Commissioning of the In-vessel Calibration Light Source at JET

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Oak Ridge National Laboratory

ORNL Fusion Energy Science & Technology Seminar
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Fusion Energy Division

Oak Ridge National Laboratory

Managed by UT-Battelle for the Department of Energy

Thanks to . . .

- **Oak Ridge National Lab., USA**
  - Don Hillis, Steve Meitner
- **Culham Science Centre, UK**
  - Klaus-Dieter Zastrow, Mike Stamp, Garry Kaveney
  - Ian Hassall, Chris Belcher, Colin Stunell
- **Labsphere, Inc., USA**
  - Dan Scharpf, Rich Montminy, David Herr, Yang Wang

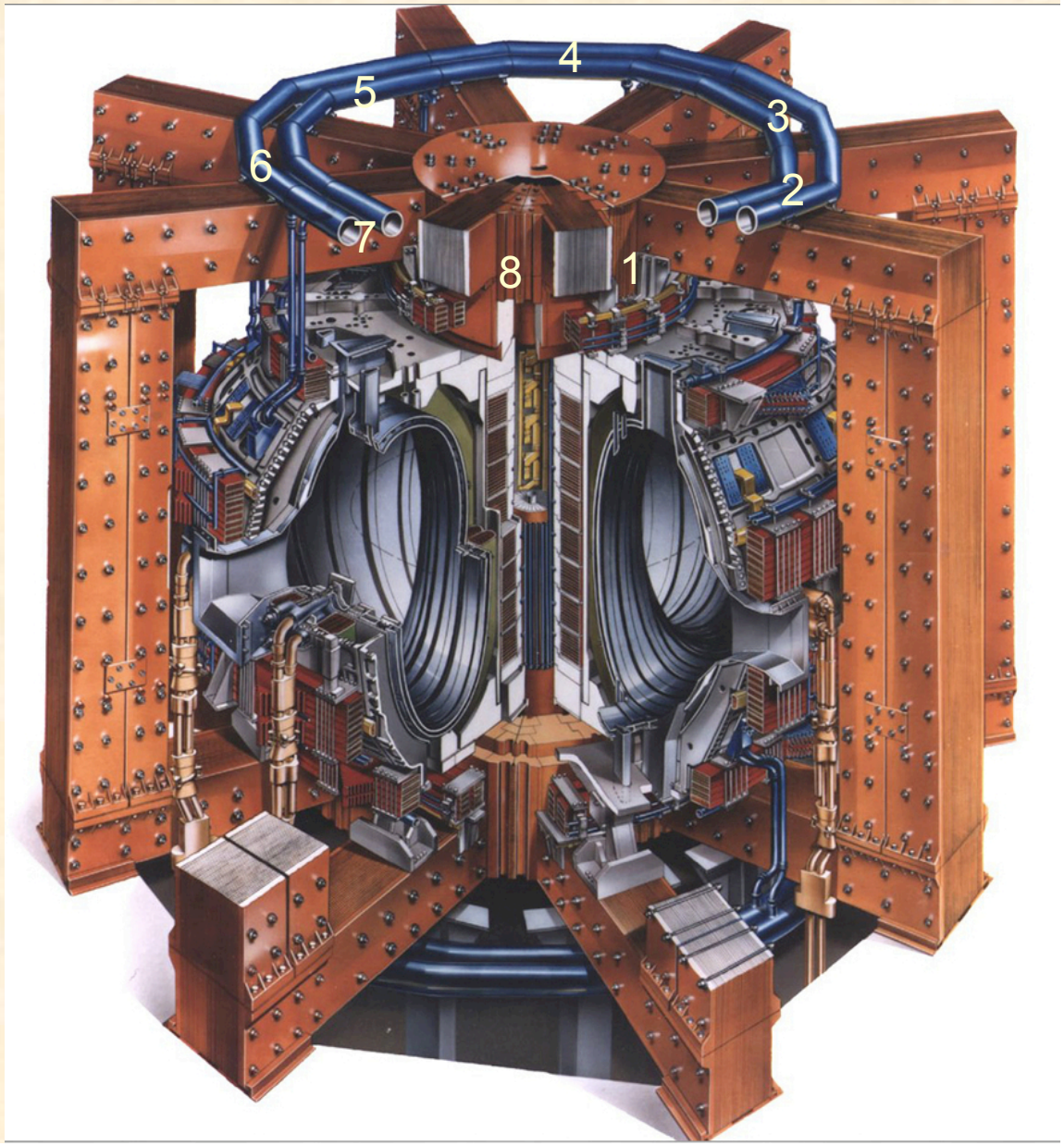
Outline

- The Joint European Torus (JET) experiment at the Culham Science Center
  - ORNL participation in CXRS
- In-Vessel Calibration Light Source (ICLS)
  - Motivation & Proposal
  - Delivered System
  - Commissioning and Calibration (video)
- JET schedule going forward and ICLS

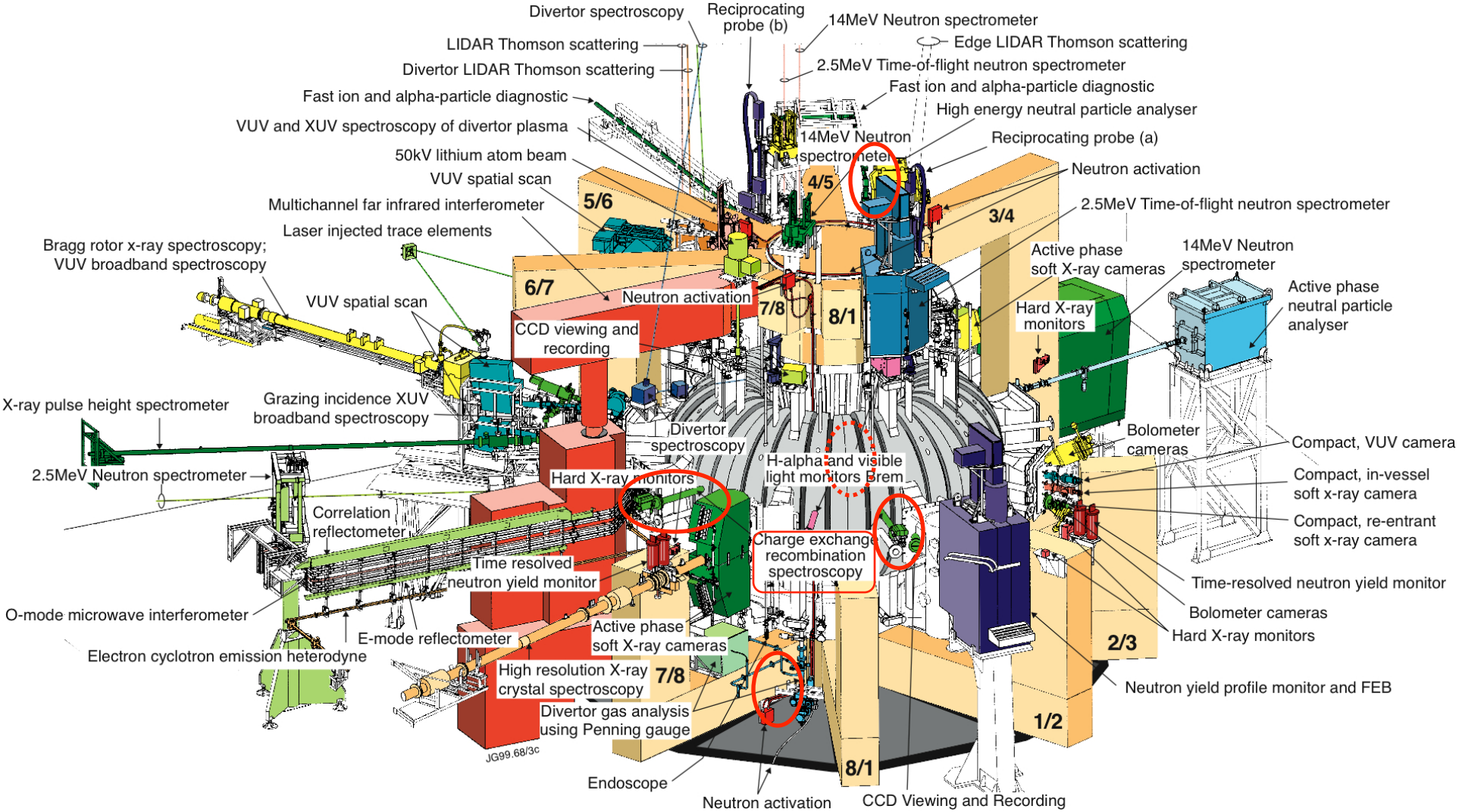
Role of JET in Oxfordshire

The Joint European Torus (JET)

- Culham Science Centre, Oxfordshire, UK
- UKAEA and EFDA
- R ~ 3.1 m, a ~ 1 m
- I_p < 5 MA
- B_T < 4 T
  - 8 transformer limbs: "octants"
- P_{NBI} < 24 MW
- P_{RF} < 20 MW
- 30 s pulse typical

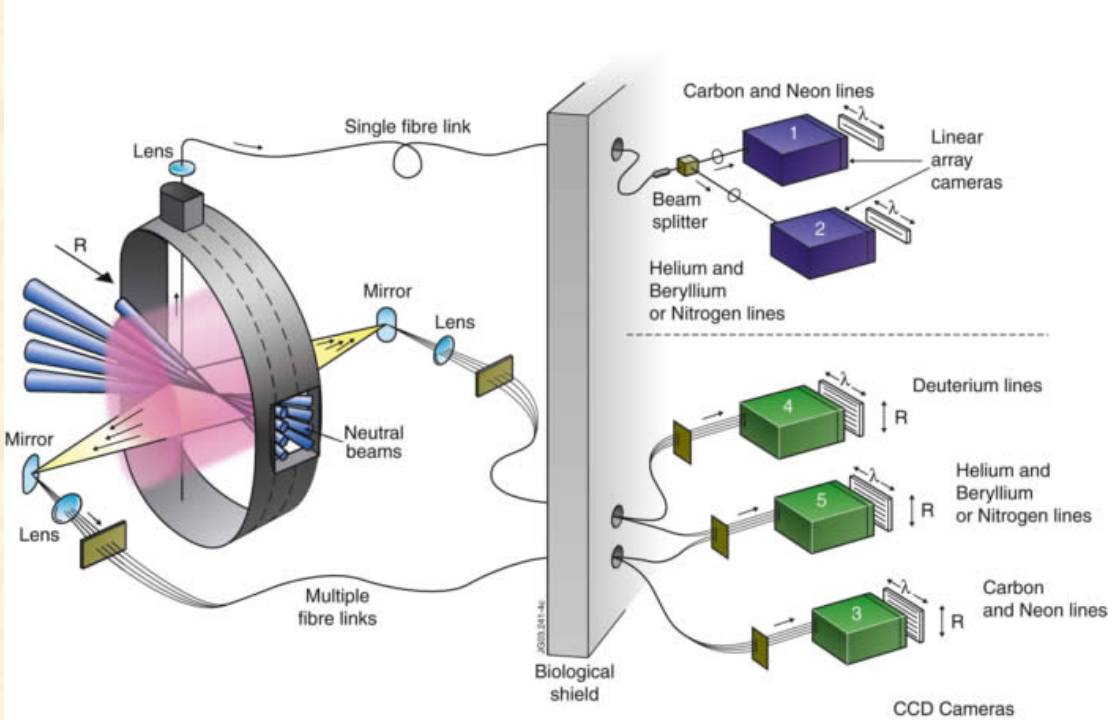


JET Diagnostics



Charge-Exchange Recombination Spectroscopy (CXRS) on JET

- Measurement of rotation, temperature, and concentration from light emitted by plasma ions excited via Neutral Beam Injection (NBI).
- CXRS system consists of a suite of instruments on JET
  - Core CXRS (-0.2 < *r/a* < 0.8)
    - KS4 A B: EFDA
    - KS5 A B C: EFDA
    - KS5 D E: ORNL
  - Edge CXRS (0.5 < *r/a* < 1.0)
    - KS7 A B C: EFDA
    - KS7 C D: ORNL



Integrating Sphere History

- 1801: carbo
- 1878: incan
- 1879:
- 1892: theor
- 1894: integ
- 1920: meas
- 1933: spher
- 1968: sulfat
- 1990: indus

www.pro-lite.co.u

Key Integrating Sphere Features

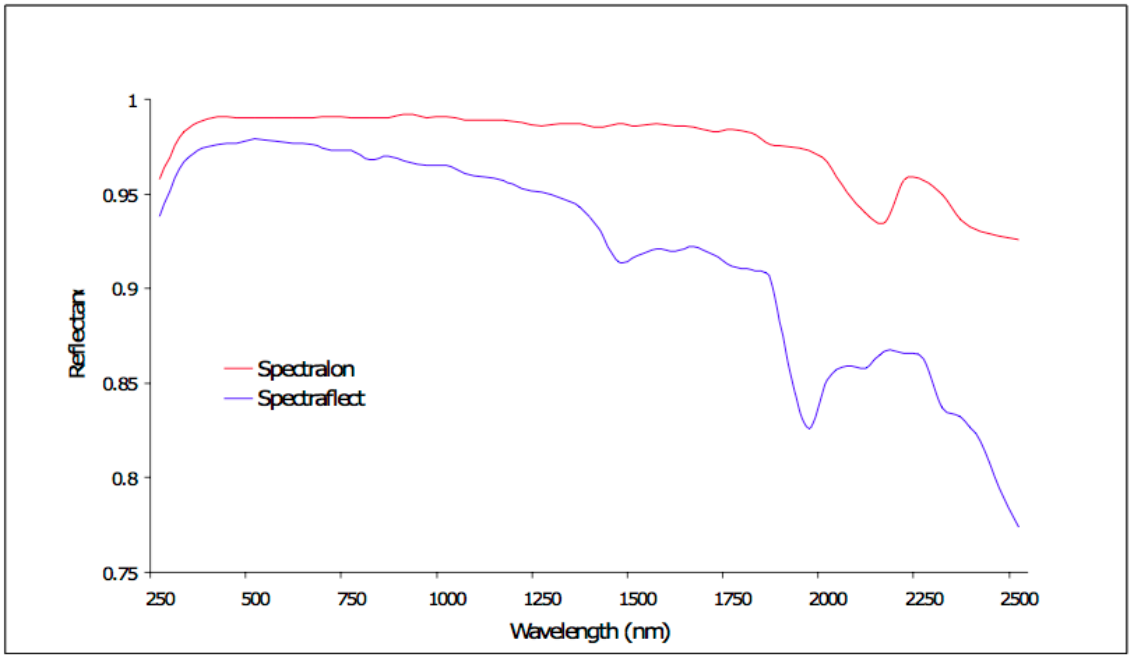
Diffusely reflecting coating

Ports to let light in or out

www.pro-lite.co.uk

High reflectance

UV-VIS-NIR Reflectance Difference



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Light Measurement Seminar
November 2007

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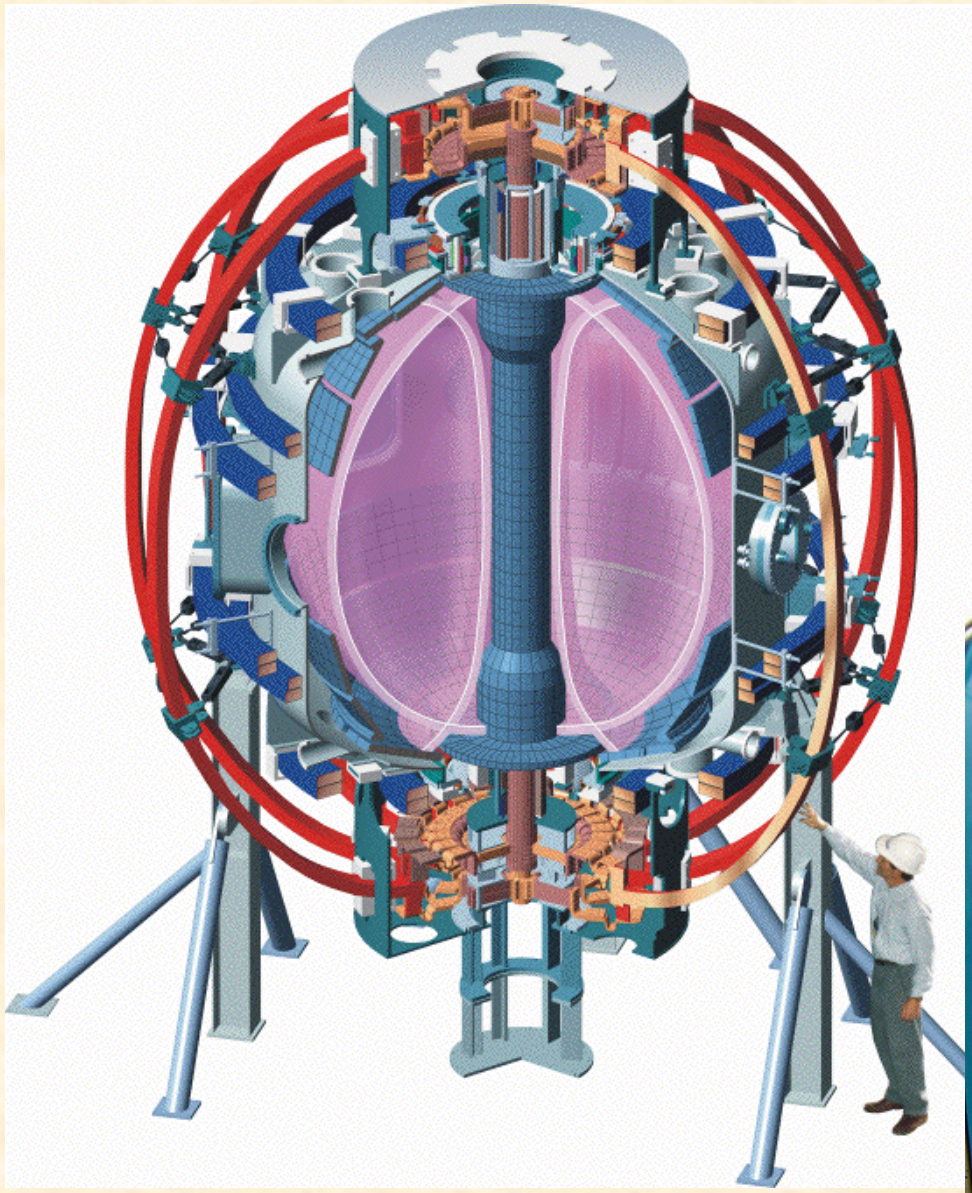
National Spherical Torus Experiment



