.0)	29 Mar 2013 12:20	29 Mar 2013
Report on Radiation Shielding Calculation for the ITER DRGA (ITER_D_DHXJDM v1.0)	29 Mar 2013 12:25	29 Mar 2013
Seismic Response Analysis (ITER_D_EAWR34 v1.0)	03 Apr 2013 20:34	28 Mar 2013
Structural Integrity Report (ITER_D_EAXVST v1.0)	03 Apr 2013 20:39	28 Mar 2013

No. of Records : 21

DRGA I&C Architecture



History of DRGA project

- 2007: Diagnostic Systems design review
- July 2010: CDR for DRGA (W. Gardner, *et al*.; ORNL)
- September 2011: PA signed (5.5.P1.US.01) between ITER IO and US DA (IDM: D2G28K)
  - Official begin to PD phase
- November 2011: ORNL QP established as supplier to US DA (ITER_D_57384X)
- December 2011: MOA signed between ORNL-PPPL
- R&D, Preliminary Design, etc.
- April 2013: PDR
  - Documentation (IDM: D2G28K), Presentations (IDM: ENR3XF)

CAS Milestones for DRGA

ActivityID	Activity Name	Finish
USDA0604001400	IO - RGA CAS - Preliminary Design G4 Residual Gas Analyzers Approved by IO	10-May-13
USDA0604002400	IO - RGA CAS - Final Design Review G4 REsidual Gas Analyzers Approved by IO	13-Jan-14
USDA0606002944	IO - RGA CAS - Manufacturing Readiness Review and MIP Approved by IO	21-Aug-14
USDA0607016730	IO - RGA CAS - Delivery of Vacum Interface G4 Residual Gas Analyzers EQ11 to Integration Site	2-Mar-15
USDA0607020030	IO - RGA CAS - Delivery of G4 Residual Gas Analyzers EQ11 to Integration Site	7-Dec-16
USDA0607023530	IO - RGA CAS - Delivery of G4 Residual Gas Analyzers LP12 to Integration Site	31-Jul-17
USDA060702750	IO - RGA CAS - Manufacture G4 Residual Gas Analyzers EQ11 Complete	2-Sep-15
USDA060703200	IO - RGA CAS - Factory Acceptance Testing G4 Residual Gas Analyzers EQ11 Approved by IO	25-Aug-16
USDA060704050	IO - RGA CAS - Manufacture G4 Residual Gas Analyzers LP12 Complete	31-Aug-15
USDA060704700	IO - RGA CAS - Factory Acceptance Testing G4 Residual Gas Analyzers LP12 Approved by IO	21-Jun-16
USDA060L011500	IO - RGA CAS - Successful Agreement of Commissioning Work Plan	13-Jan-14

- PDR – Apr. 2013
- FDR – by Jan. 2014
- MRR – by Aug. 2014
- FAT – by Aug. 2016
- Delivery to site – by July 2017

PCR impact of ~2 years

- Peer Review – Feb. 2014
- FDR – by May 2015
- MRR – by Aug. 2016
- FAT – by Aug. 2018
- Delivery to site – by July 2019

