In-Vessel Neutron Calibrations Planning, Progress, Constraints

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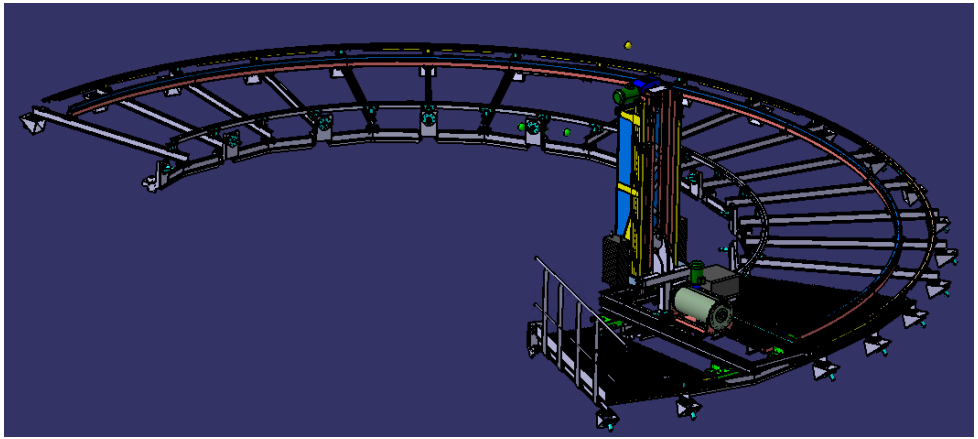
Introduction

- **The purpose of the In-Vessel Neutron Calibration is to calibrate the Neutron Diagnostics in order to obtain accurate measurements of:**
  - Neutron fluence
  - Fusion Power
  - Fusion Power Density
  - Neutron and Alpha source Profile
  - Neutron Yield
- **Important: Fusion Power and Tritium accountancy**
- **How:**
  - A neutron source is placed in the VV and irradiates the neutron diagnostics with known neutron fluxes, at predetermined positions/times, with energy distributions as close as possible to the plasma emission
  - ITER Machine neutronic models validation
- The calibration measured data and the validated model allow to **correlate detectors count rates to the measured parameters**



IVNC 1st Campaign Staging

IVNC Neutron Generator and control unit (NG-24 by VNIIA)

Introduction

- IVNC Campaigns need to be repeated periodically for:
  - Neutronic models progressive improvement
  - Compensate for machine configuration changes
  - Compensate for long term detectors drifts and wear out effect in the machine

- 1st Campaign:
  - 3 Calibrated Diagnostics: NFM in EP#1, NAS in UP#18 and DNFM
  - Few irradiation points
  - First correction of the models: methodology consolidation

- 2nd and 3rd Campaigns:
  - Calibrated diagnostics and irradiation points maximization
  - Progressive improvement of the models
  - Machine configuration toward completion

- Following Campaigns
  - To compensate machine wear out and detectors drift

IVNC Schedule

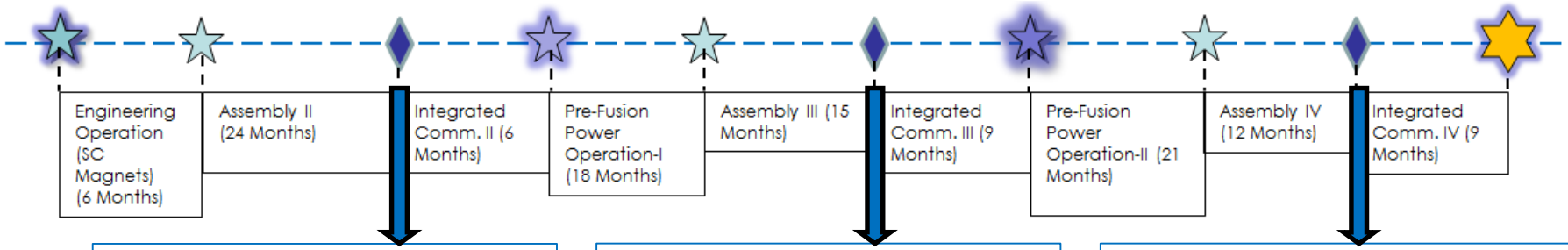
IVNCs shall be performed periodically

FP
First Plasma

PFPO-I
Start of Pre-Fusion Power Operation-I

PFPO-II
Pre-Fusion Power Operation-II

FPO
Fusion Power Operation



IVNC – 1
In-Vessel deployment tool

IVNC – 2
Remote Handling - ART

IVNC – 3
Remote Handling - ART

Access to the VV Allowed

Access to the VV not allowed

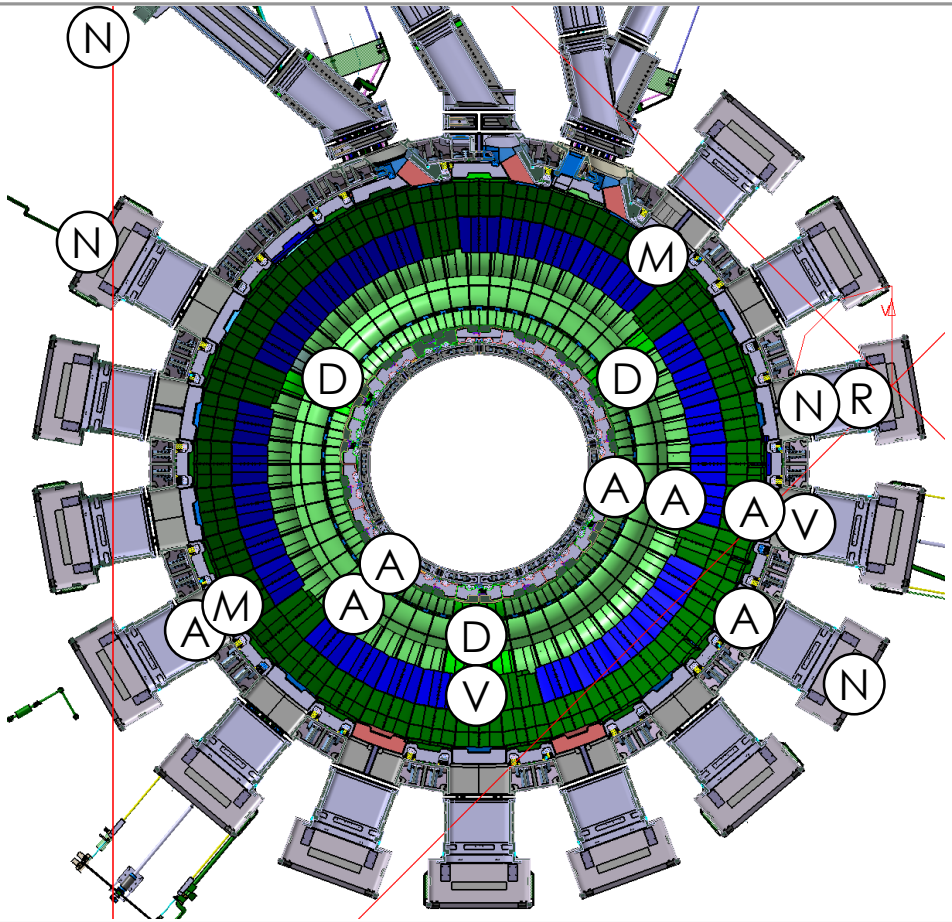
General planning

Neutron Diagnostics shall be well calibrated especially for DT operation

- ITER is a DT machine
- DD operation
  - Limited
  - Reaches low power
  - No significant Tritium production
- The baseline foresees calibration campaigns focused on DD generators
- Moving toward a strategy mainly focused on DT generators