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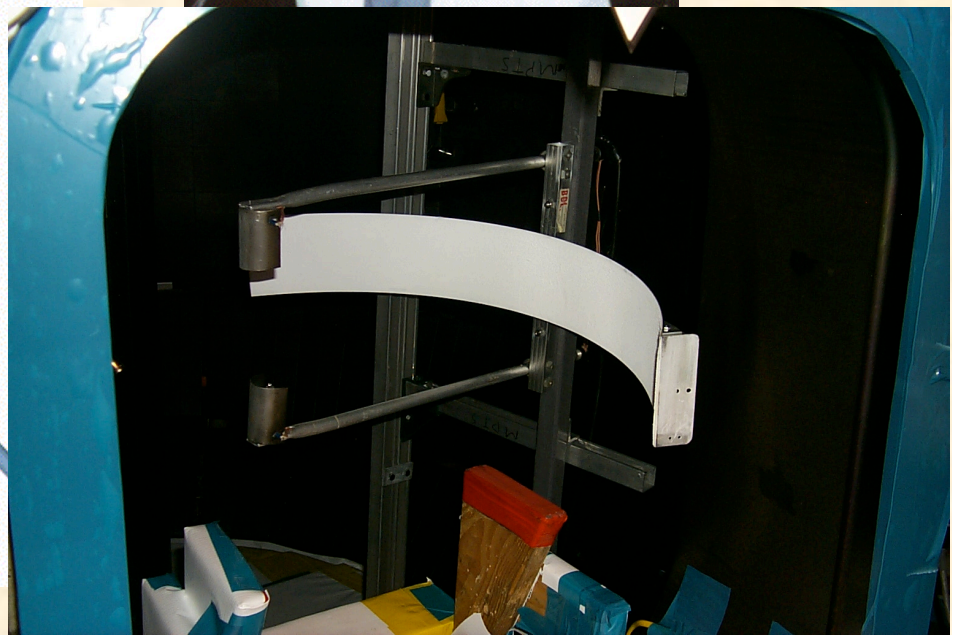
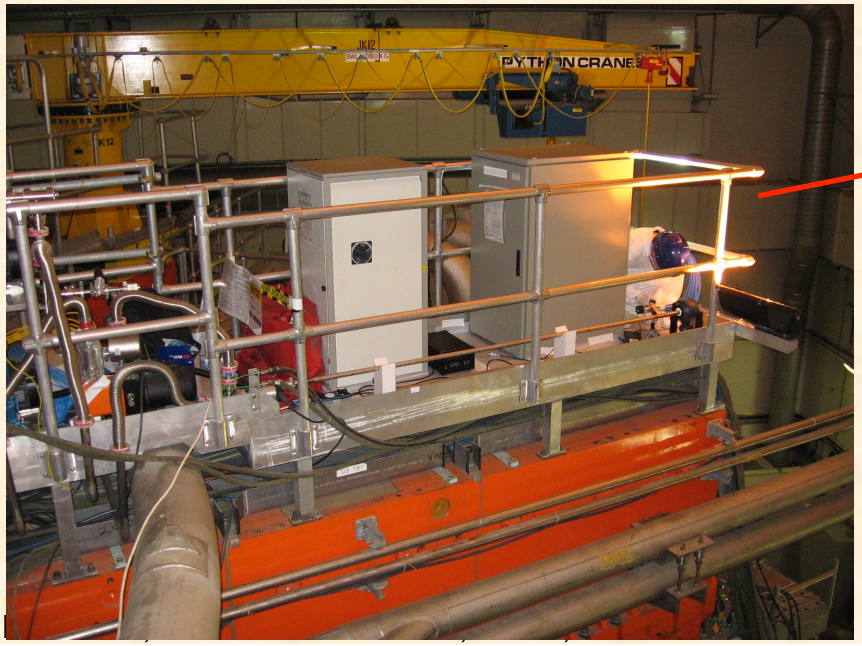
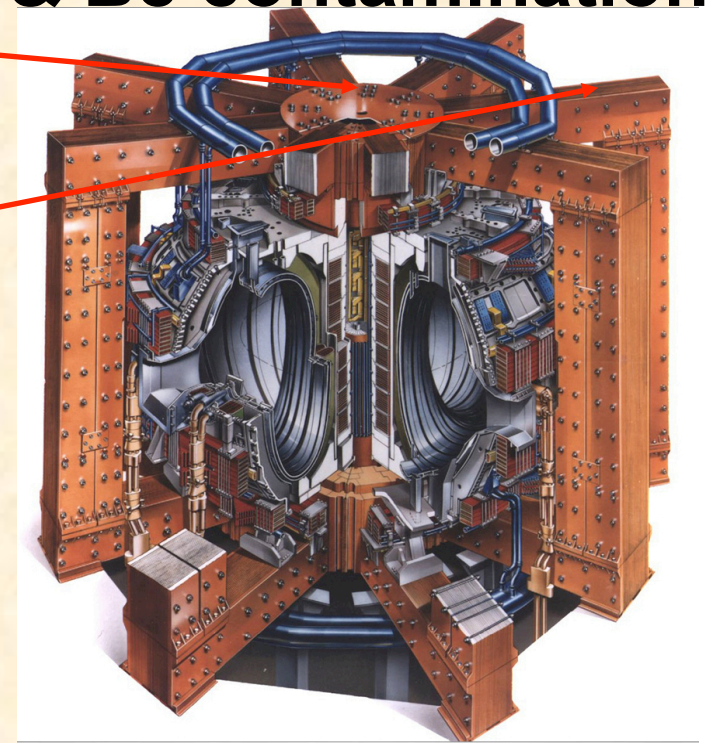


JET Calibration Activit

- In-vessel activity restricted due to T & Be contamination

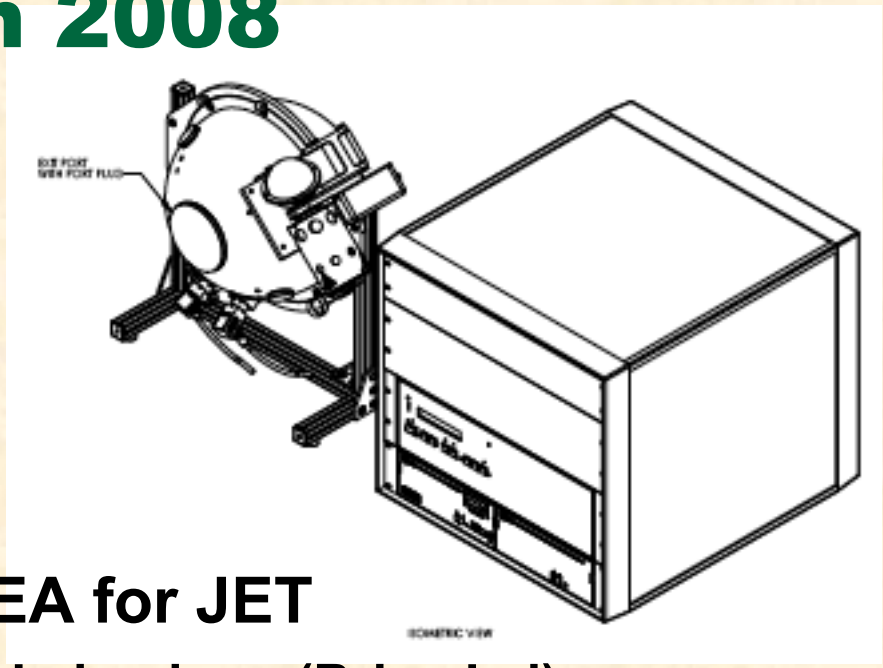




In-Vessel Calibration Light Source (ICLS): Motivation

- A significant amount of mechanical stress is placed on optical fiber bundles during removal of JET periscopes
- Window transmission must be measured separately
- An *in-situ* calibration capability is desired

ICLS Proposed in 2008



- **ORNL proposal to UKAEA for JET**
  - **Based on USS-1200 from Labsphere (Brian Lai)**
- **Poster presentation at *17th High Temperature Plasma Diagnostics* conference (Albuquerque, NM)**
  - **"A proposed in-vessel calibration light source for the Joint European Torus," T.M. Biewer, *et al*., RSI 79 10F530 (2008).**

The Remote Handling Arm (RHA)

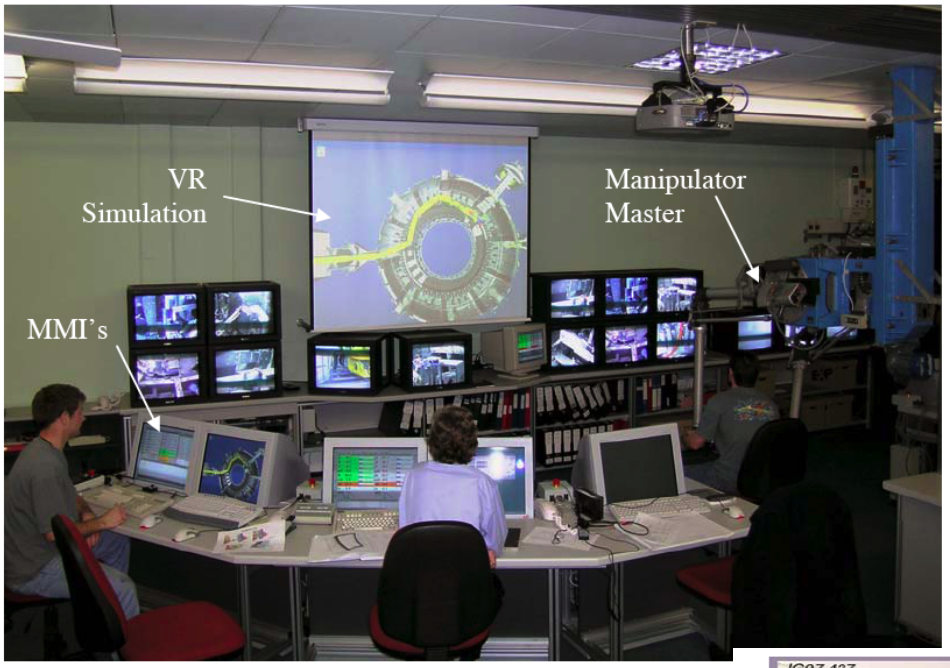
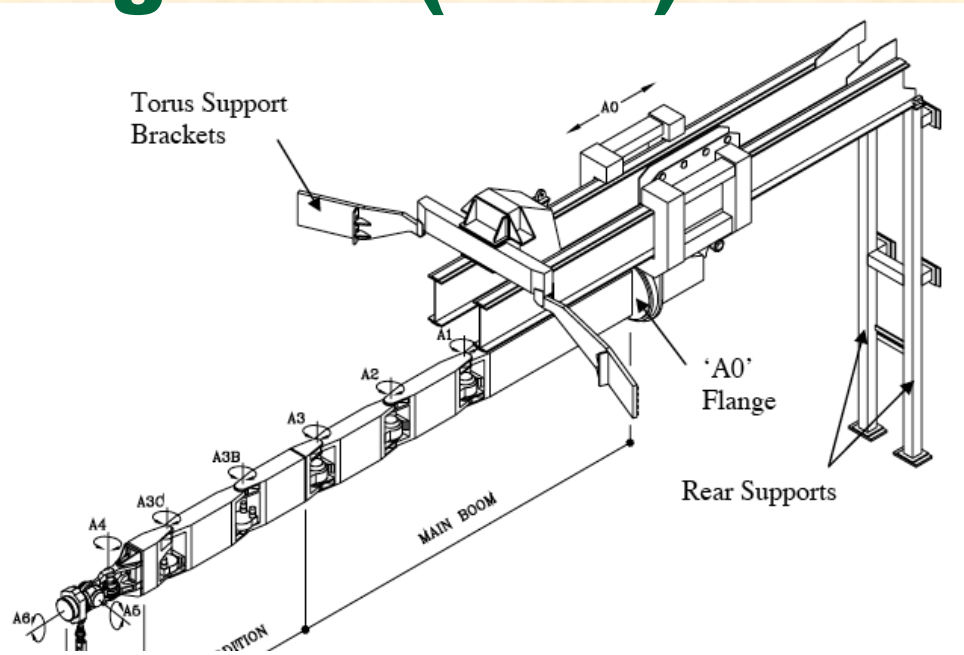


Figure 3.2-2 : JET RH Control Room



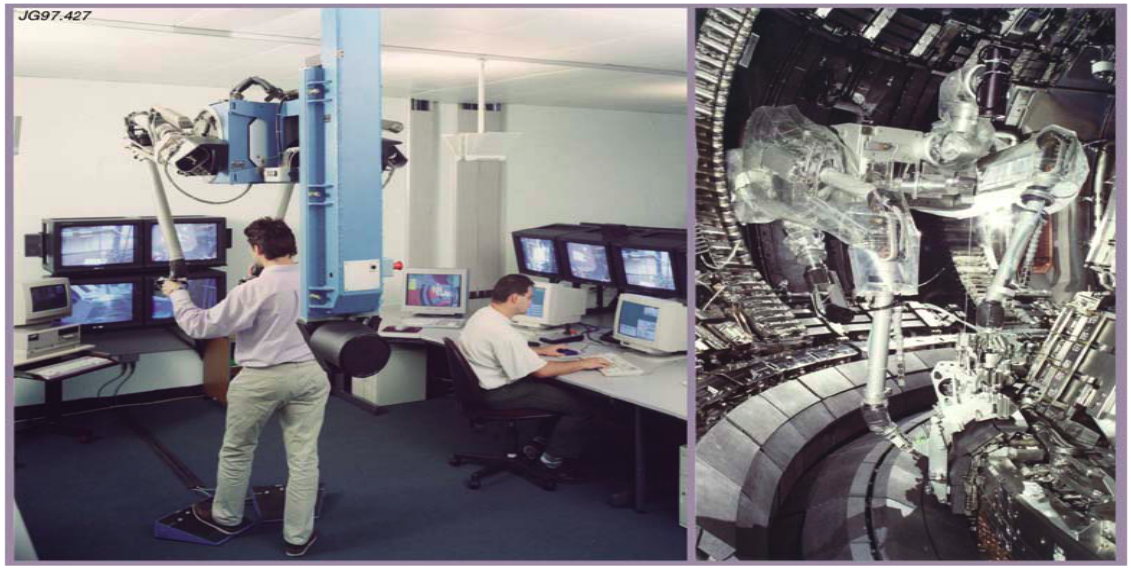
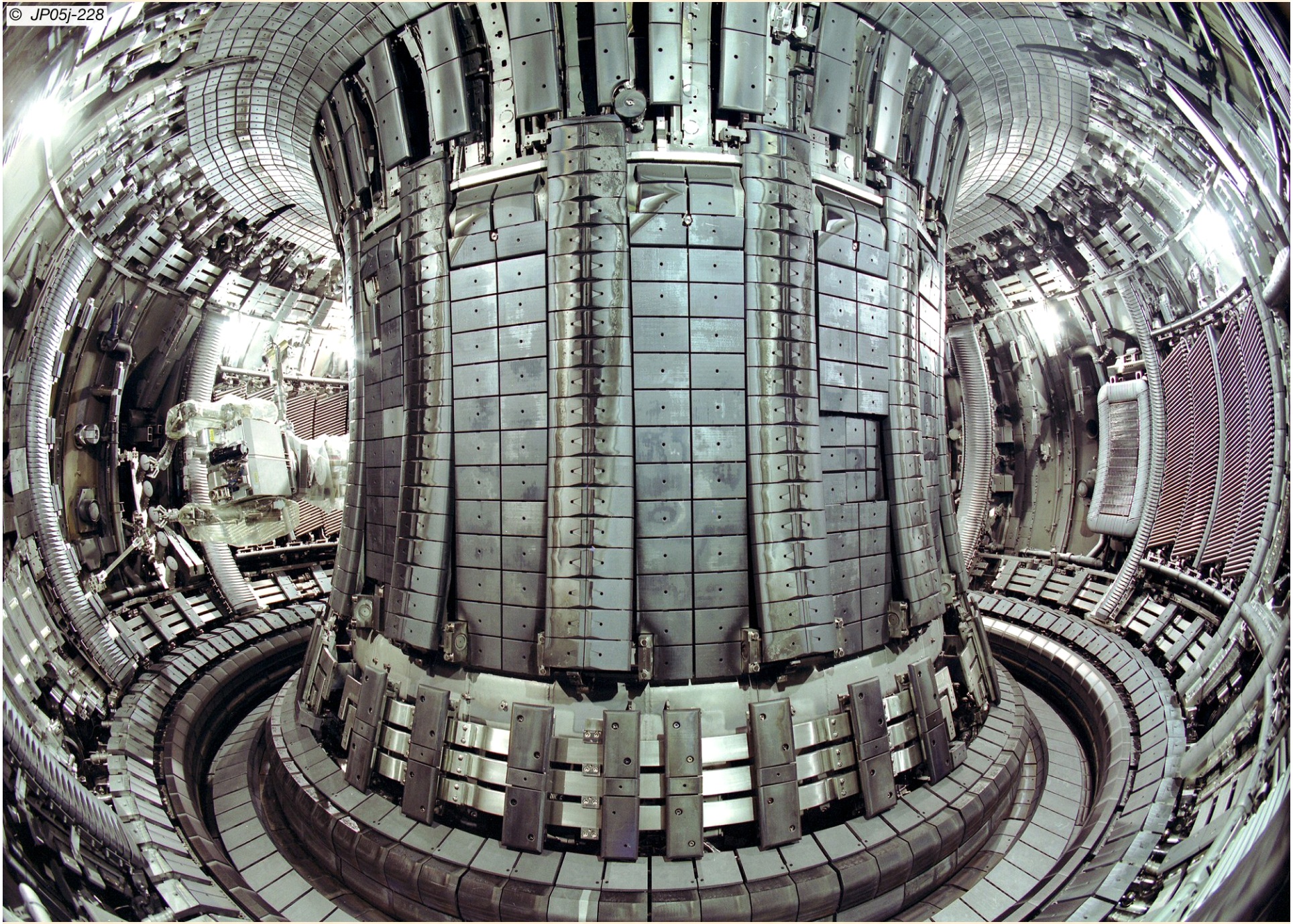


Figure 3.4-2 : MASCOT Manipulator - Master (left) and Slave (right)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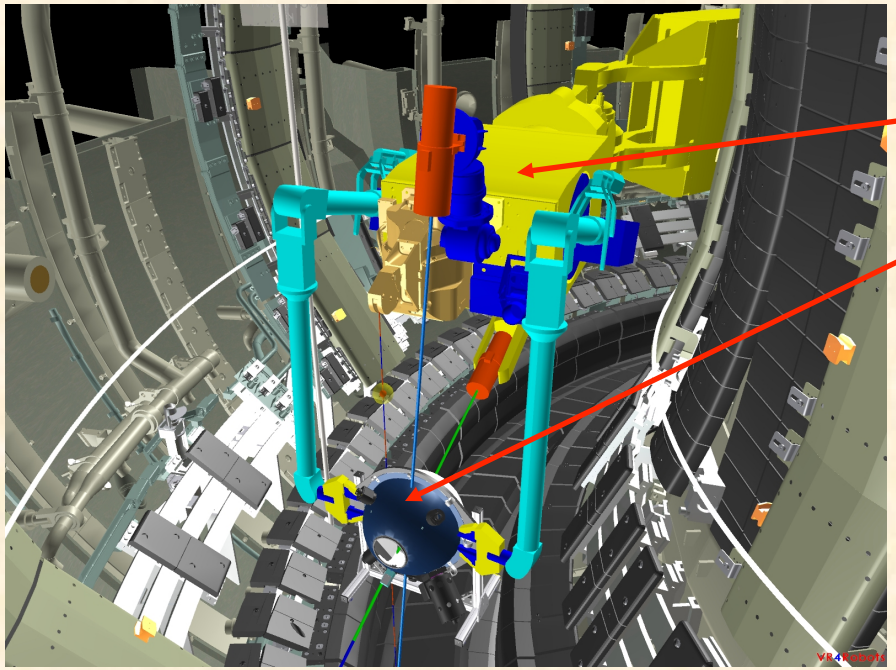
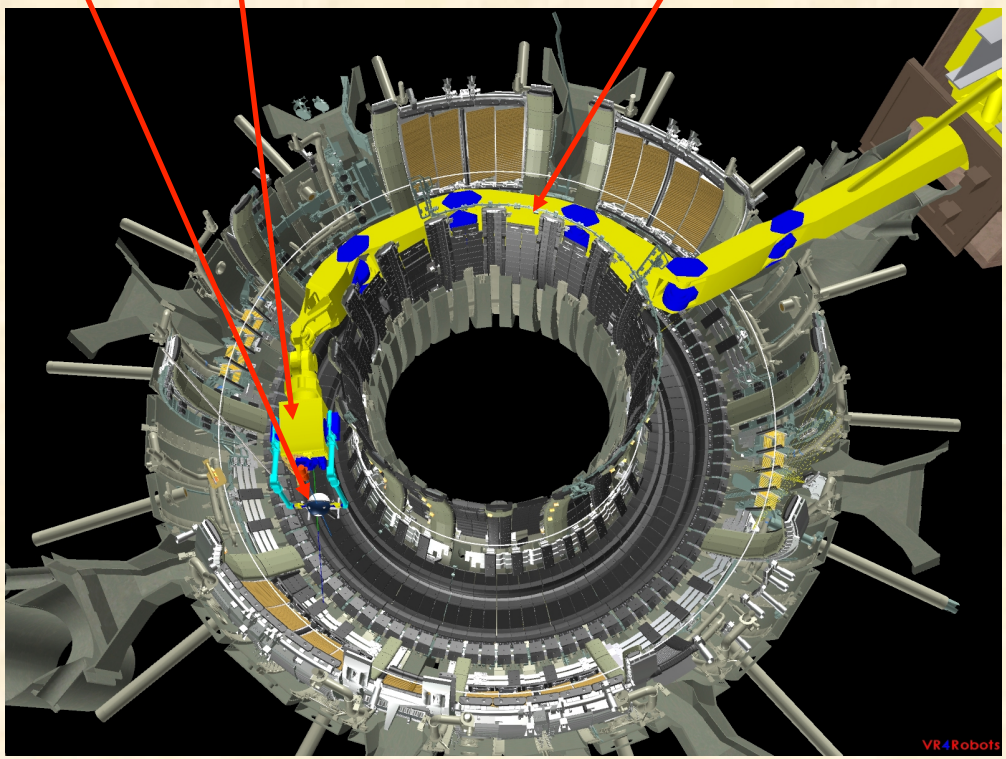
RH deployment of the ICLS in JET