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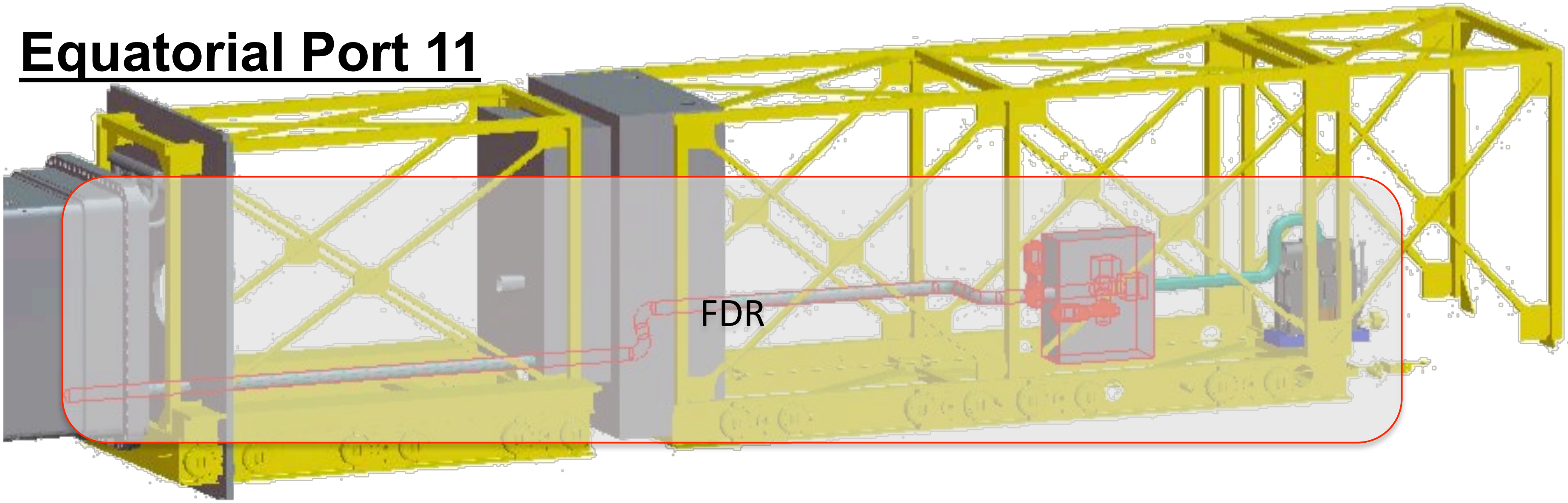
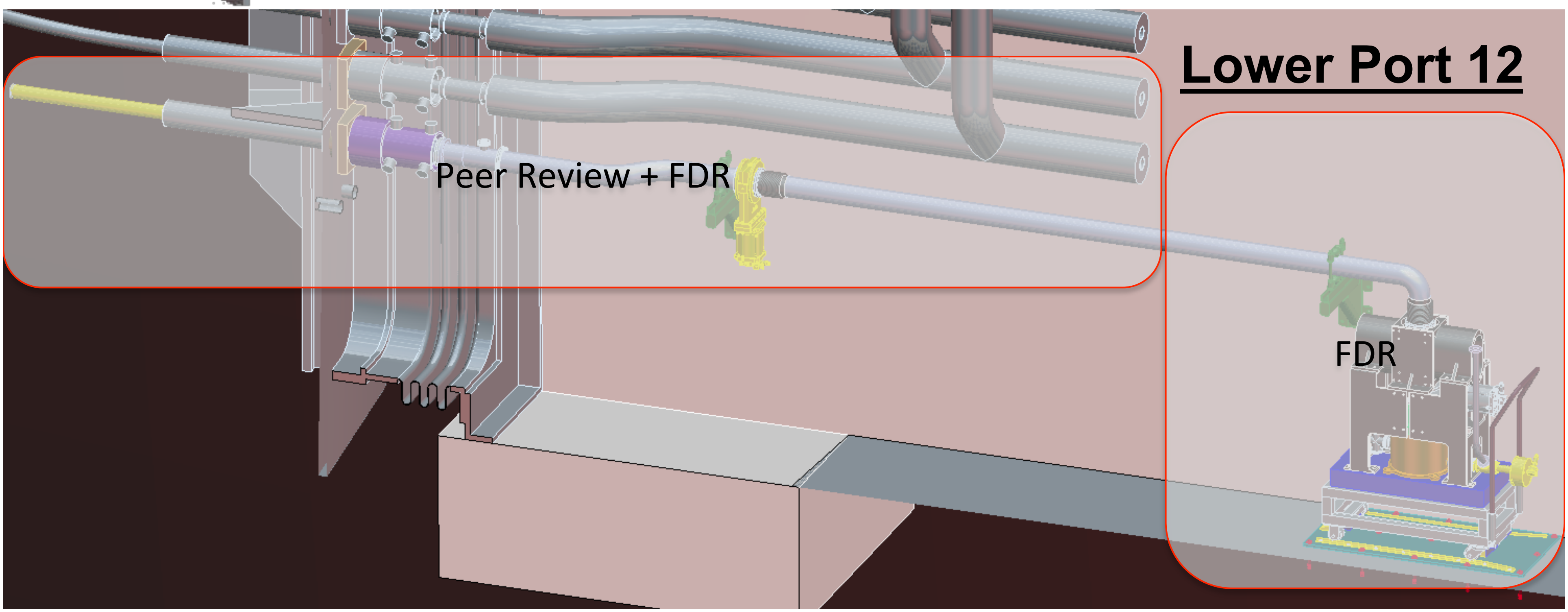
Strategy for Final Design phase

- FDR date ~May 2015 following PCR.
- ITER design issues impacting DRGA design
  - Approved double-seal flange designs
  - Finalized TMP selection (~Summer 2014)
  - EP11 port integration baseline (???)
  - LP12 port integration: glove box/pipe extractor & PCR 502 (???)
  - Outstanding DRGA R&D (~Summer 2014)
- Conjecture: delay DRGA FDR (with PCR)
  - "Peer Review": Mar. 2013; mechanical design of LP12 system needed for port integration
  - FDR: ~May 2015; allows time for E11 port cell design to stabilize; will include all components of LP12 and E11.