Campaign	Phase	NG Type - Baseline	NG Type - Proposal
I	Pre-PFPO-1	DD	DD & DT
II	Pre-PFPO-2	DD	DT
III	Pre-FPO	DT	DT
Following	During Operation	DT	DT

Calibrated Diagnostics Location



- (N) Neutron Flux Monitors
- (D) Divertor Neutron Flux Monitors
- (M) MicroFission Chambers
- (A) Neutron Activation System
- (R) Radial Neutron Camera
- (V) Vertical Neutron Camera

The number of directly calibrated detectors shall be maximized

- Calibration sources limited source strength allow direct calibration of only part of the Neutron Detectors
- Through the IVNC Campaigns, we are targeting to directly calibrate at least the most sensitive detector in the location specified below:
  - NFM#1 (1/4)
  - One MFC location (1/2)
  - NAS in UP#18, EP#17, VV surface in Sector 9 (4/8)
  - Two DNFM locations (2/3)
- Cross-Calibrations with standard plasma discharges will be performed for the other diagnostics

Can we calibrate the Cameras in-situ?

Neutron Source Choice

The neutron source used during IVNC shall be as close as possible to the fusion plasma source.

- Former candidates:
  - DD Campaigns: ^{252}Cf (2.5 MeV neutrons)
  - DT Campaigns: Neutron Generators (14 MeV neutrons)

- **Current choice: Neutron Generators only (2.5 MeV and 14 MeV)**

- Californium discarded because:
  - Difficult recovery
  - High activity
  - Difficult shielding
  - Highly regulated