MASCOT

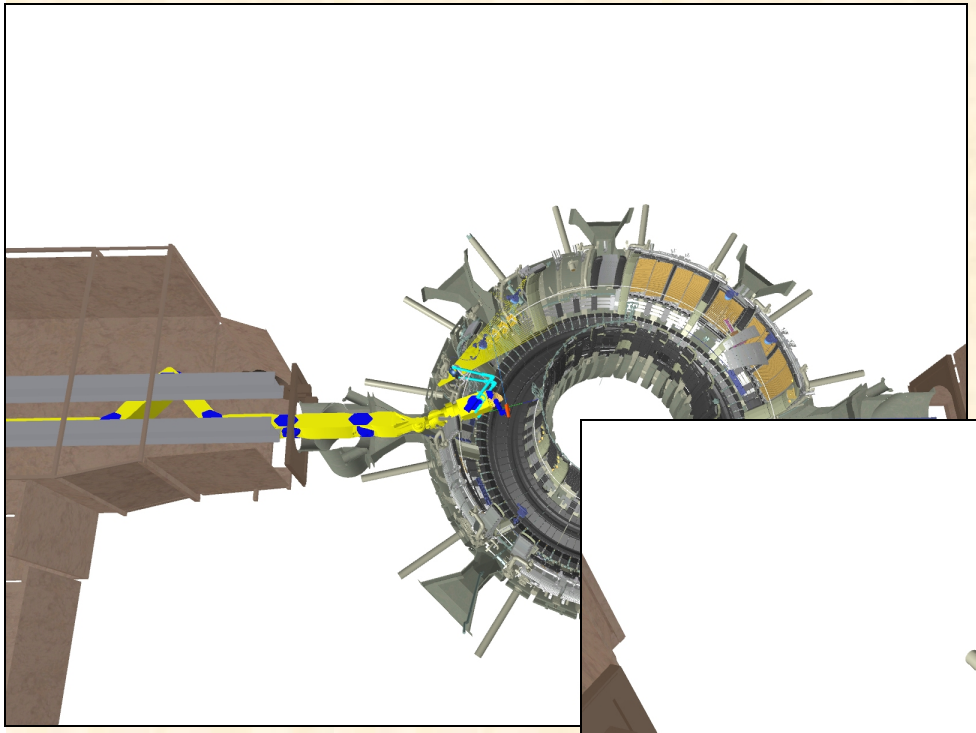
ICLS

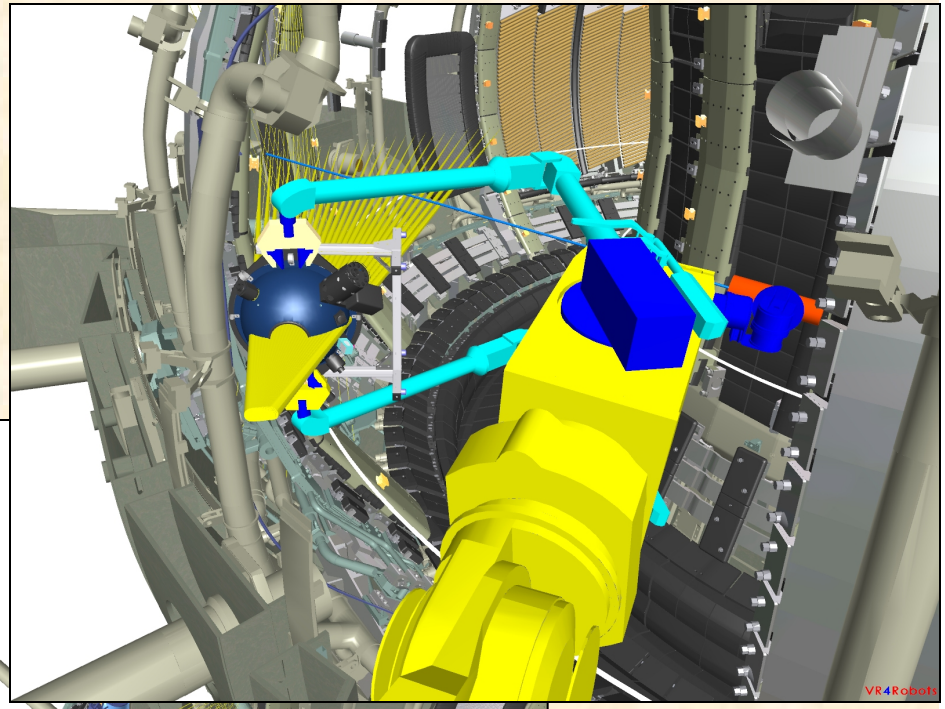
Remote Handling Arm

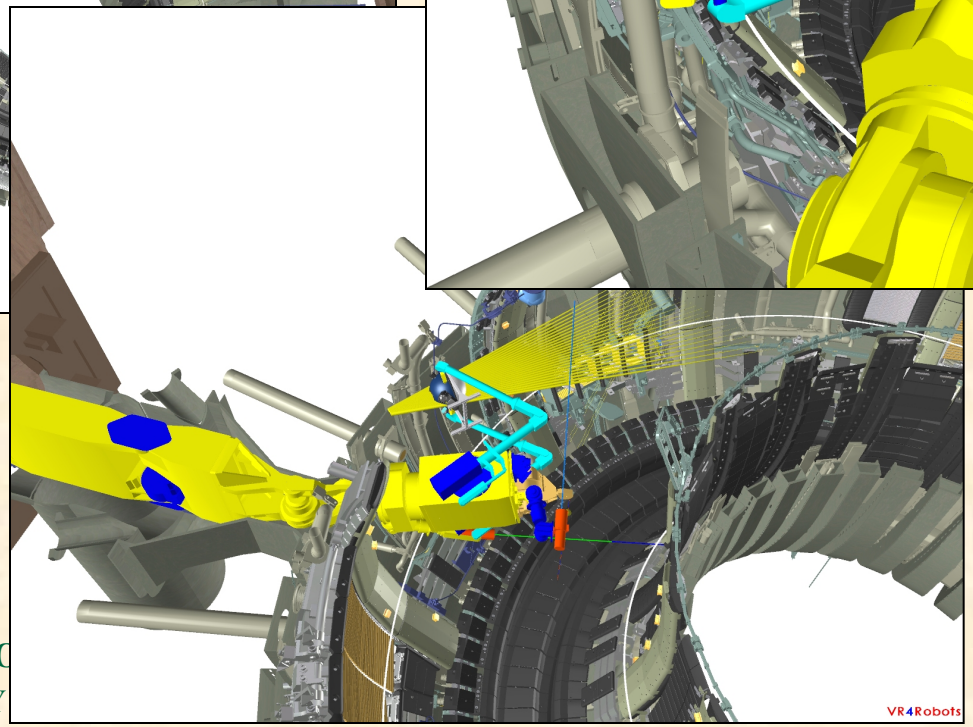


- **Full VR simulation of movement within the JET internal environment to avoid obstructions.**

Overview of a typical deployment





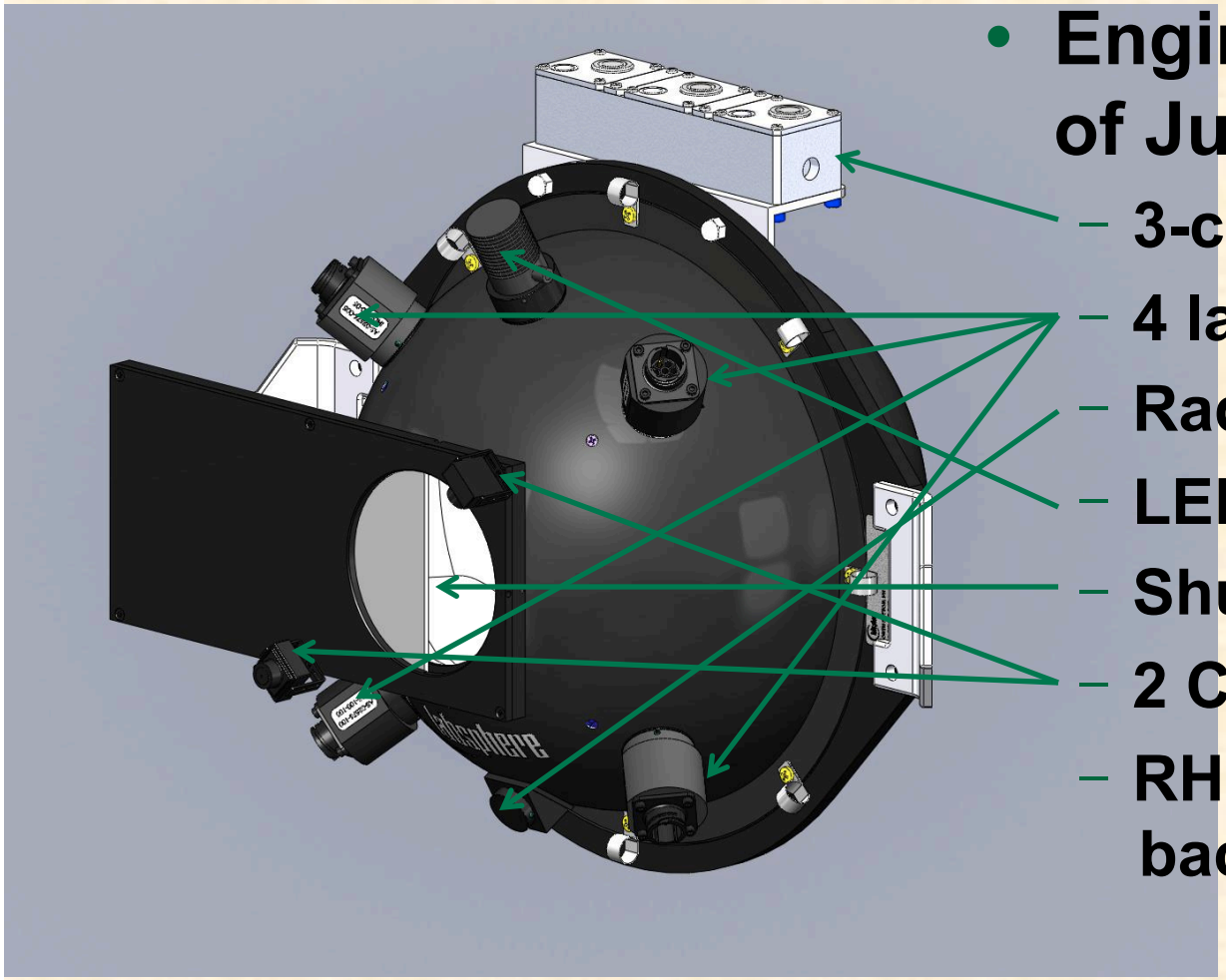


Diagnostic Requirements

Diagnostic	Description	R.O.	Ports	Factors	Shifts	Lamp hours
KS3	Vis. Spec.	M. Stamp	3	4-6 lamp pos.	12-16	12-16
KS4	Vert. CXS	A. Meigs	1	Post, var λ,pre.	4	16
KS5	Tor. CXS	C. Giroud	2	Post, var λ,pre.	4	24
KS7	Pol. CXS	Y. Andrew	3	post, pre.	6	18
KS8	Zmn. Spec.	M. Stamp	1	post, pre.	2	4
KS9	MSE Spec.	N. Hawkes	1	Rotary polarizer	2	4
KT1	Scan. VUV	K. Lawson	2	3-5 rot. mir. pos.	12-20	12-20
KE11	HRTS	M. Beurskens	1	post, pre.	2	4
KT3	Div. Spec.	A. Meigs	1	var λ	4	16
KT4	VUV Spec.	I. Coffey	1	post, pre.	2	2
KT7	VUV Spec.	I. Coffey	1	post, pre.	2	2

Total: 52-64 shifts, 114-126 lamp hours

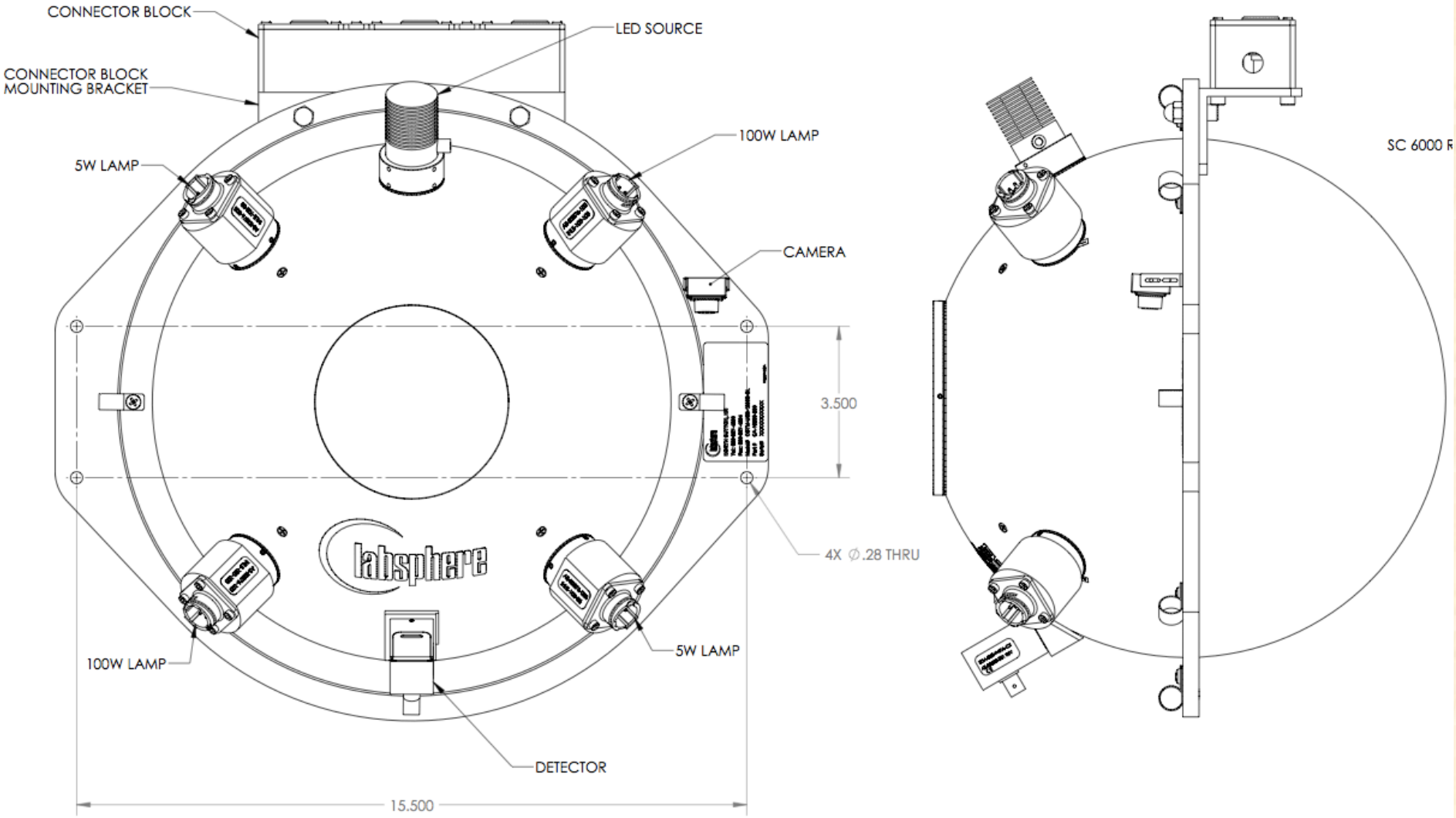
In-vessel Calibration Light Source(ICLS)



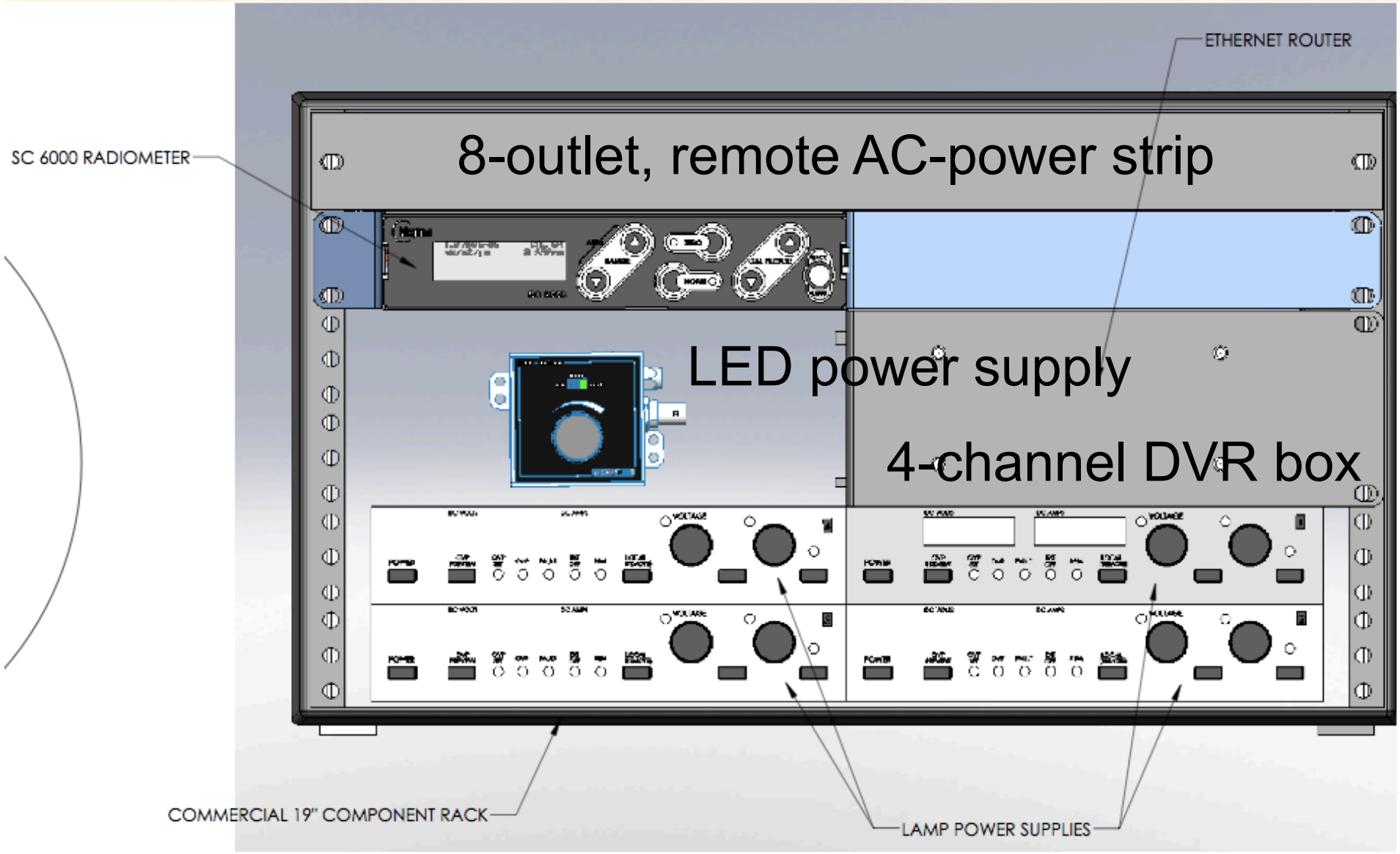
- Engineering Model as of July 9, 2010
  - 3-connector design
  - 4 lamps: 2x 100W, 2x 5W
  - Radiometer
  - LED “torch”
  - Shutter
  - 2 Cameras
  - RH grip-mounts (slightly backwards)