Visual representation of FDR1/FDR2 boundary

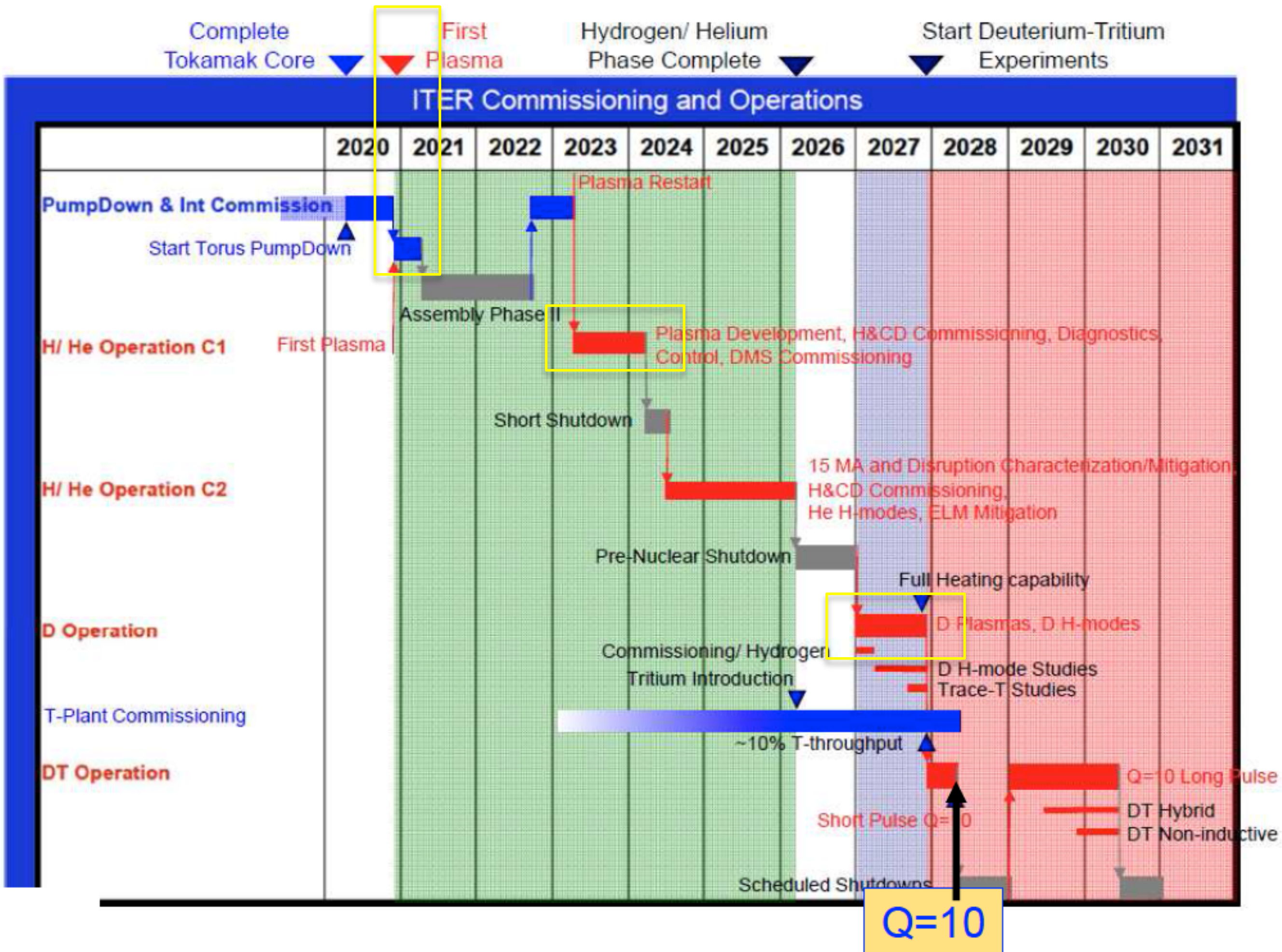




ITER schedule from G. Sips, JET GPM5

Motivation – The ITER Research Plan

The ITER Research Plan: Allows less than two years to go from first deuterium operation, to Q=10 in DT by early 2028.



ITER-IO, 2012

Summary and Conclusions

- To first order, the project is "on schedule and on budget", assuming a timely completion PDR Cat 1 Chits.
- Some R&D tasks have been delayed.
  - Those R&D tasks will be completed in the Final Design phase.
- ITER port cell design is impacting ability of DRGA system to meet FDR milestone.
  - We propose delaying the FDR (with PCR) so that "front end" components reach "Peer Review" earlier, allowing port cell design to formalize.
- Three sensor design allows for measurement redundancy if any 1 gauge fails.
- Two complete DRGA systems are expected to be delivered to ITER in Summer 2019.

Reprints

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