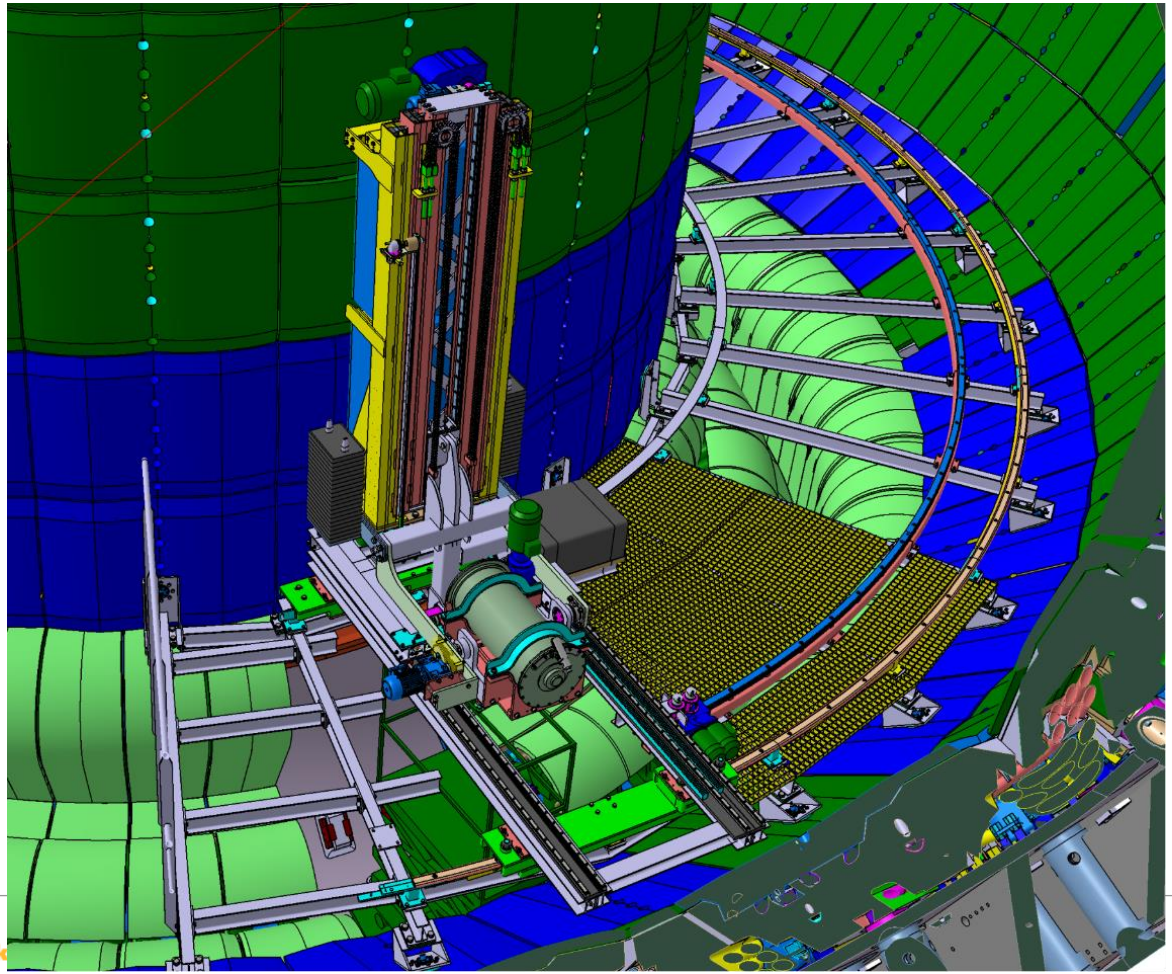
Required Machine Condition

Calibration conditions shall be as close as possible to operation conditions

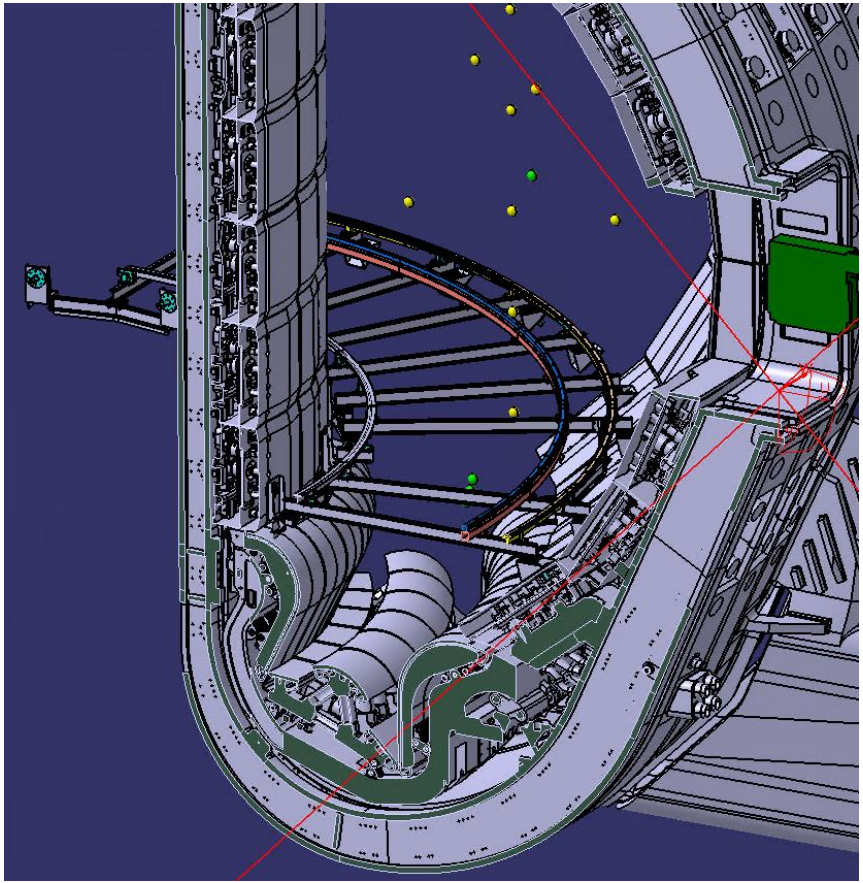
- As close as possible to Operation conditions
  - Blanket modules in place
  - Divertor Cassettes in place
  - Port Plugs in place
  - Cooling water in IBED loops (room temperature and 1 bar)

- Set of already commissioned systems:
  - Calibrated Diagnostics
  - IBED cooling loops
  - 55.BV components

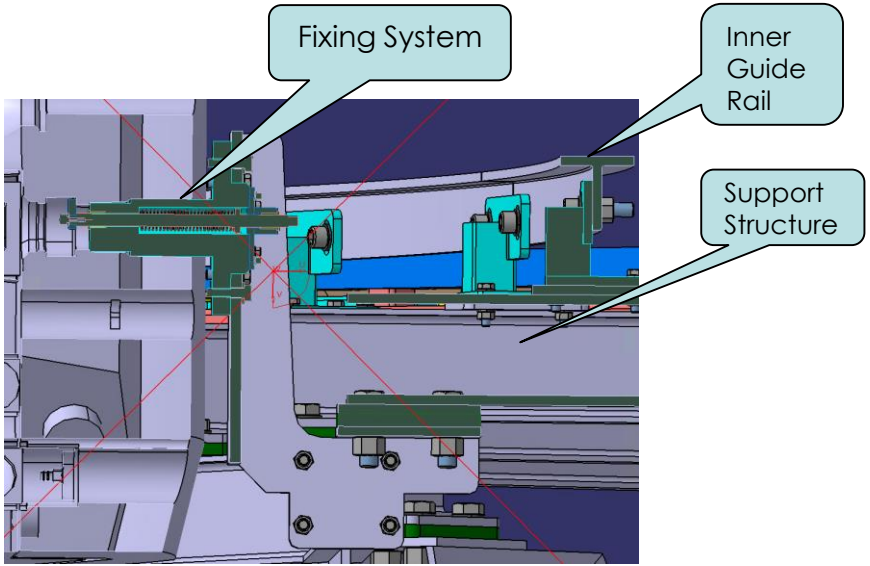
Campaign 1



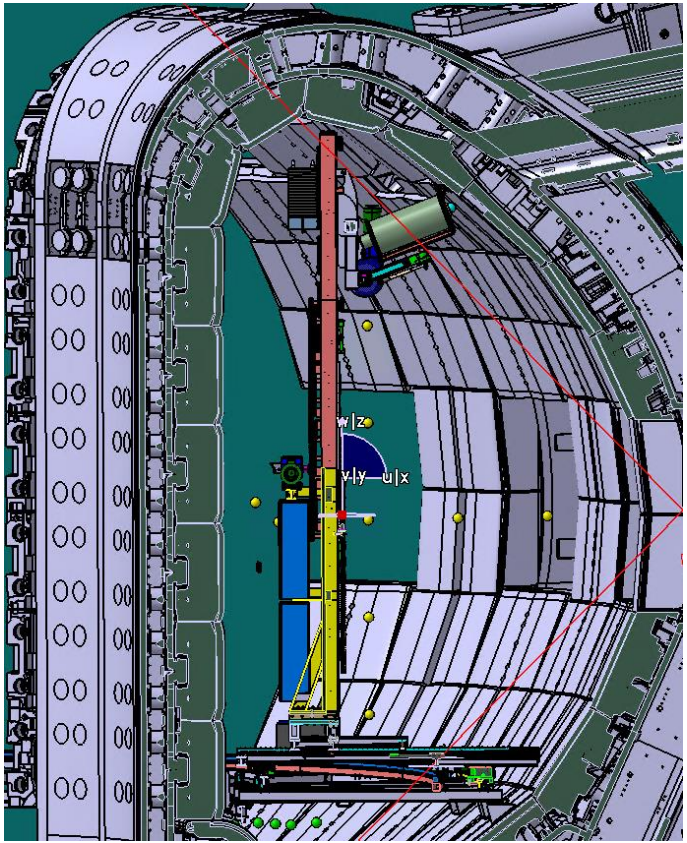
Campaign 1 – Support Structure & Railway