ICLS detail view

- **Engineering Model as of June 23, 2010**



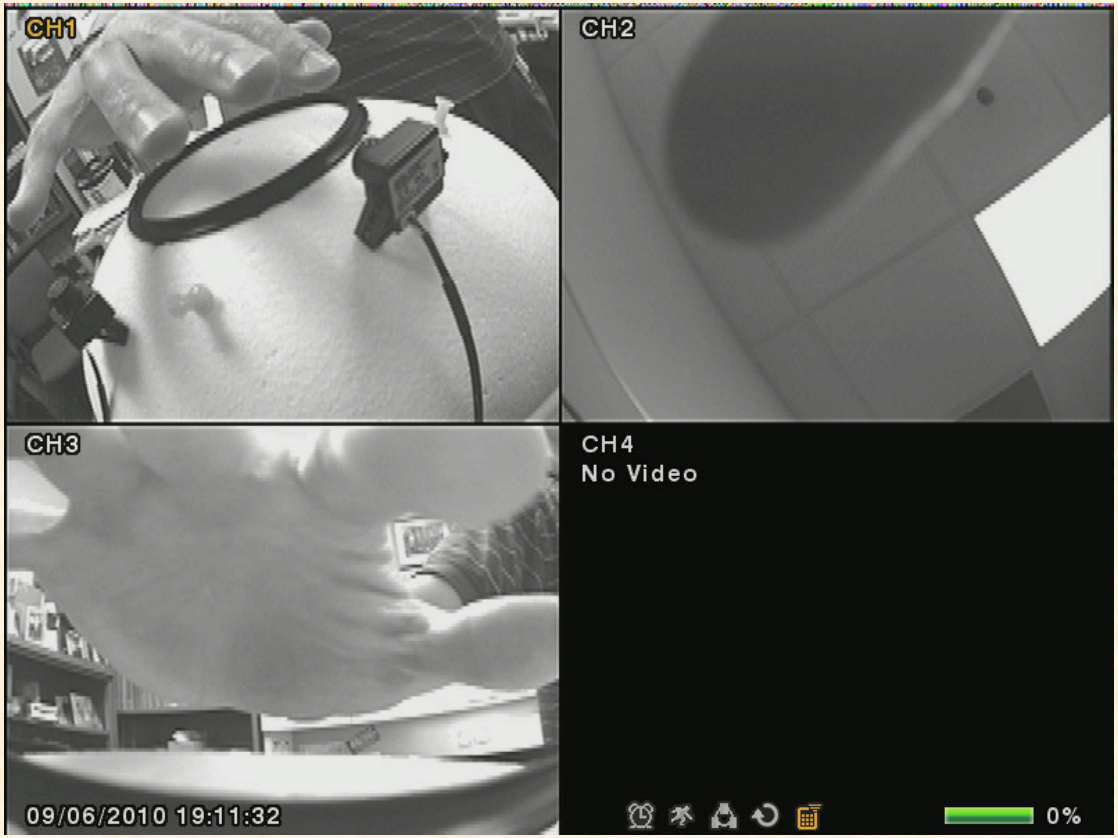
ICLS ex-vessel electronics



ICLS ex-vessel electronics (cont.)

- Inputs to ex-vessel electronics: AC power and network cables
- Outputs
  - ICLS umbilical
  - Network to PC:
    - Labsphere control: lamps, shutter
    - AC power (on/off): cameras (2), LED "torch" (1), lamp power supplies (4), DVR box (1)
    - DVR data: camera signals (~5 day continuous recording capacity)
- PC can be located anywhere on JETnet

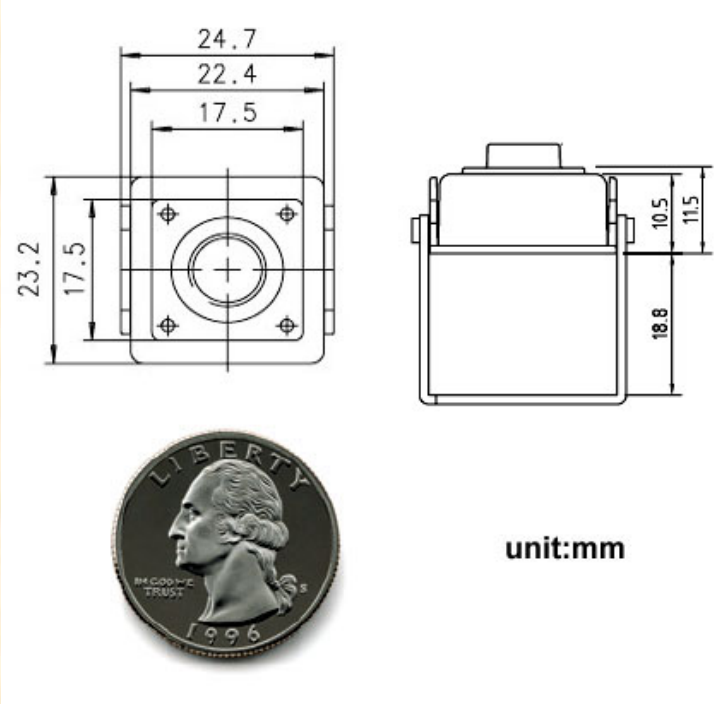
Ancillary electronics tested



- Mock-up of sphere with cameras, DVR, remote-AC, etc tested using ICLS PC
- Successful!
- PC, DVR, cameras, remote-AC, etc shipped to Labsphere (NH, USA)
- Equipment selected to be US/UK power and NTSC/PAL dual compatible

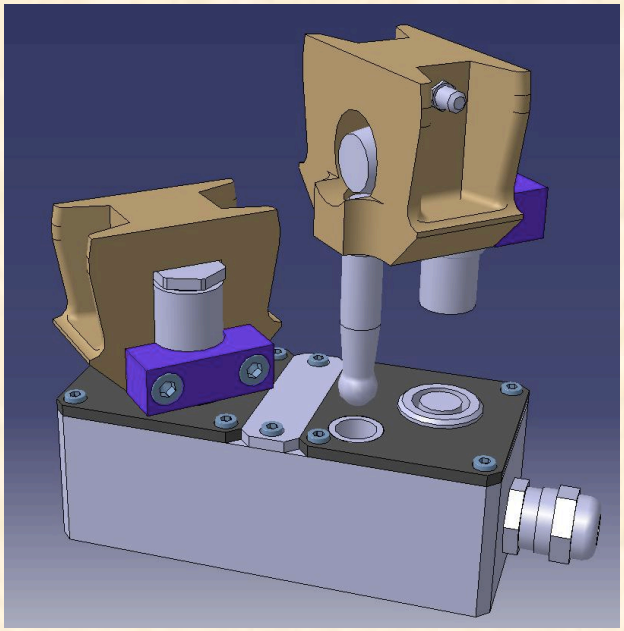
Camera/DVR details

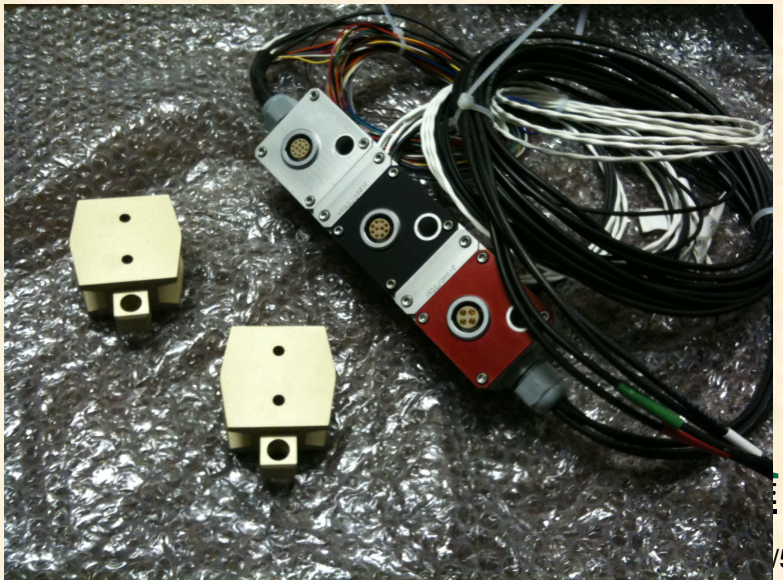
- 2 B&W cameras
  - 600 TV lines (507x492 pixels)
  - 0.0003 lux sensitivity
  - auto-exposure



- DVR: simultaneous record, playback, transfer
  - 4-channel, 120 fps
  - 250GB capacity
  - ~5 days continuous recording (full resolution)
  - Web-viewable w/o loss of performance at 4 connections

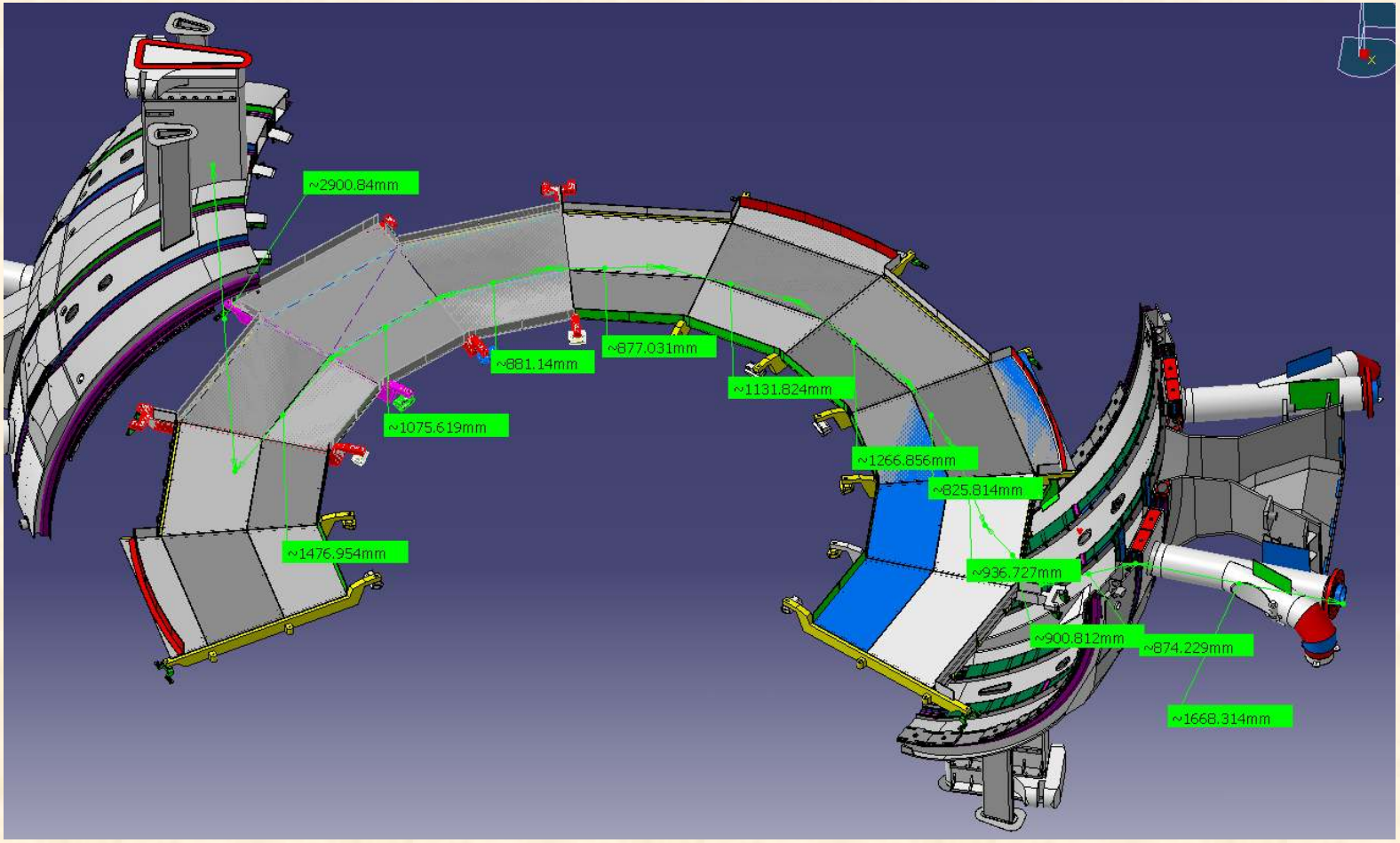
RH compatible connectors





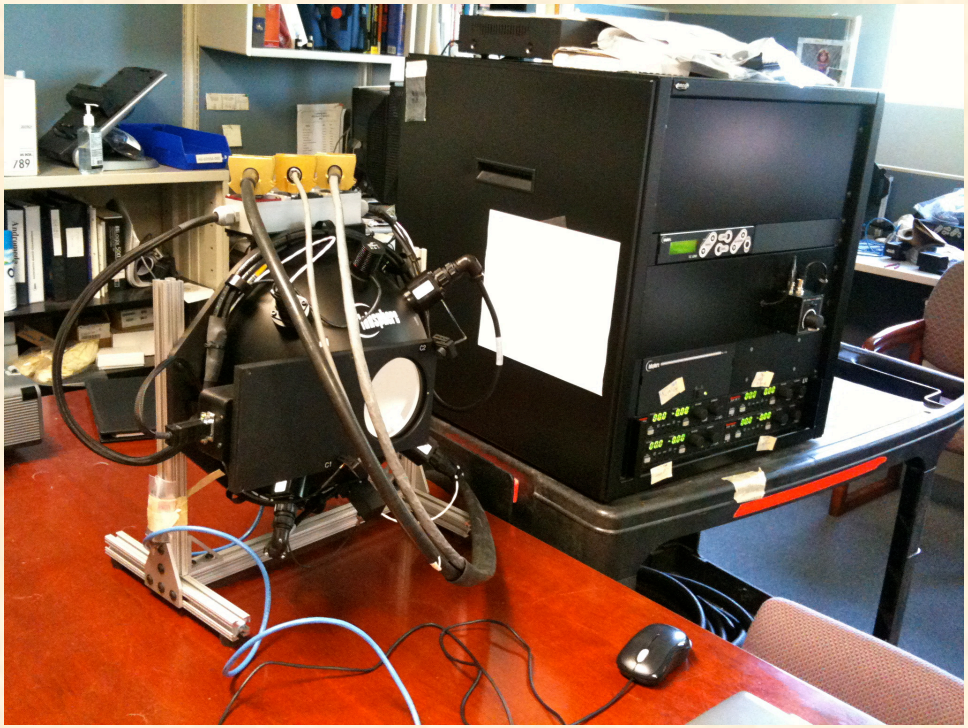
- 3 connector design
- Full RH manipulation

20 m Umbilical Cable



Estimated cable length from Oct outer limiter guide tube to top of outer vessel at Oct 5 = **~15m** However, some extra might need to be added to be safe. This does not include the length required ex-vessel to the power supply etc.

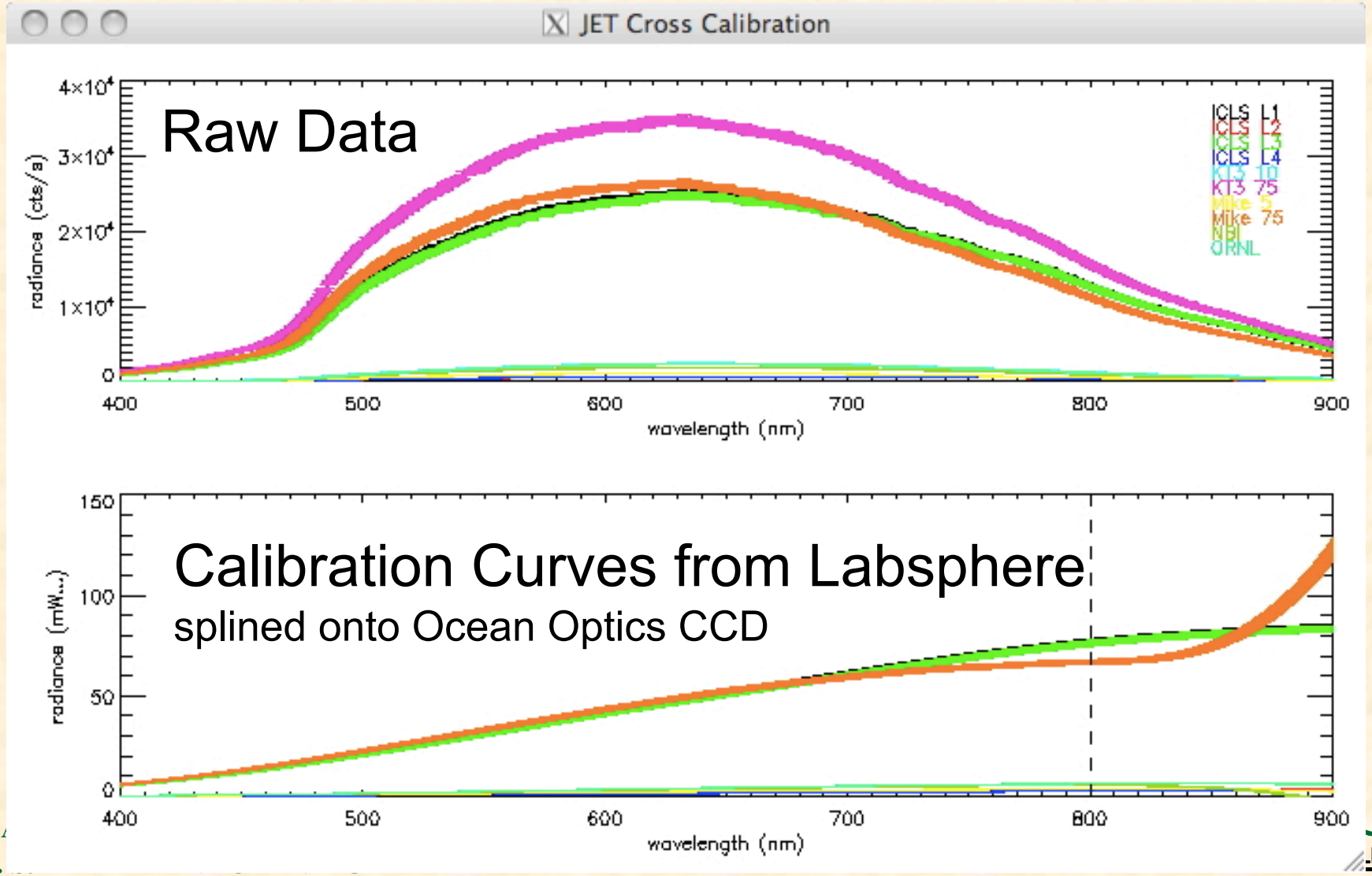
ICLS custom built by Labsphere



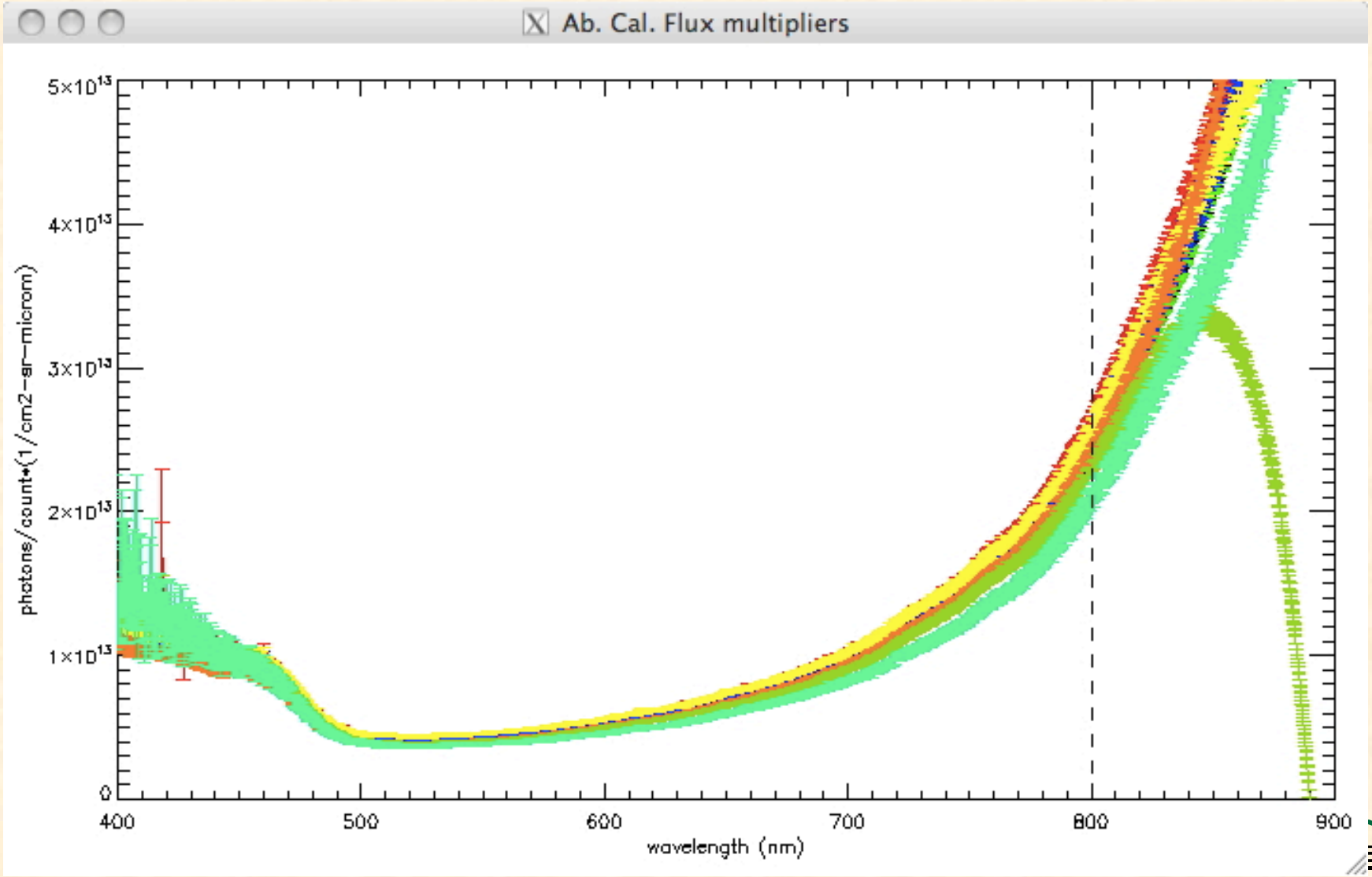
ICLS arrived at JET on 9/6/2010

- ICLS arrived 1 week before intended calibrations
  - Assembly
  - Testing
  - Modifications
  - Repair
  - Cross Calibration
  - Deployment
- Calibrations in-vessel delayed by 2 days

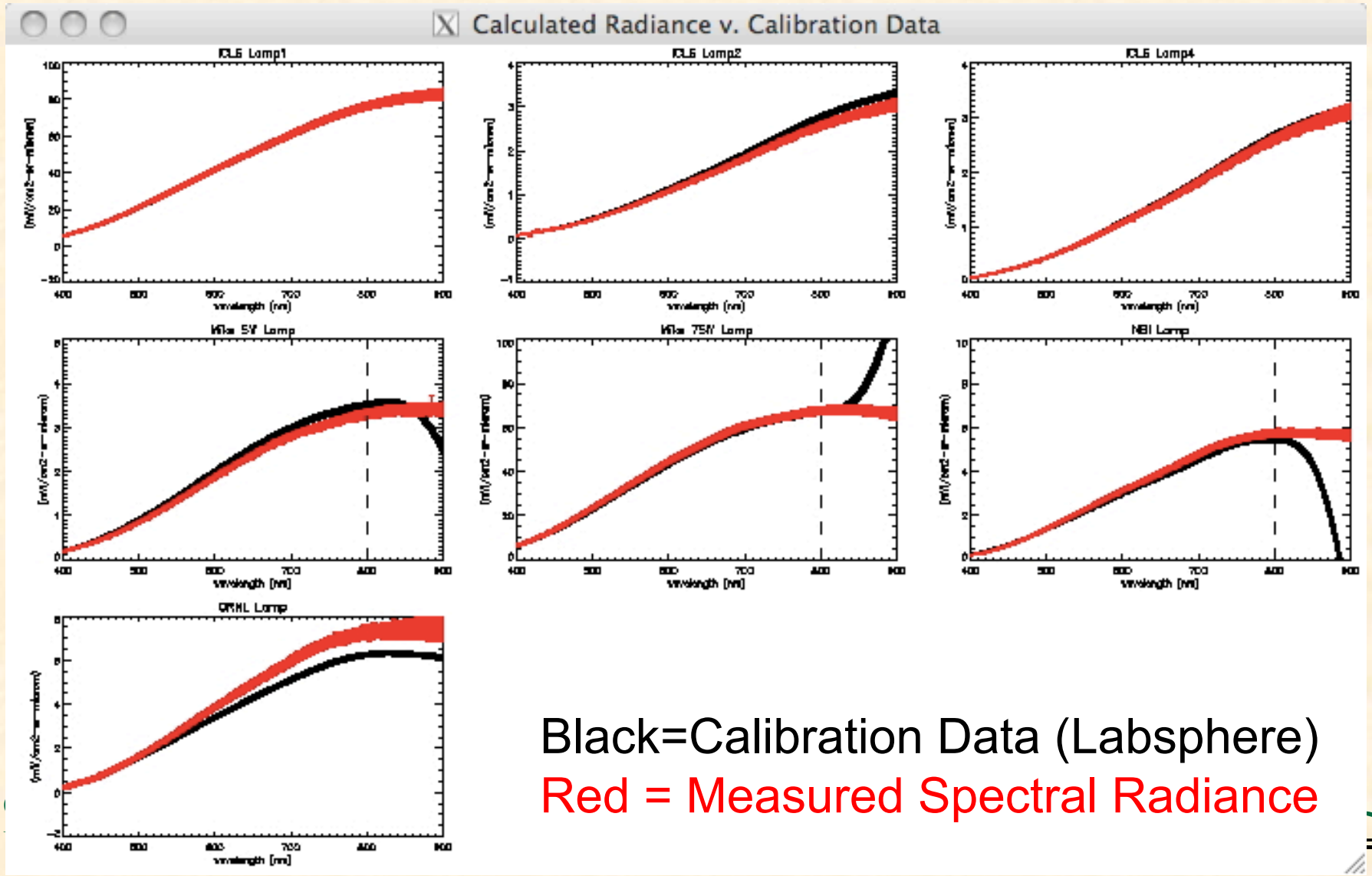
Cross-calibration with JET lamps



Measured calibration factors



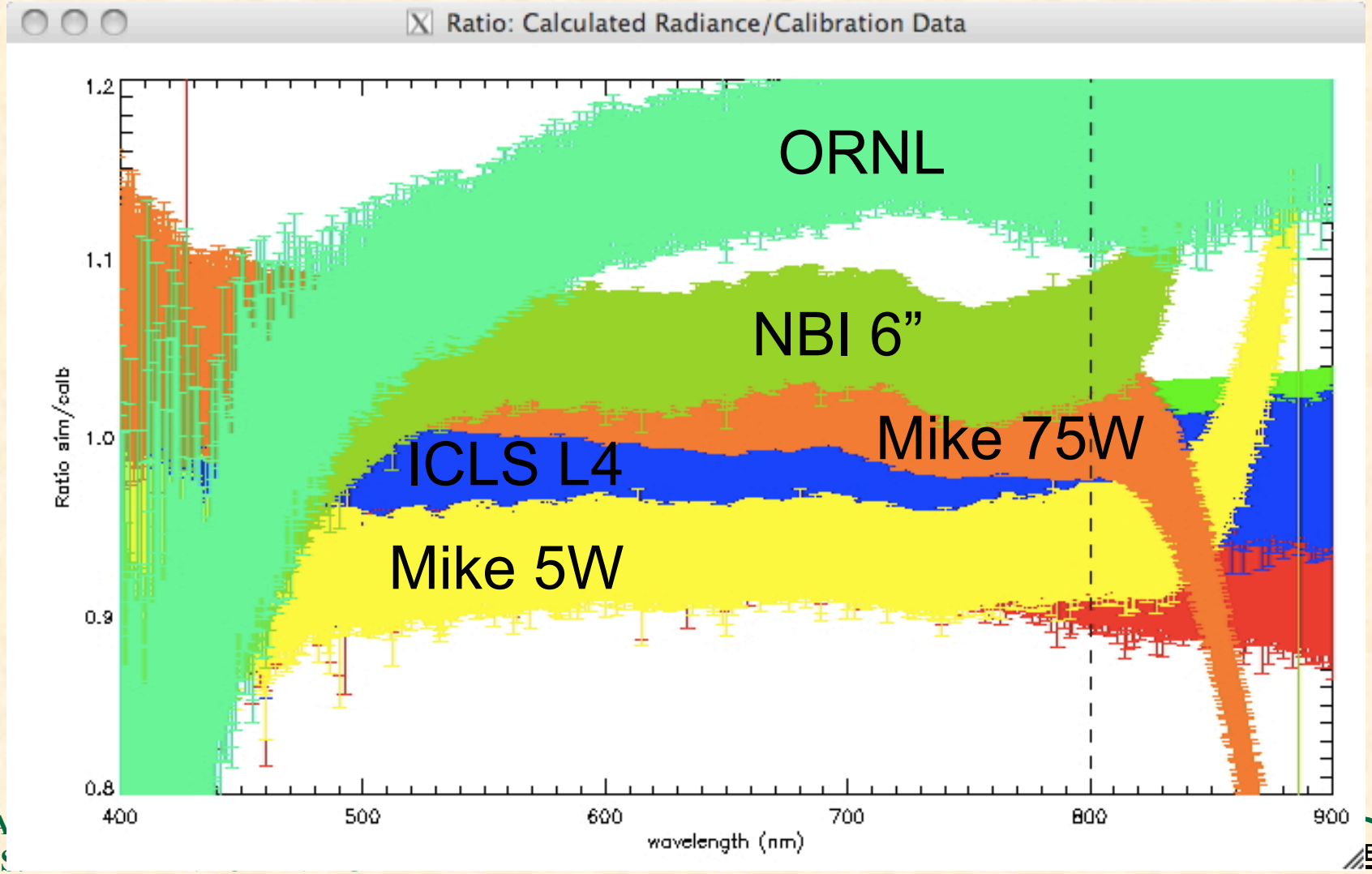
Use ICLS Lamp #3 as "perfect standard"



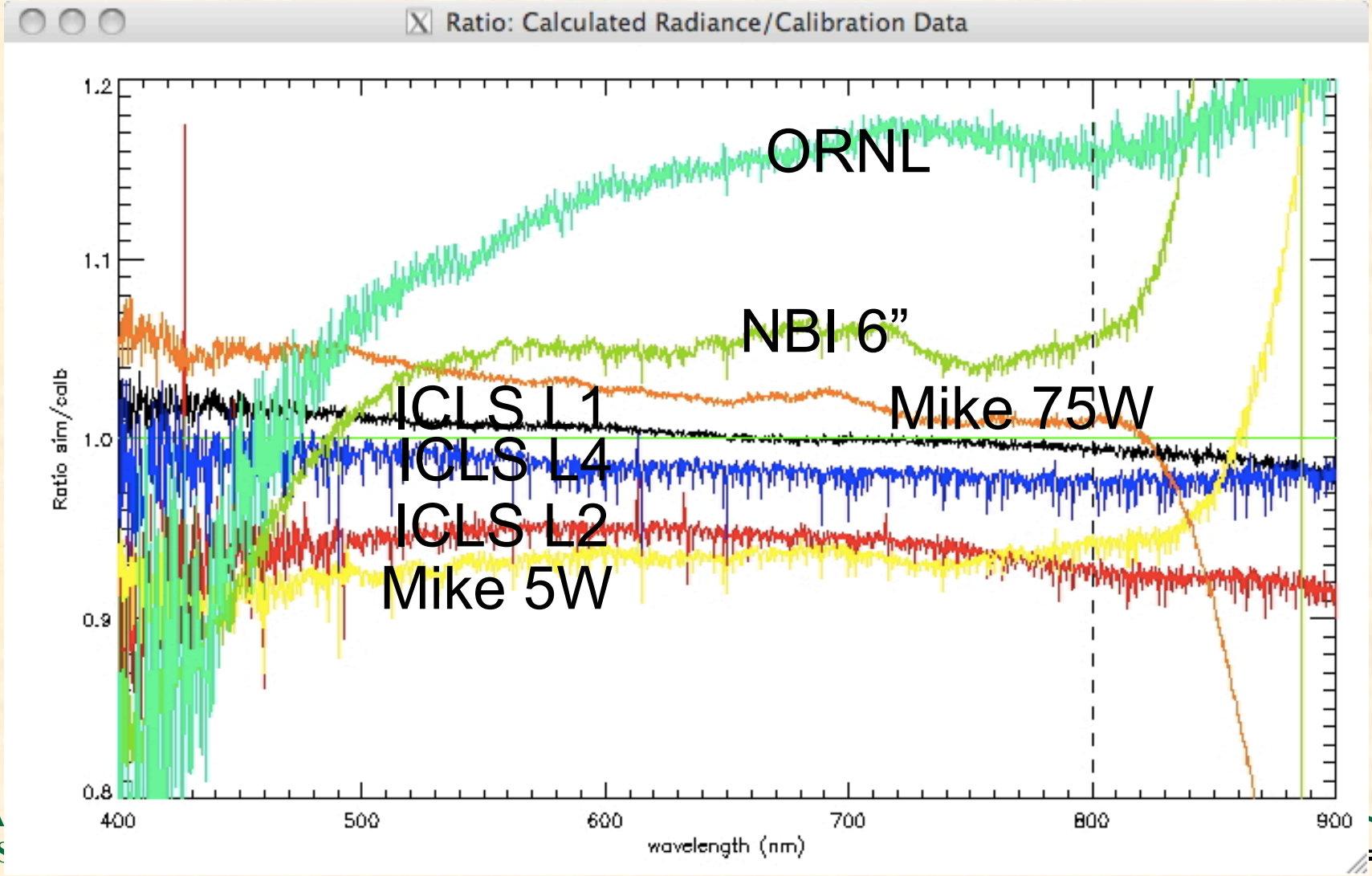
Black=Calibration Data (Labsphere)

Red = Measured Spectral Radiance

Ratio of Calculated/Calibration Data



Ratio of Calculated/Calibration Data

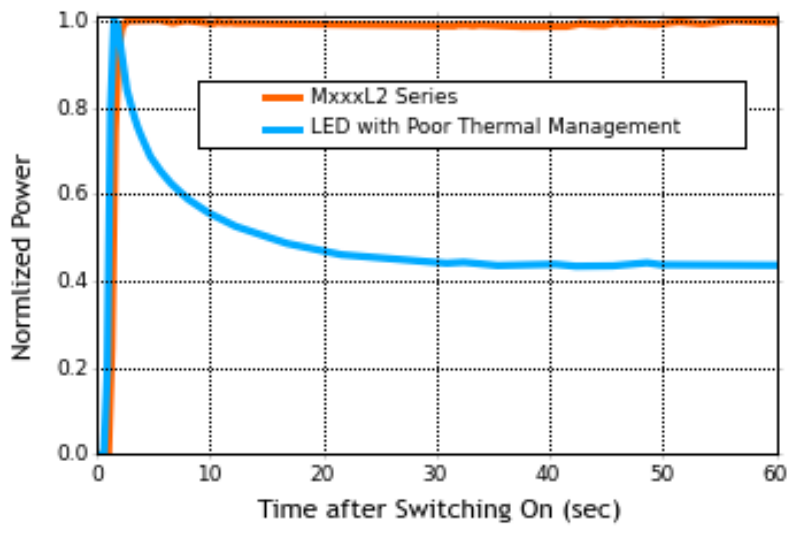


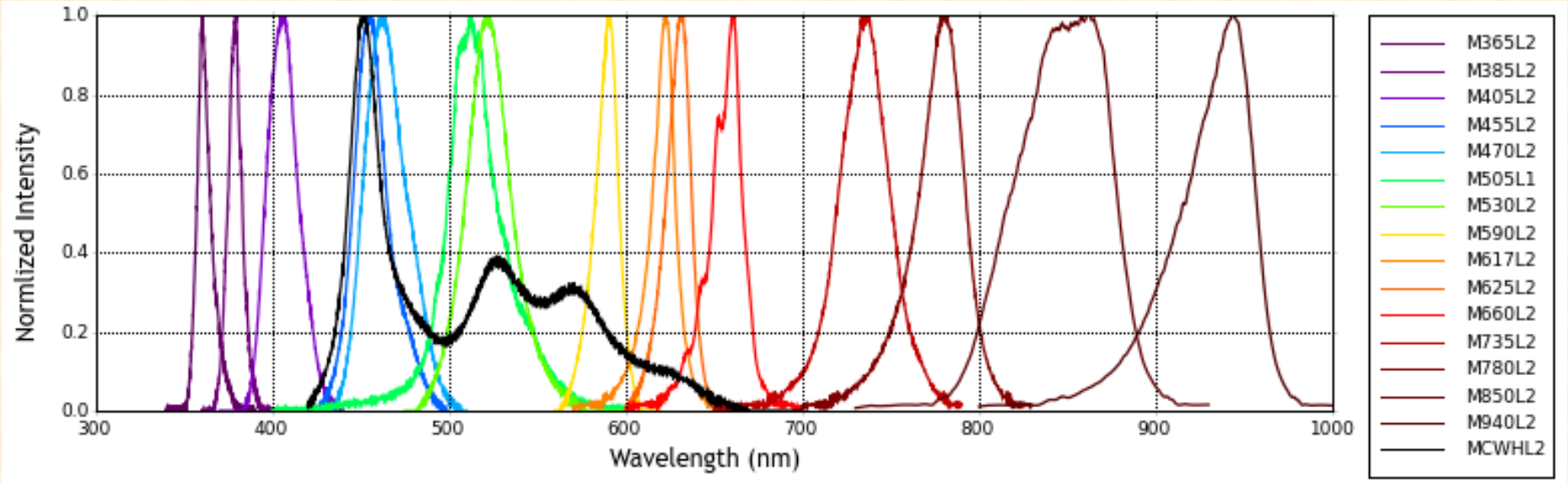
Cross-Calibration Results

- Within error bars, most lamps (reasonably) conform to their calibration certificates.
  - ORNL lamp (2004) needs recalibrating.
  - NBI 6” lamp (2008) is marginal.
- 5x as much data left to be analyzed (at other exposure settings.)
- Need to compare with Mike’s measurements, and with Giles/Genady’s.
- Need to spline data onto Calibration Certificate grid, not other way around (as done here), and/or fit to blackbody spectrum.