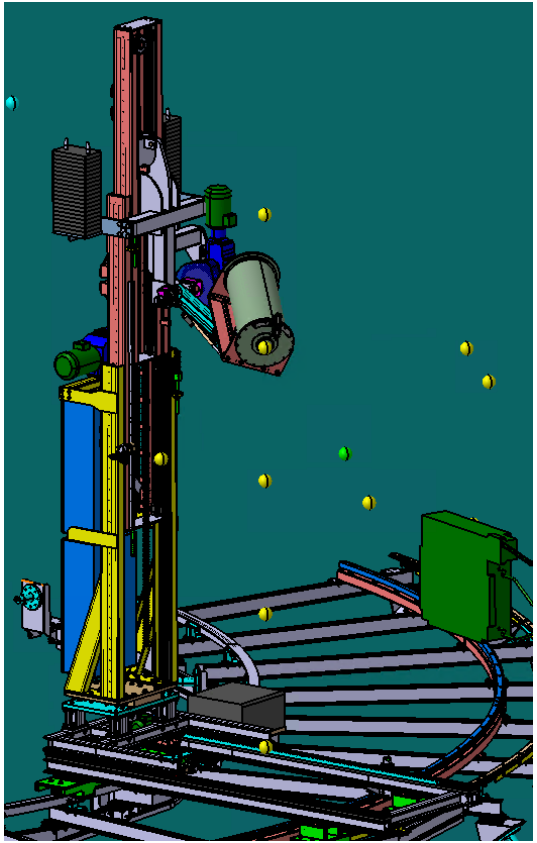


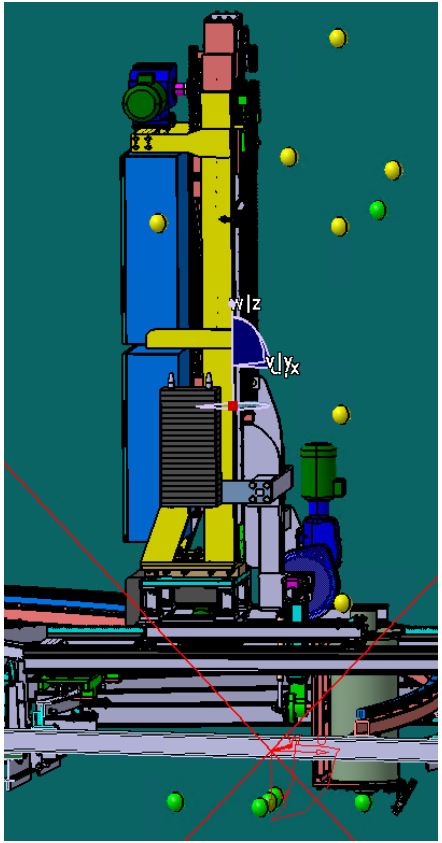
- A Support Structure is installed on the Fixing System which is pre-installed in the Blankets by MA
- Guiding Rails are used by the Tool to move toroidally.
- The complete angle of this Railway is 210°



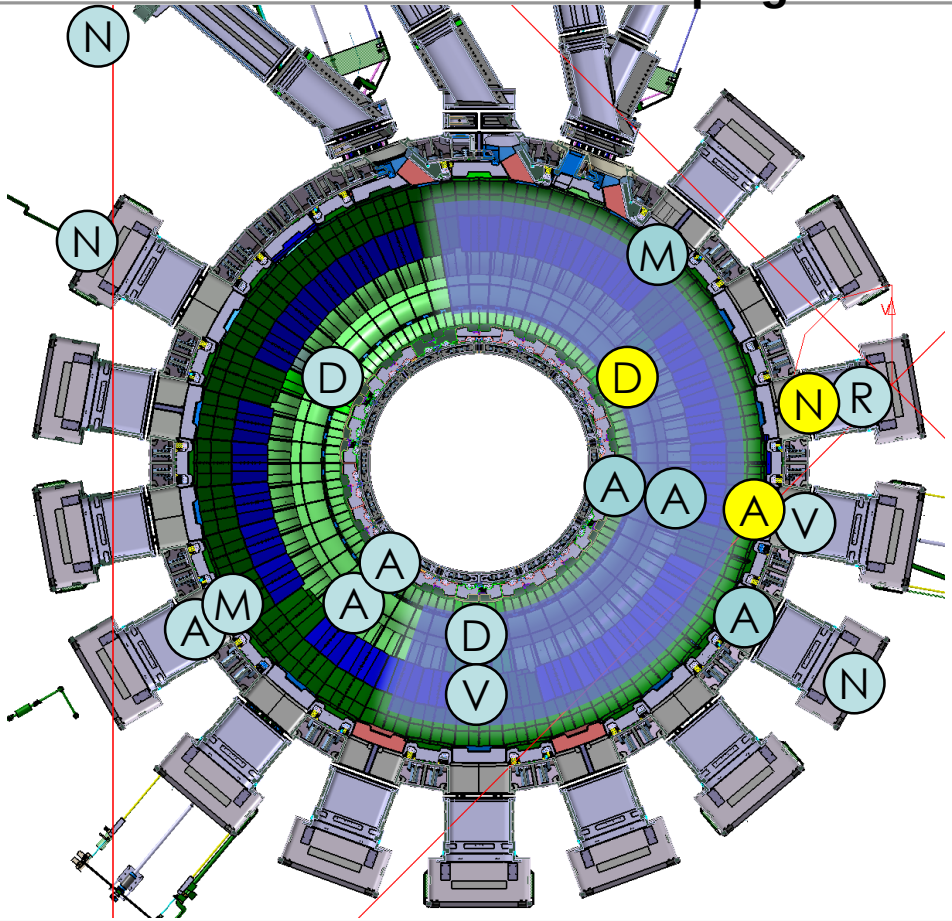
Campaign 1 – Some NG Positions







Campaign 1 - Target Diagnostics



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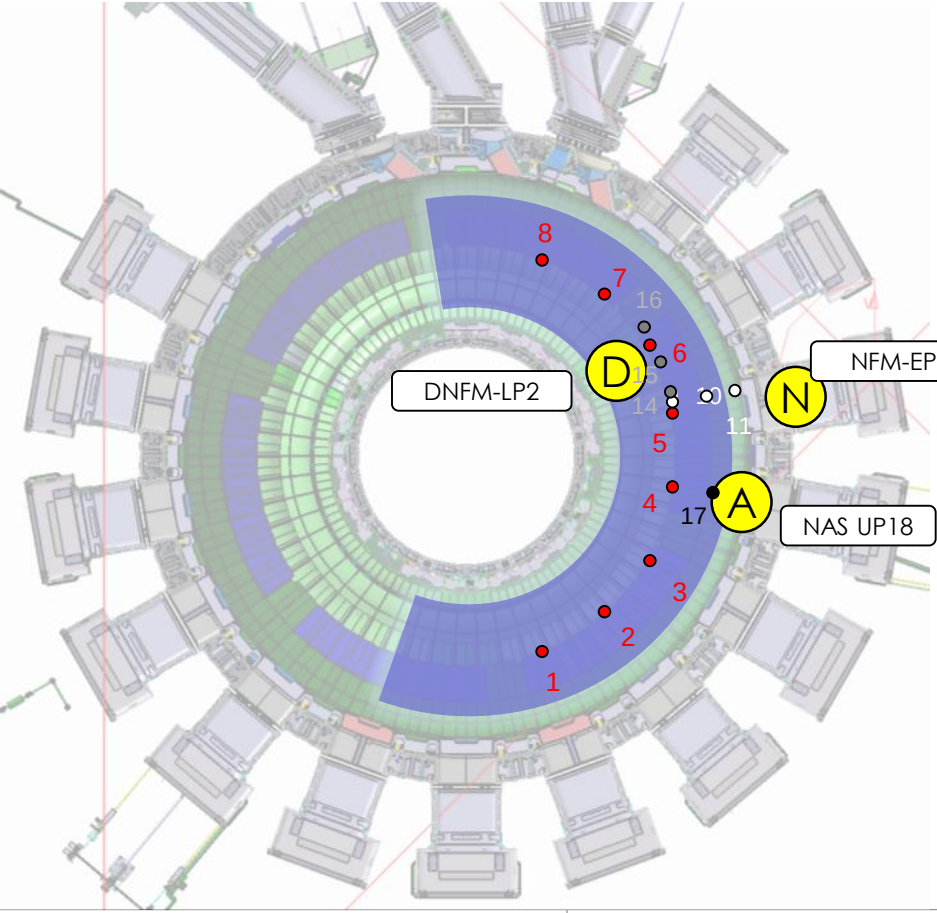
Targeted Diagnostics