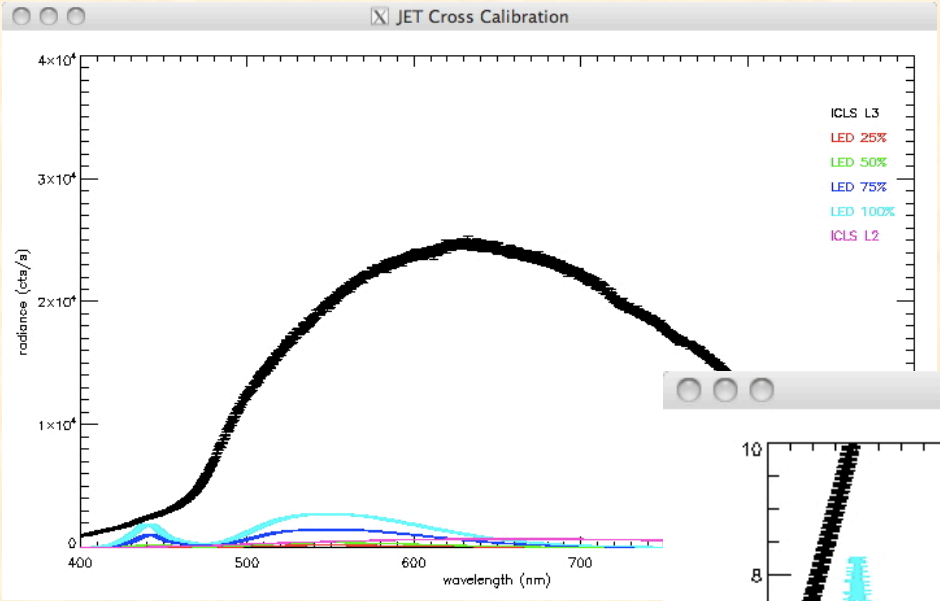
LED "torch" details

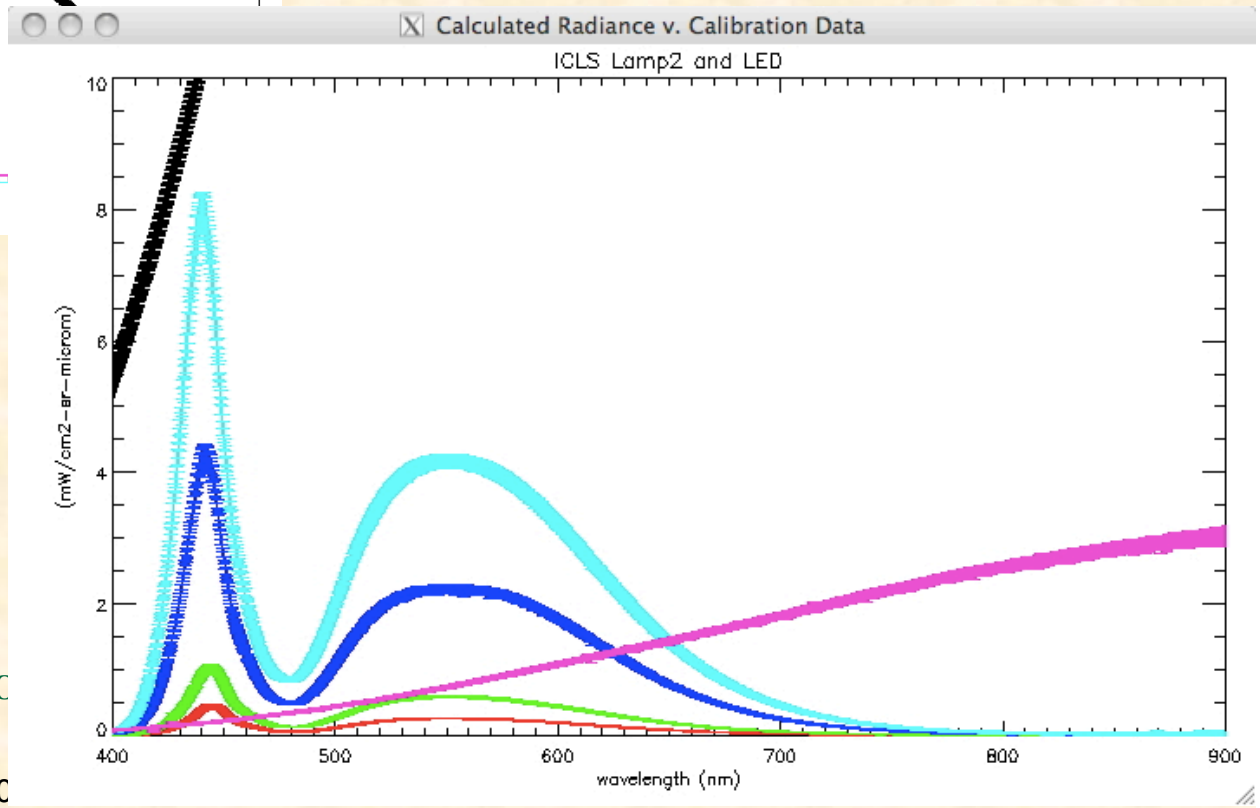
- **THORLABS: MCWHL2**
  - **~80 cd (400 lm)**
  - **"white" spectrum**
  - **50,000 hr lifetime**
  - **~5% stability over 60 s**



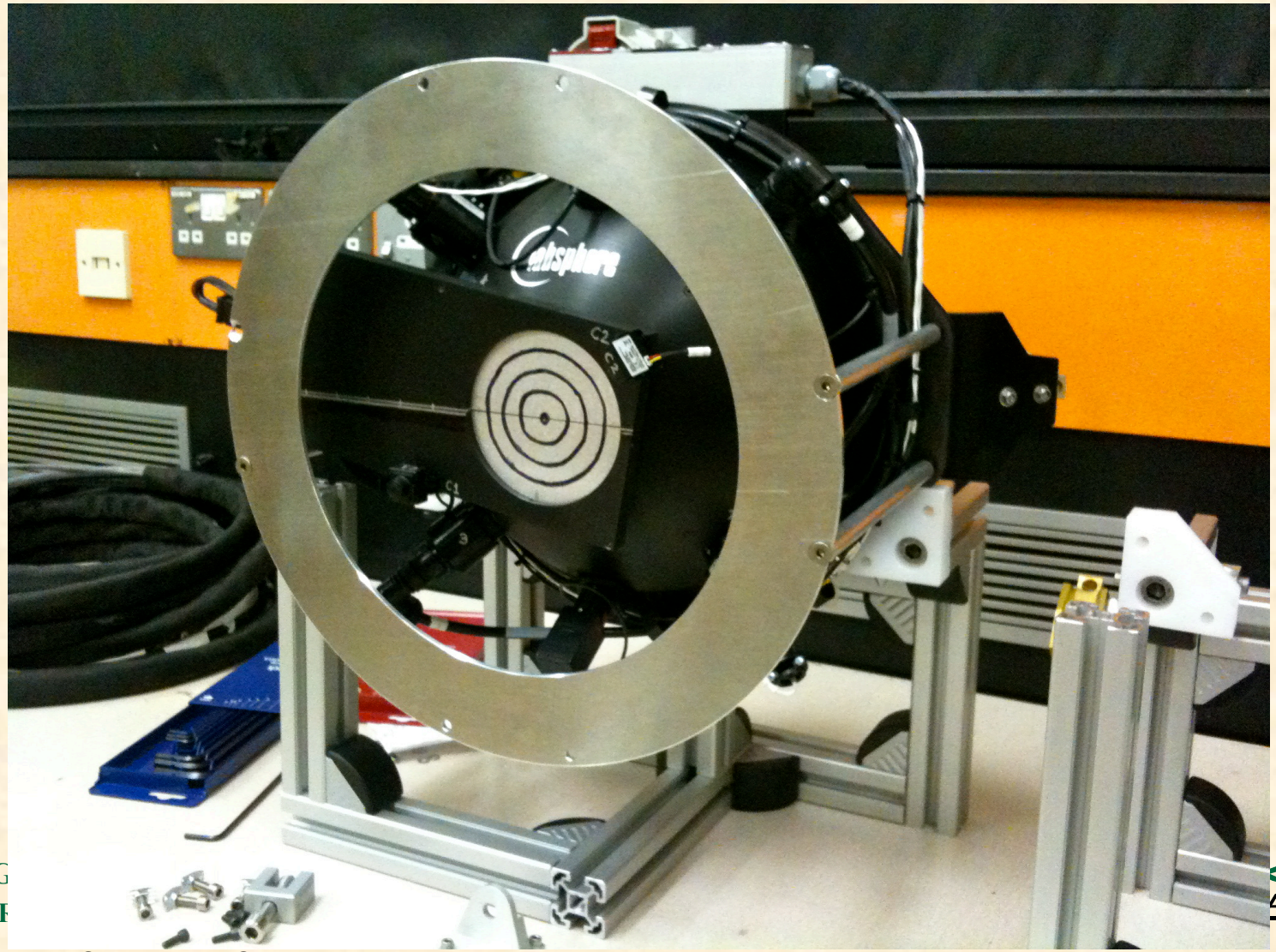


LED torch characterization

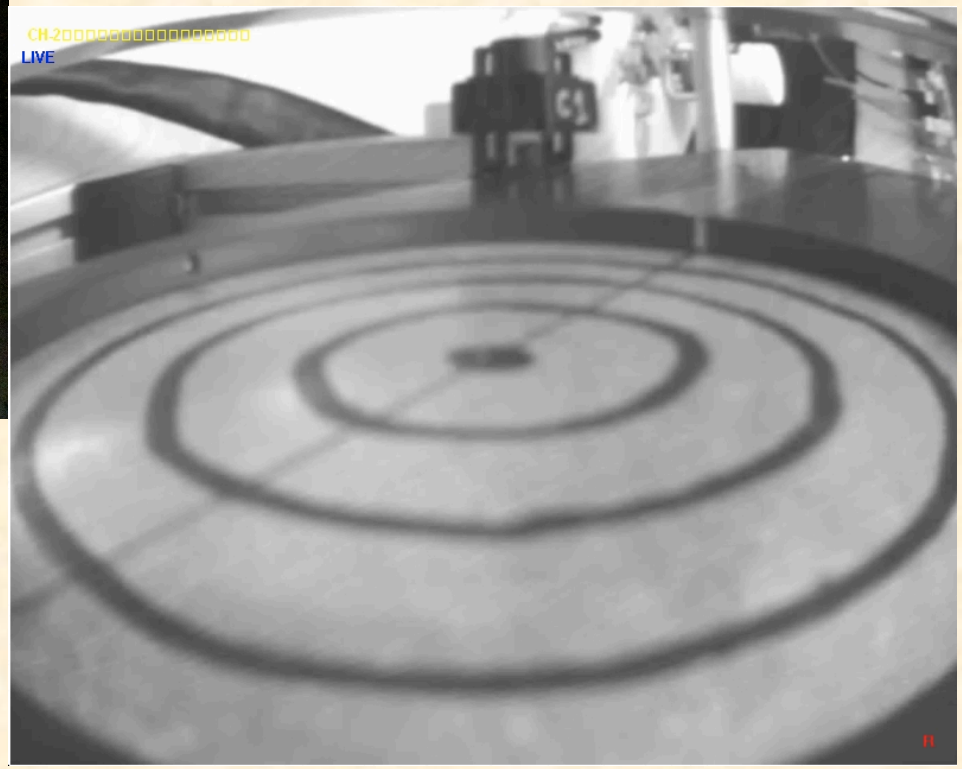


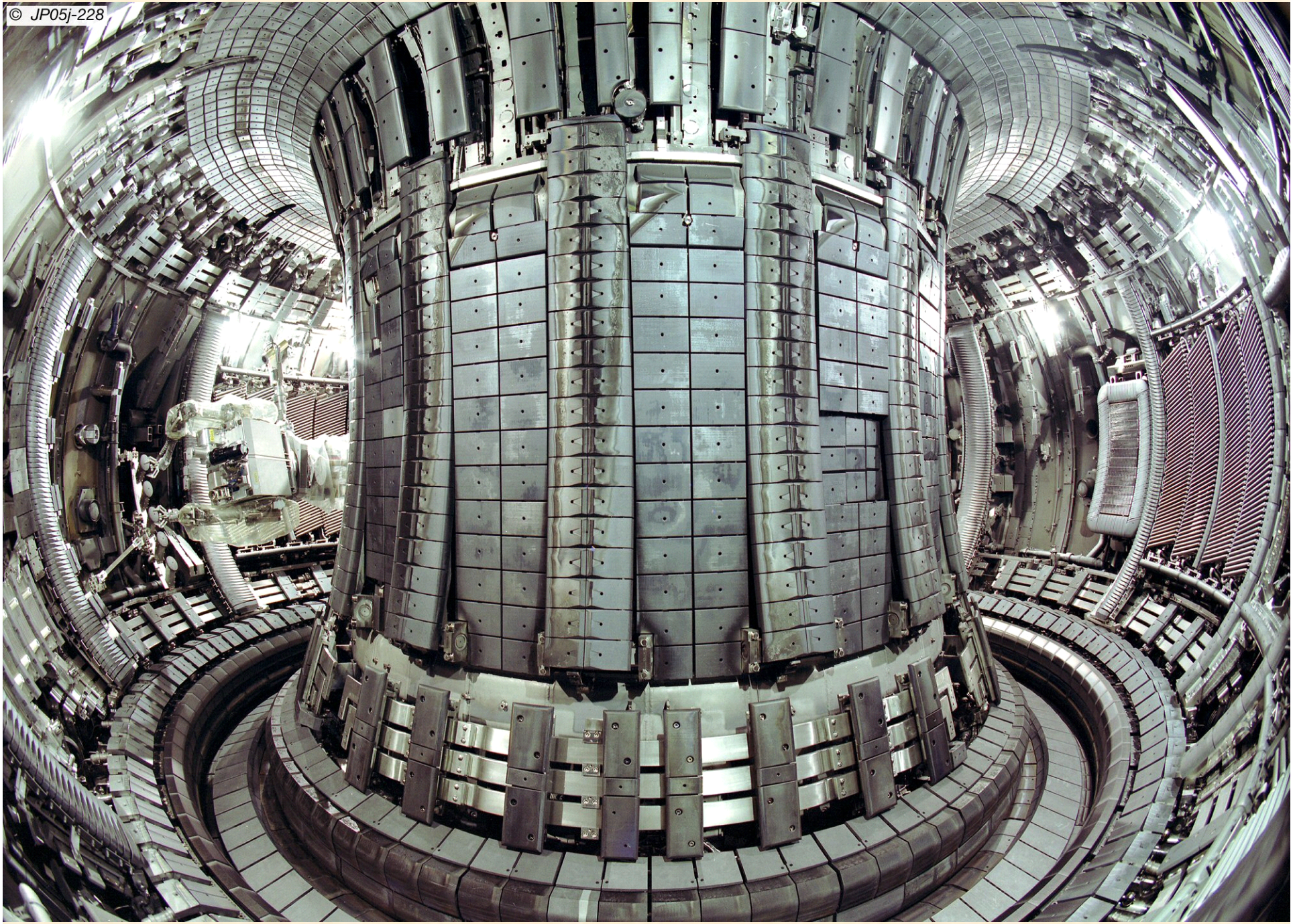


ICLS as of Sept. 13, 2010



Landmarks on shutter guide alignment

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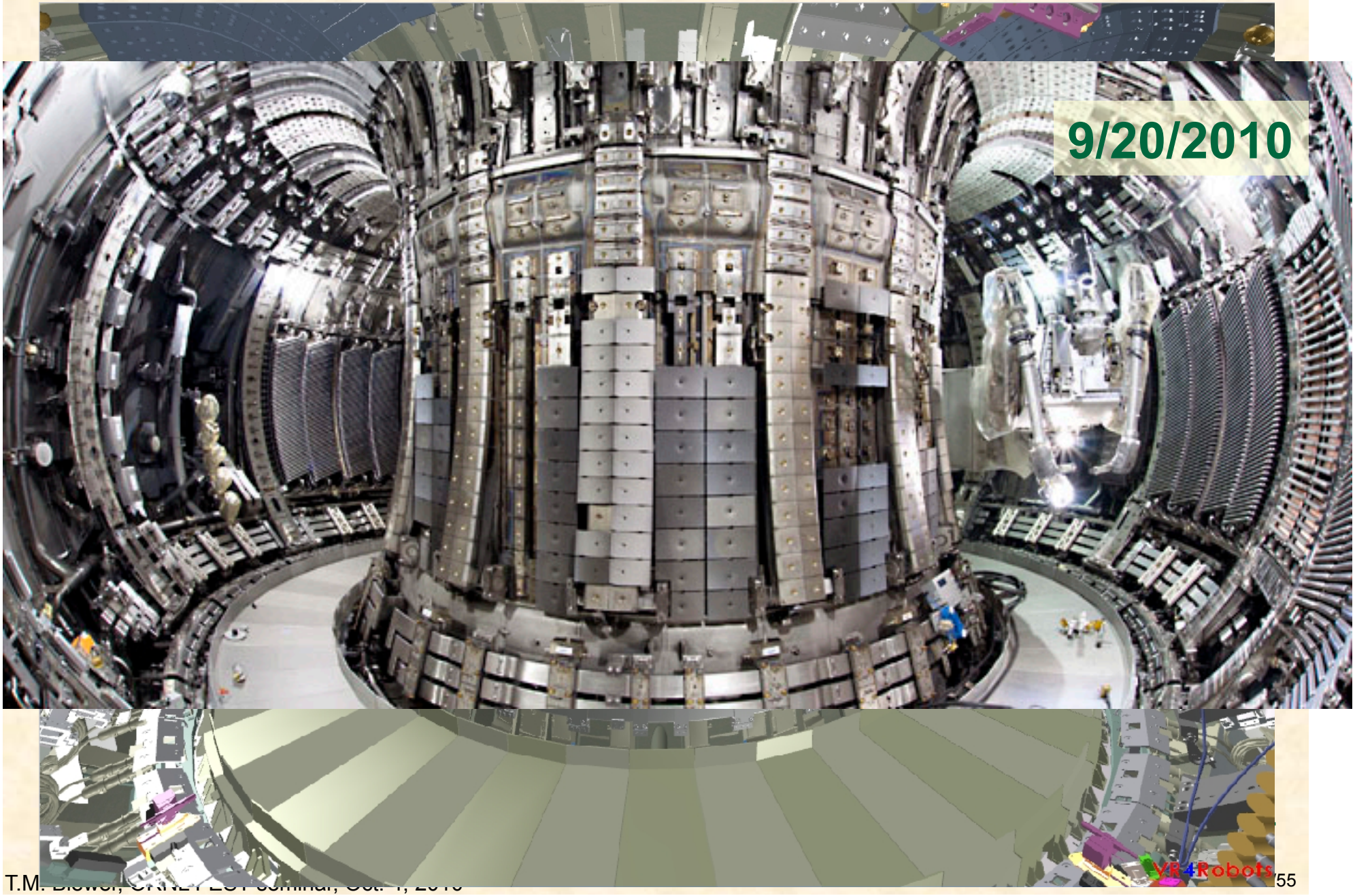
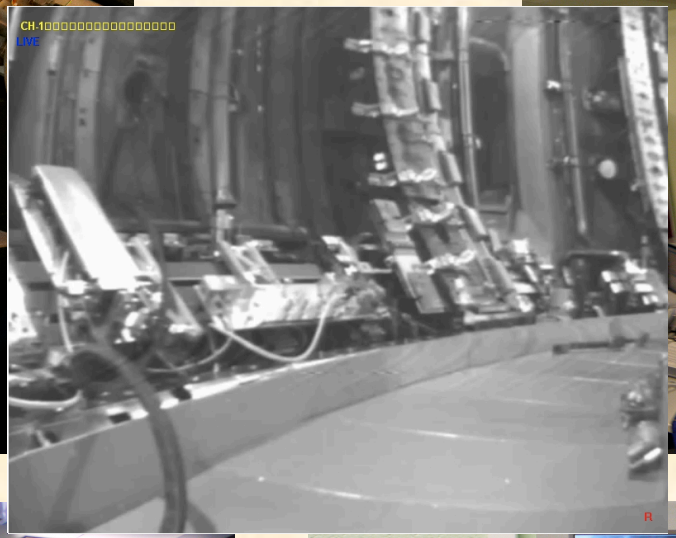
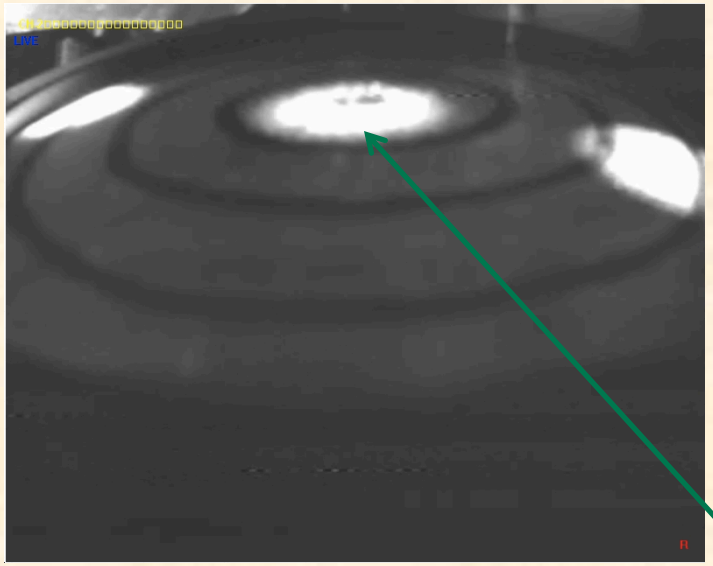
In-vessel Status on 7th September 2010

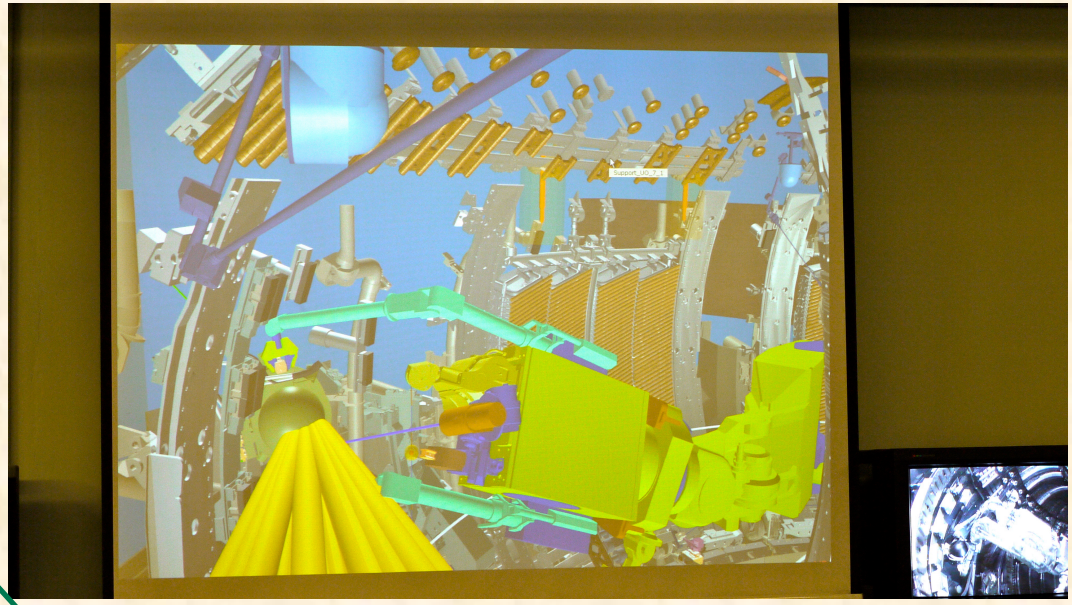


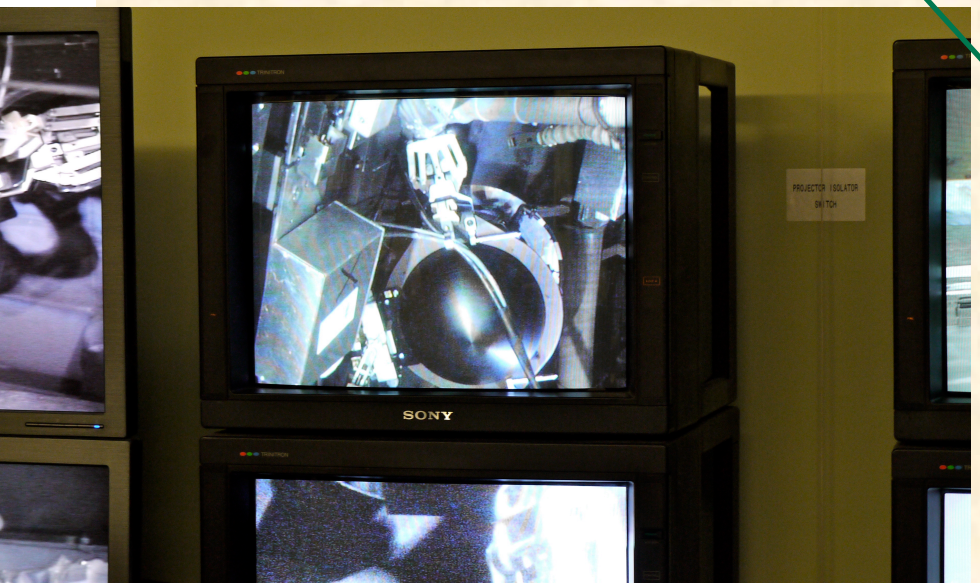
ICLS operation from RH control room



KS5 (CXRS) Calibration (8.5 hrs)



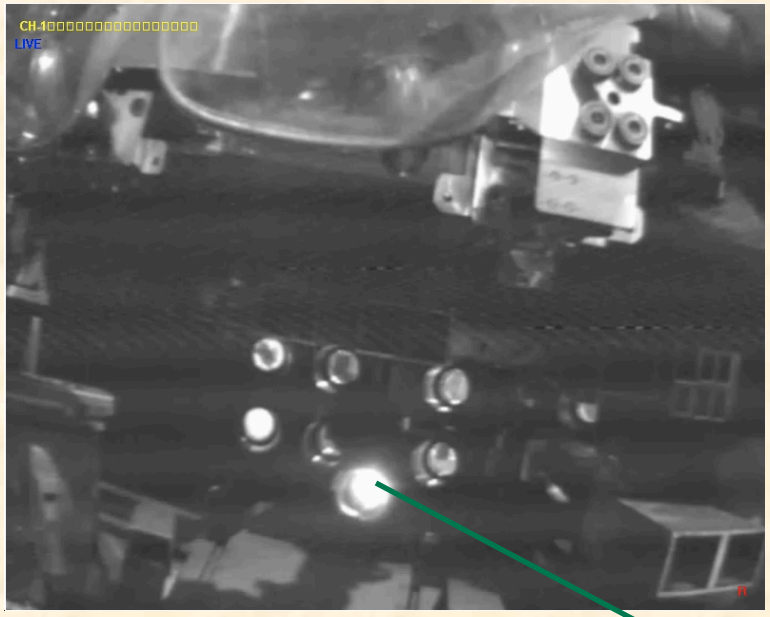




- Back-lit lines of sight centered on ICLS target
- Entire sightline array captured.
- 2 hrs positioning, 6.5 hrs calibrating

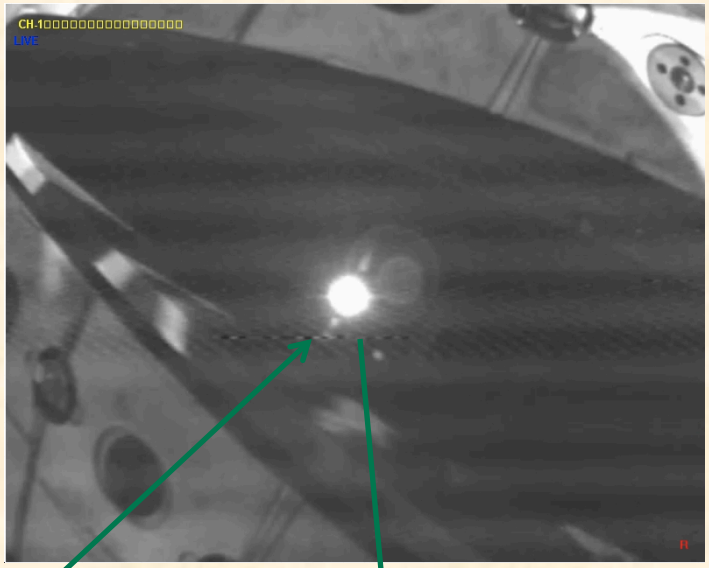
UT-BATTELLE

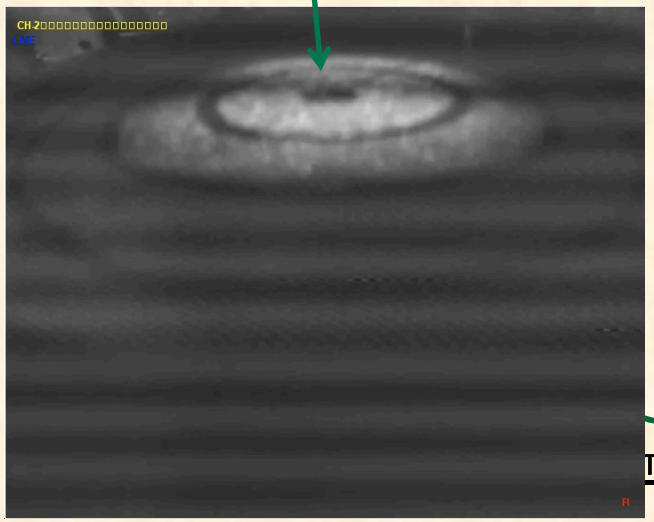
KL7 (IR camera) Calibration (2 hrs)



- **Single line of sight aligned to bullseye**
- **0.5 hr positioning, 1.5 hr calibrating**

KT7 (VUV spectr.) Calibration (2hrs)





- **FF Cam 1 clearly shows misalignment of sightline through port.**
- **Alignment tweaked, saves the diagnostic.**
- **1.5 hrs positioning, 0.5 hrs calibrating**

KS7 (eCXRS) Calibration (15 hrs)

- **Octant 4 Lower Port**
  - **1 hr positioning**
  - **4 hrs calibrating**
- **Octant 8 Lower Port**
  - **0.5 hrs positioning**
  - **6 hrs calibrating**
- **Octant 4 Upper Port**
  - **0.5 hrs positioning**
  - **3 hrs calibrating**

1st "block" of ICLS calibrations

- Sept. 13-15: scheduled 1st block
- Sept. 15-17: calibrations took place
  - Continuous from 8:00am (9/15) to 2:00am (9/17)
  - Used 42 hrs of 46 hr allotment (finished early)
  - Lamp "on" for 27 hrs: 64% duty factor
- Calibrated (all or in-part): KE11 (HRTS), KL7 (IR spec.), KS3 (div. spec.), KS5 (CXRS), KS7 (eCXRS), KS8 (vis. Brem.), KT7 (VUV spec)
- ICLS positions "saved" for easy revisiting.
- Direct in-vessel v. ex-vessel (with window transmission) calibration comparisons for KS5 and KS8: to be analyzed

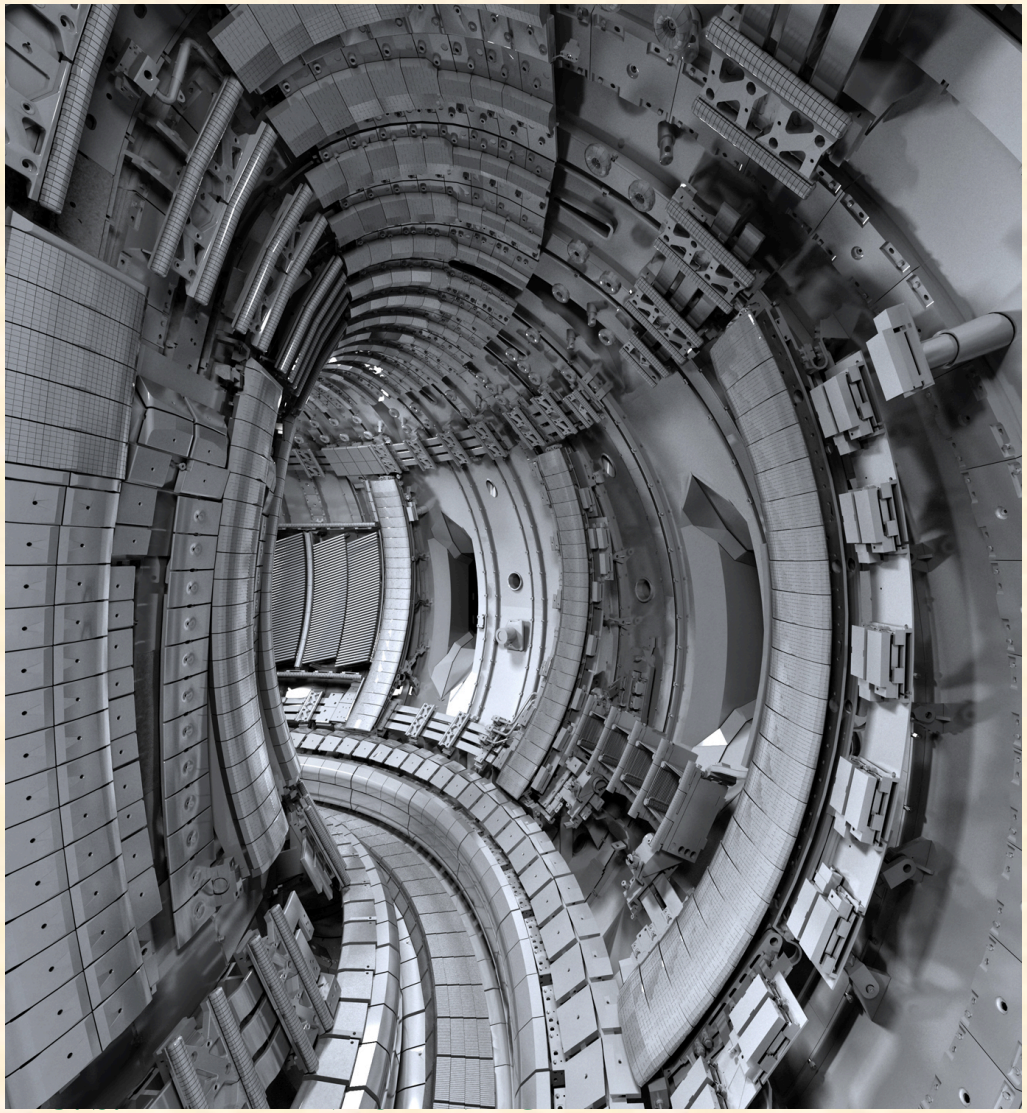
Schedule for ICLS

- 1st block of calibrations
  - September 15-17, 2010
- 2nd block of calibrations (?)
  - 5 days (ouch): October 25-29, 2010?
  - 2-3 day split: October 20-22, 2010?
- 3rd block of calibrations (??)
  - 3-2 day split: November 17-19, 2010?
- Storage of ICLS until 2012 intervention
  - Electronics in Mike Stamp lab
  - ICLS head in KT4 controlled area?
- Feedback to Labsphere on design and control program improvements
- Cross-calibration data analysis
- Calibration data analysis

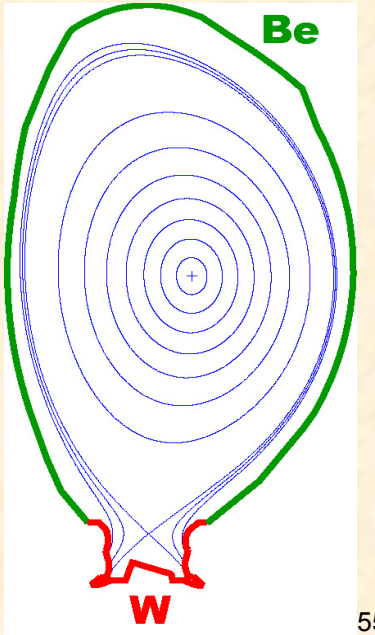
Schedule for JET

- Since Nov. 2009: "ITER-like Wall intervention"
  - Every protective tile being replaced in JET
- In-vessel activities until Dec. 30, 2010
  - 7-day/week activity to meet deadline
- Ex-vessel activities until March 29, 2011
- Plasma Restart on April 25, 2011
- Experimental Campaign begins June 27, 2011
  - Short maintenance breaks
- Next "Intervention" in 2012
  - Use of ICLS again in-vessel at JET for calibrations
- ? ? ? until JET end-of-lifetime ~2016