1st Campaign Staging coverage

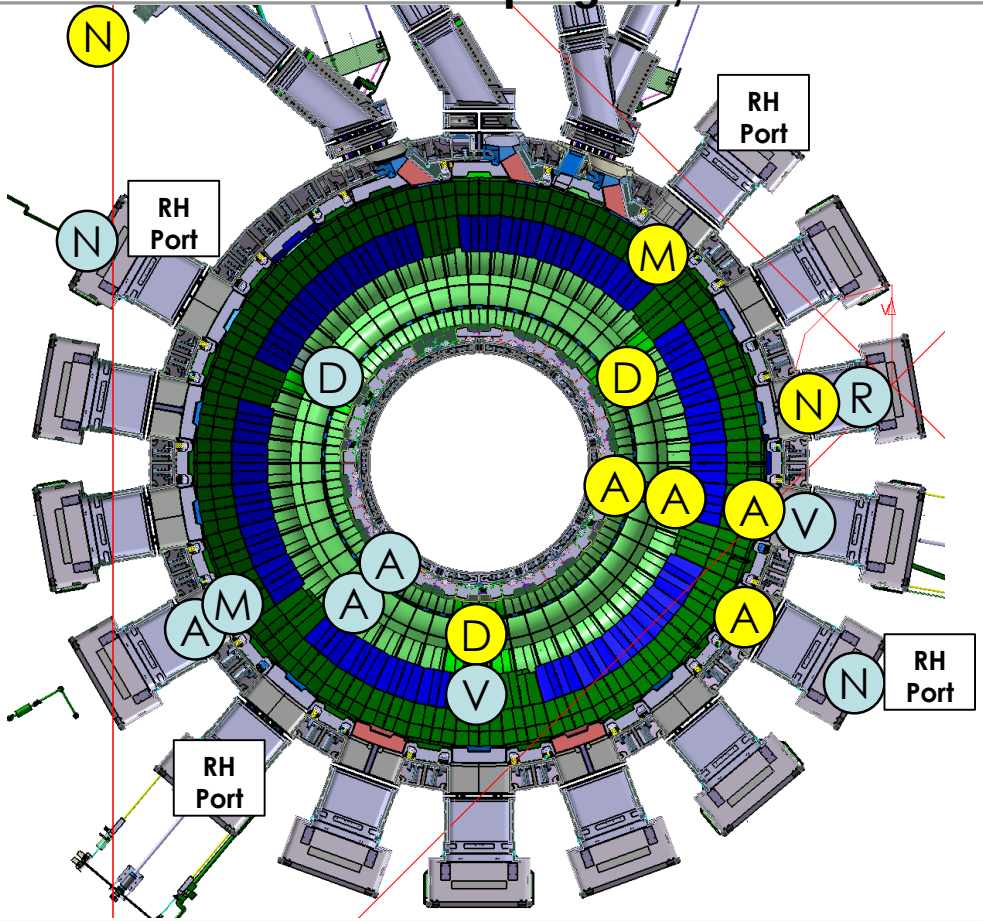
Campaign 1 - Irradiation Plan



- Toroidal scan (P1 to P8):
  - 8 irradiation positions 20° apart from each other
  - Magnetic axes level
  - Covering 140° (Port 15 to Port 4)
- Neutron Flux Monitor (P9 to P13):
  - Radial scan (3 positions)
  - Vertical scan (2 positions)
- Divertor NFM (P14 to P17):
  - One position below the staging
  - Toroidal scan just above the platform (3 points 10 ° apart)
- Neutron Activation System (P18):
  - In front of the irradiation end

Campaign 2, 3 and following

Campaign 2, 3 and following - Target Diagnostics



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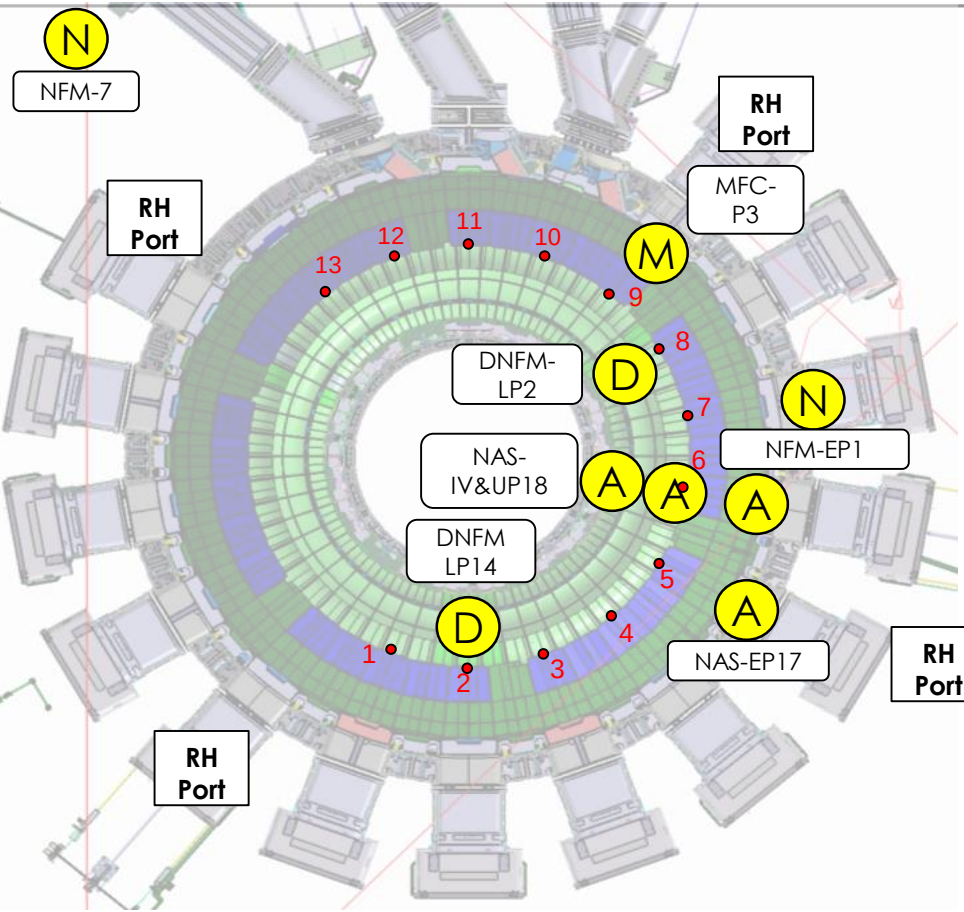
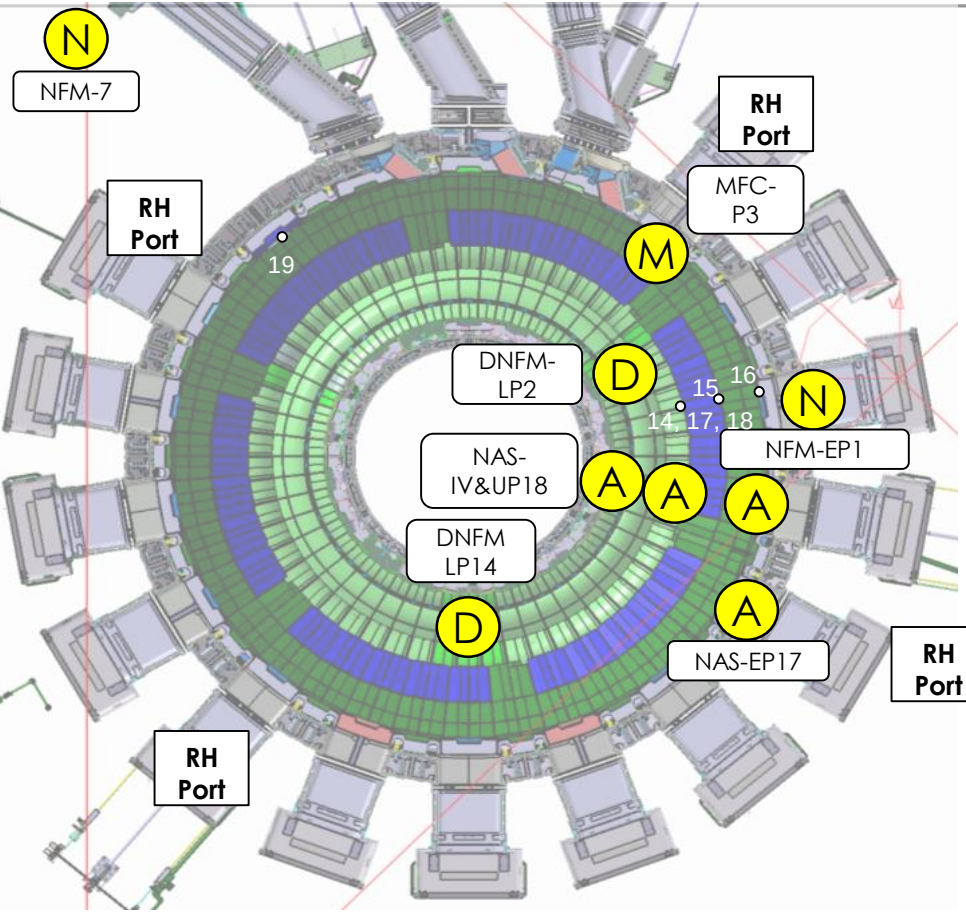
- Calibration Primary Target
- Secondary for Calibration

Campaign 2, 3 and following - Irradiation Plan



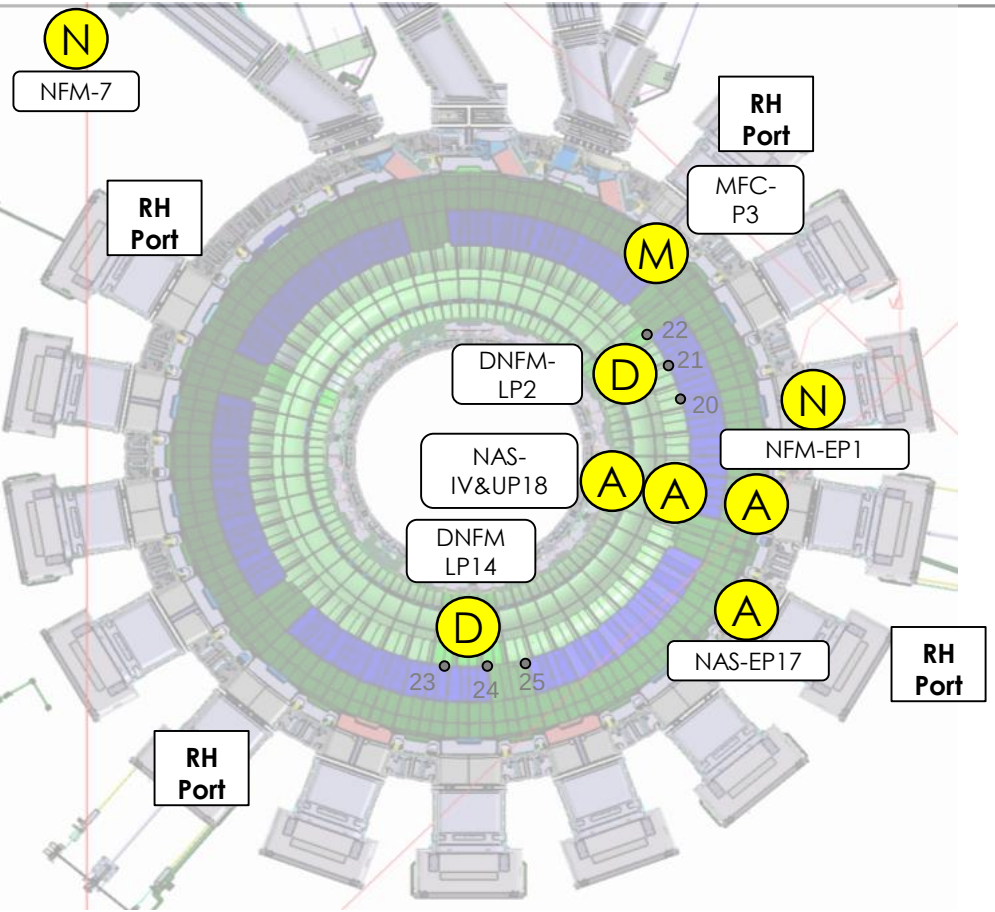
- Toroidal scan
  (13 points)
  - 13 irradiation positions 20° apart from each other
  - Magnetic axes level
  - Covering 260° (Port 13 to Port 8)