ITER-like wall in JET

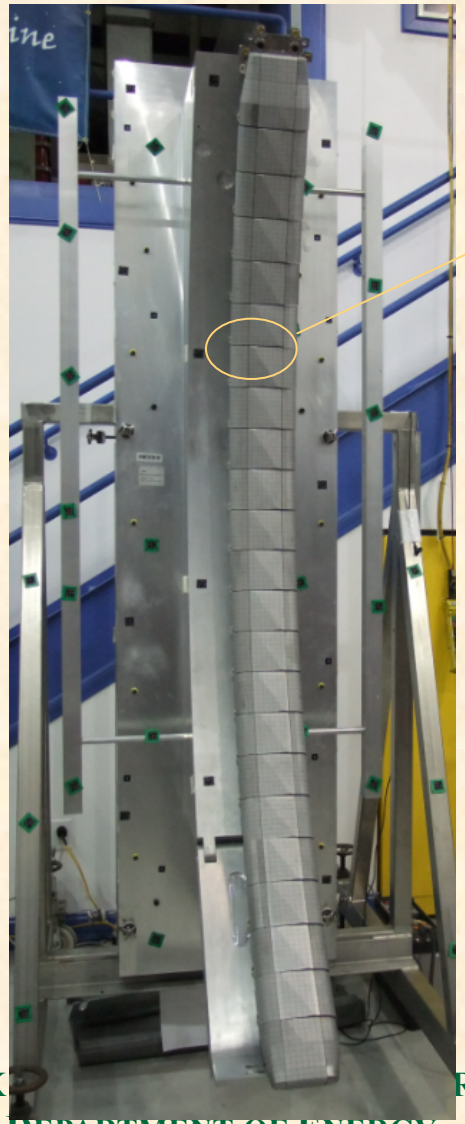


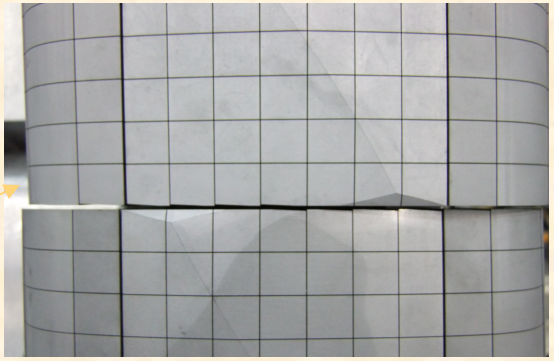
- ~8000 protective tiles (CFC) replaced
- Be (solid/coated) in main chamber
- W (solid/coated) in divertor

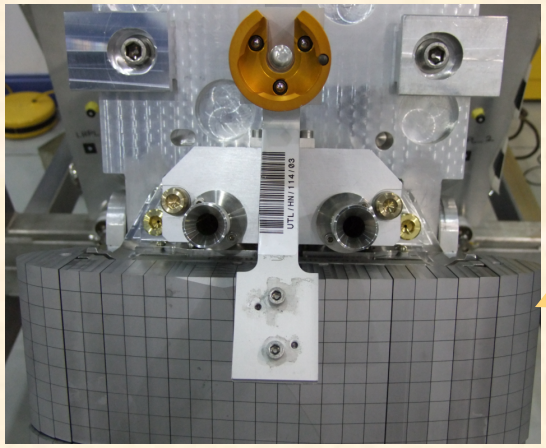


Example of beryllium limiter tiles on jigs

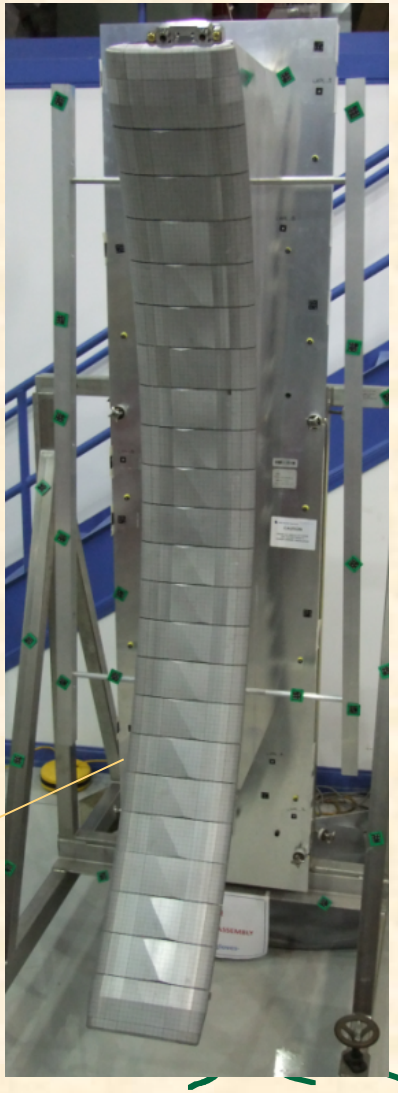
Narrow Poloidal Limiter







Wide Poloidal Limiter

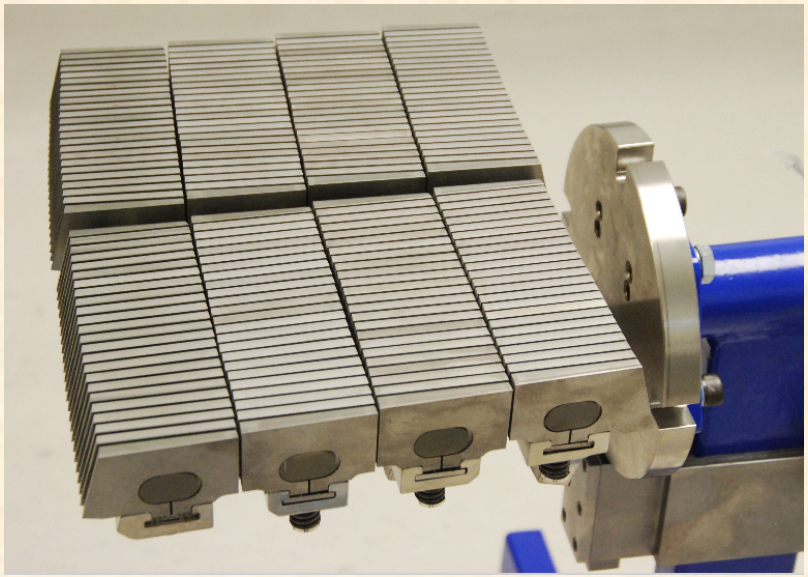


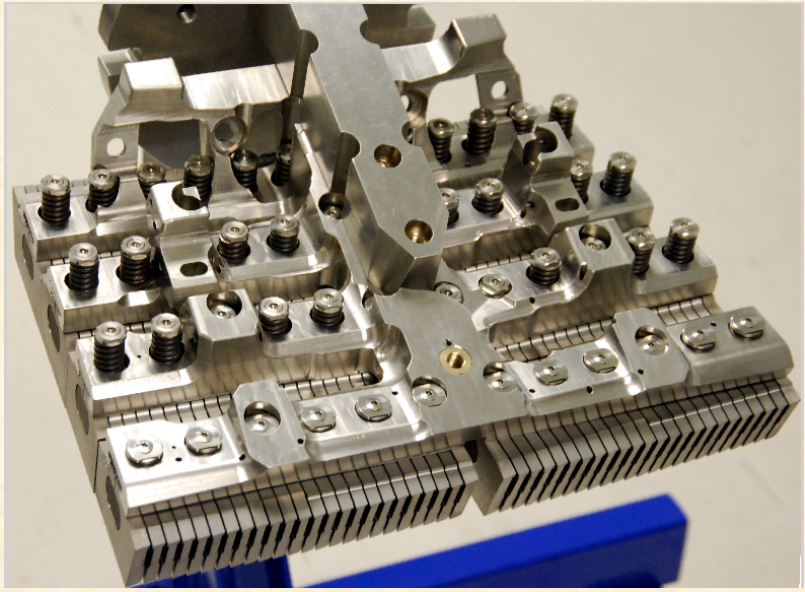
“Solid” tungsten divertor

The **bulk W LBSRP** now appears consistent with the installation plan.

First off assembly with real parts (apart from springs) went very well

- A tribute to the attention to detail of the FZJ team

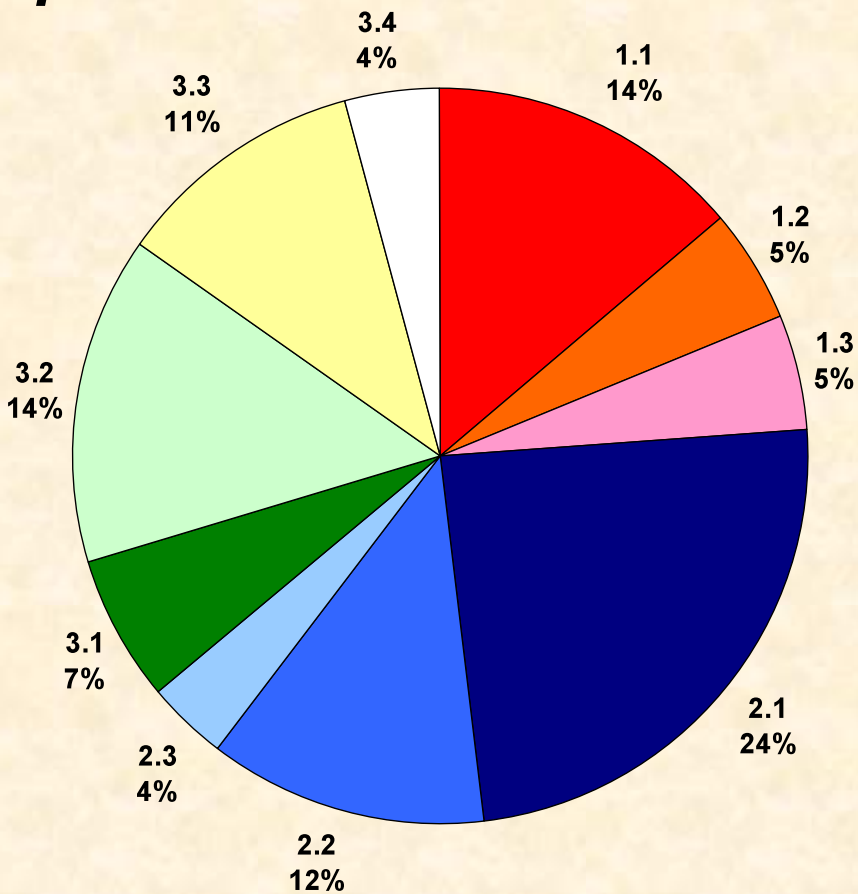




Embedded diagnostics: All thermocouples and coils are now scheduled to be available consistent with the installation plan.

Headlines for the experimental programme in 2011

Status (September 2010): 202 proposals for experiments



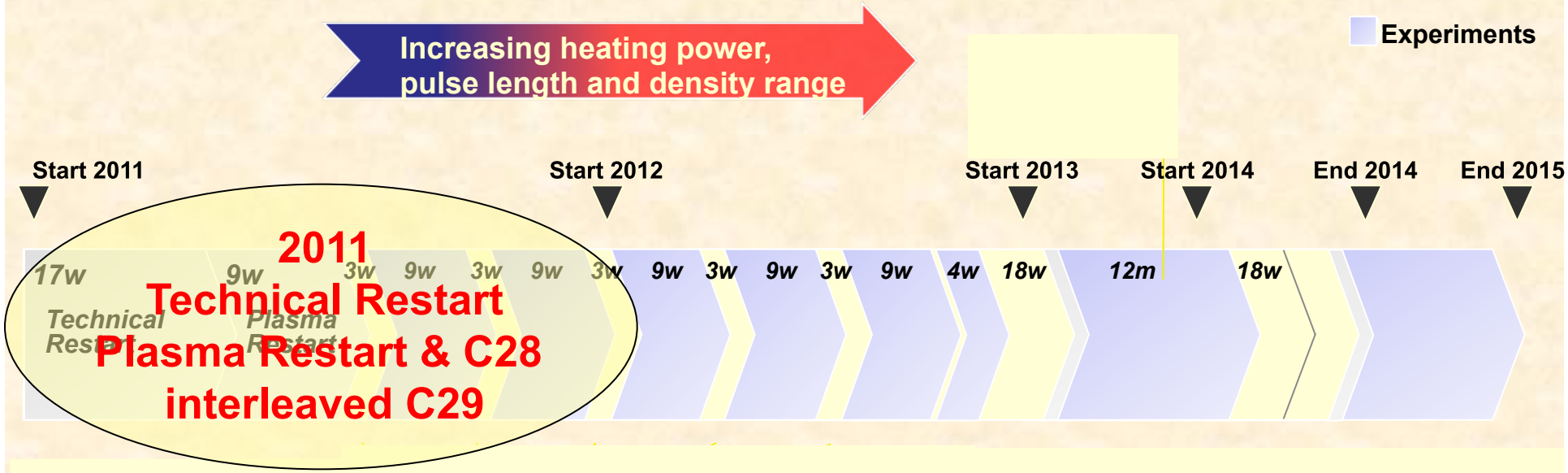
1. **Characterisation of the ITER-like Wall**
   - 1.1 Fuel retention and material migration
   - 1.2 Material limits and long term samples
   - 1.3 Transient and steady state power loads
2. **Exploration of ITER operating scenarios with the ITER-like Wall**
   - 2.1 Develop plasma scenarios.
   - 2.2 Assess plasmas scenarios
   - 2.3 Explore scenarios in domains closest to ITER dimensionless parameters
3. **Physics issues essential to the efficient exploitation of the ILW and ITER**
   - 3.1 Divertor and Scrape-Off Layer physics
   - 3.2 Confinement, pedestal and ELM physics
   - 3.3 Disruptions, MHD and fast particle physics
   - 3.4 Diagnostic issues for ITER

2011: Restart/Experiments

Vessel pump down	**Day 1**
Torus Hall beams and doors closed	week 5
Conditioning and commissioning without plasmas	
Initial commissioning complete	week 13
First plasma attempt	
Start C28	
Block 1 (ohmic: Restart & experiments)	week 14
Block 2 (L-mode low power: Restart & experiments)	week 17
Block 3 (First H-modes: Restart & experiments)	week 23
Block 4 (Start higher power operation)	tbd
Campaign C29	**29-Aug to 16-Dec 2011**

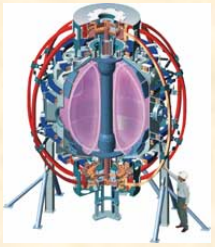
Ohmic
L-mode
H-mode
High power H-mode

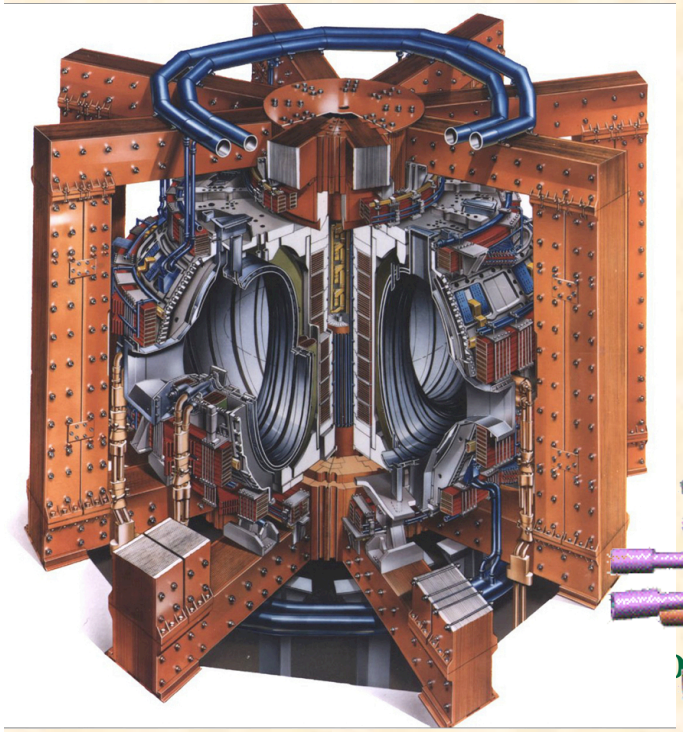
JET: A five year perspective

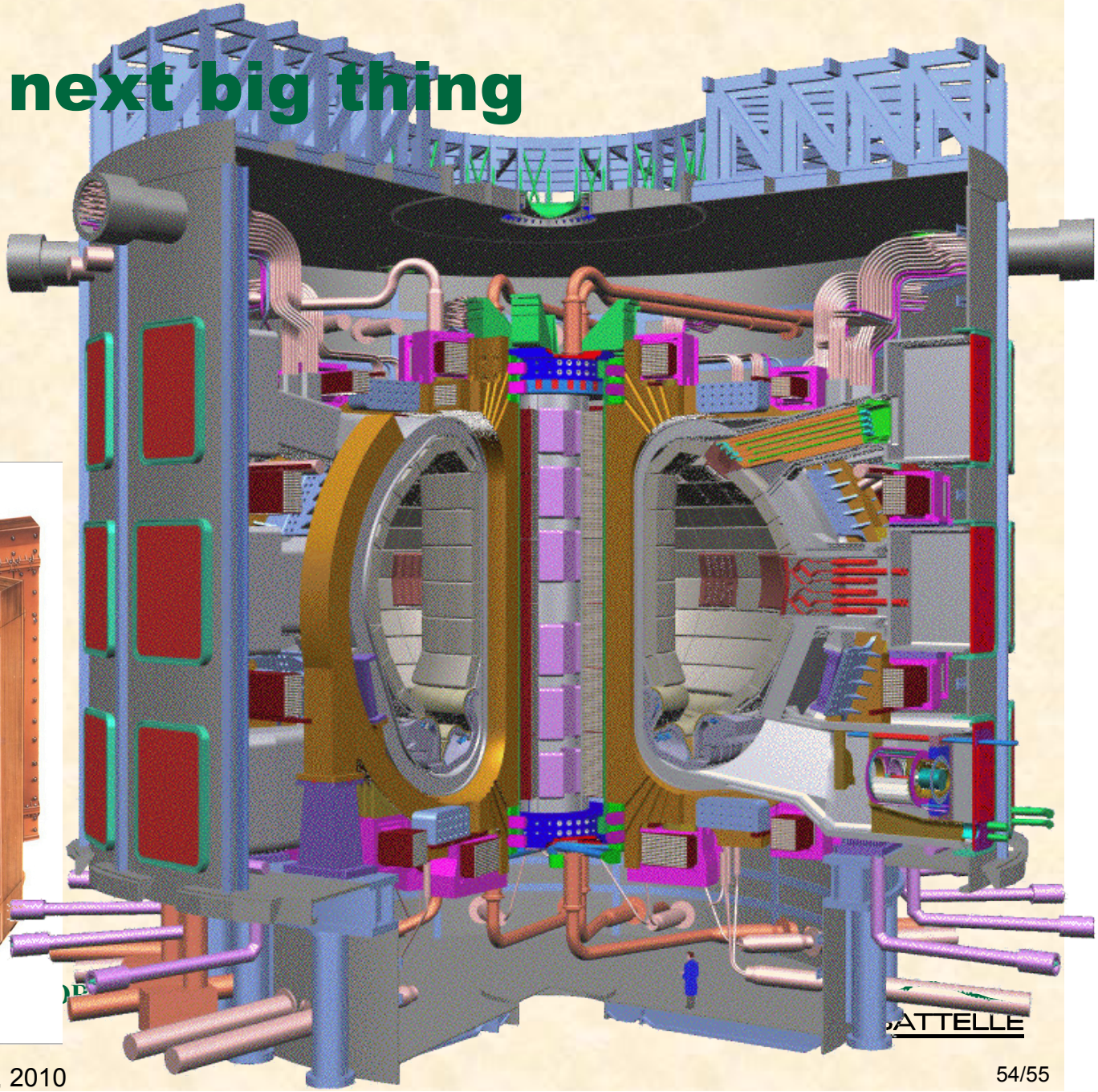


- Logical sequence of Restart and experiments (staged/phased approach, key deliverables, long term view)
- Specific experiments need to be done early
- During 2011-2013: A natural sequence of plasma operation followed by intervention(s) to remove samples, etc.
- **Emphasis for WP2011 : Complete studies of fuel retention and material migration**
  Initial scenario developments with the ILW

ITER: the next big thing







Summary/Future Work

- The In-vessel Calibration Light Source (ICLS) has been developed to calibrate visible diagnostics at JET
  - Calibrations in Sept./Oct. 2010
  - Box ICLS until 2012
  - Comparison of the improvement of measurement accuracy with ICLS
  - Present results at HTPD, EPS, APS, . . .
- The ICLS at JET is a demonstration technology for ITER