Campaign 2, 3 and following - Irradiation Plan



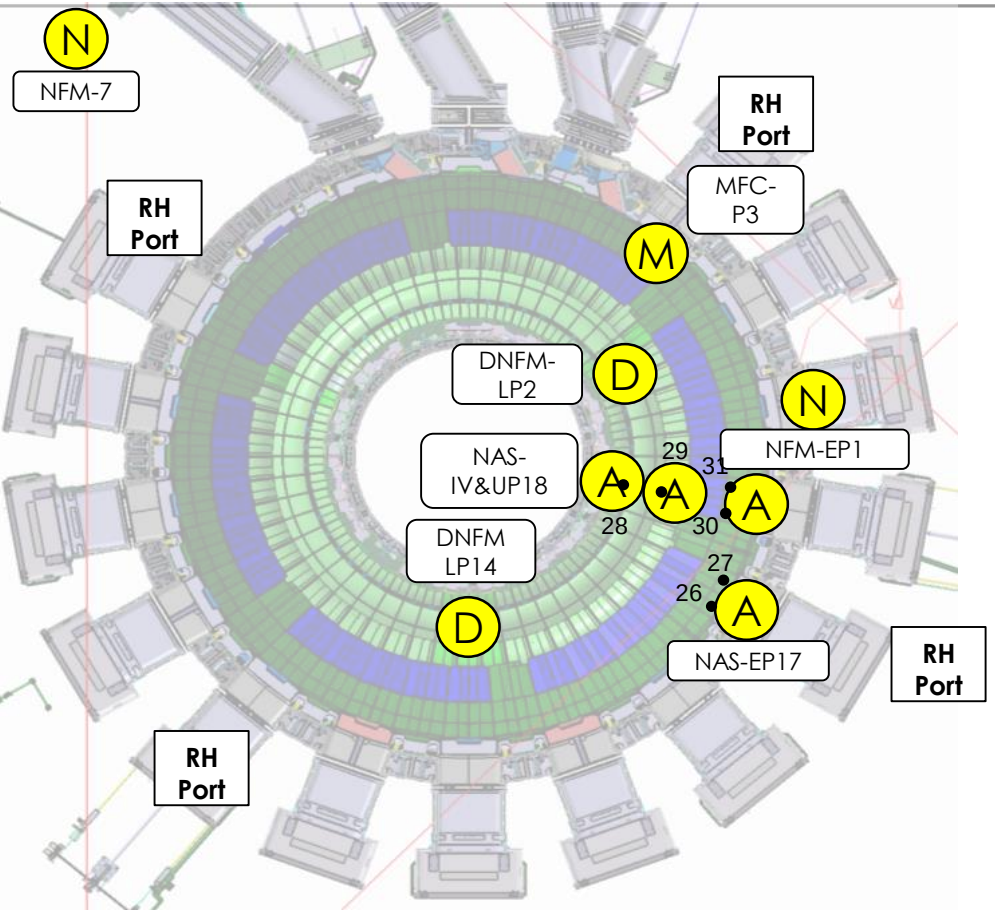
- Neutron Flux Monitors (6 points):
  - Radial and vertical scan for EP#1
  - One point for NFM#7

Campaign 2, 3 and following - Irradiation Plan



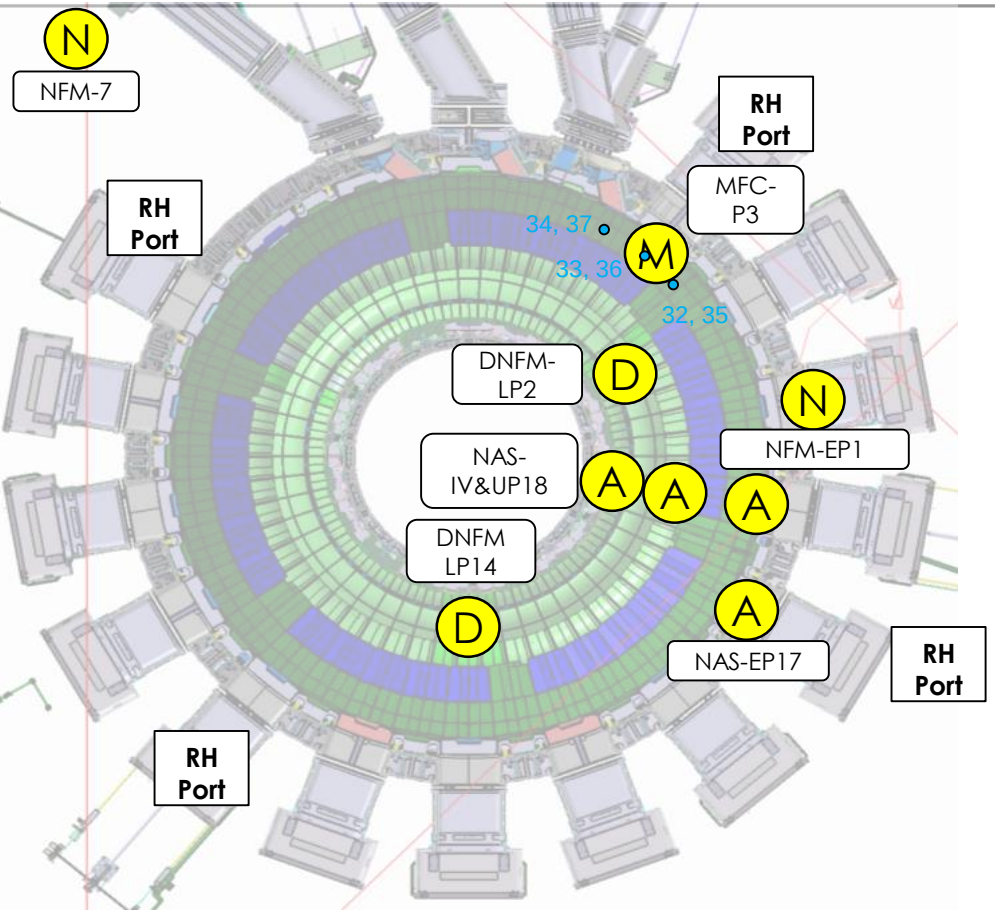
- Divertor NFM (6 points)
  - 2/3 DNFM locations
  - Toroidal scan close to the detectors (3 points/location)

Campaign 2, 3 and following - Irradiation Plan



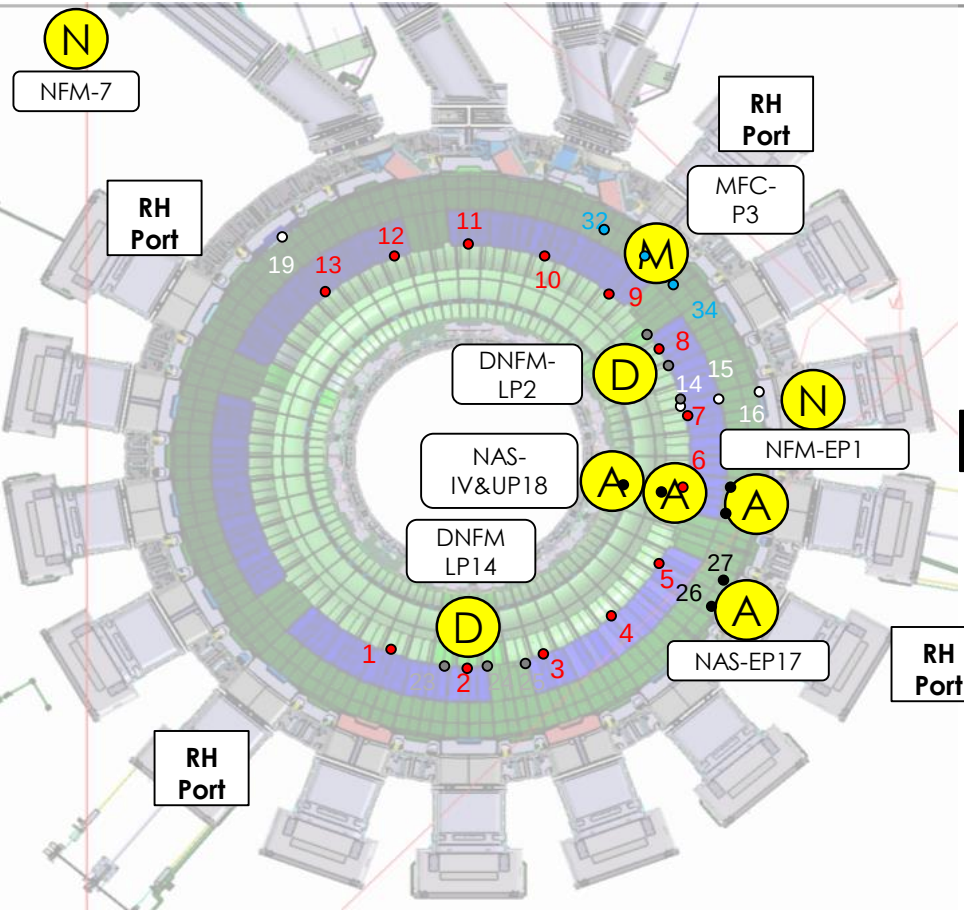
- Neutron Activation System (6 points)
  - 4/8 NAS Locations
  - One irradiation position per irradiation end

Campaign 2, 3 and following - Irradiation Plan



- Micro Fission Chambers (6 points)
  - ½ MFC locations
  - 3 toroidal positions for the upper

Campaign 2, 3 and following - Irradiation Plan Summary



- **37 Irradiation positions**
- Toroidal scan (13 points)
  - 13 irradiation positions 20° apart from each other
  - Magnetic axes level
  - Covering 260° (Port 13 to Port 8)
- Neutron Flux Monitor (6 points):
  - Radial and vertical scan for EP#1
  - One point for NFM#7
- Divertor NFM (6 points)
  - 2 locations
  - Toroidal scan close to the detectors
- Neutron Activation System (6 points)
  - One irradiation position per irradiation end
- Micro Fission Chambers (6 points)
  - 3 toroidal positions for the upper

Conclusion

- IVNC Campaigns will be crucial to achieve target accuracies and validate neutronic models
- Neutron Generators will be used to irradiate Neutron Diagnostics
- A dedicated tool (before PFPO-1) and a RH tool will be used to position the NGs in several VV locations
- Calibration Campaigns are time consuming and require specific ITER Machine configuration. Their placement in the overall schedule shall be very carefully planned

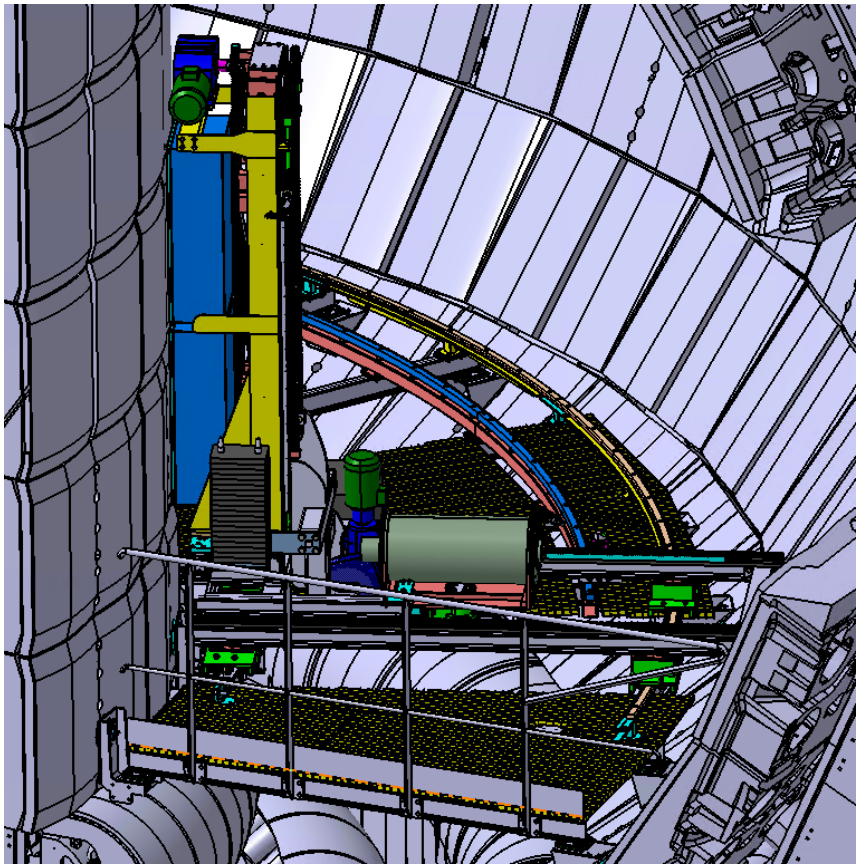
Thank you

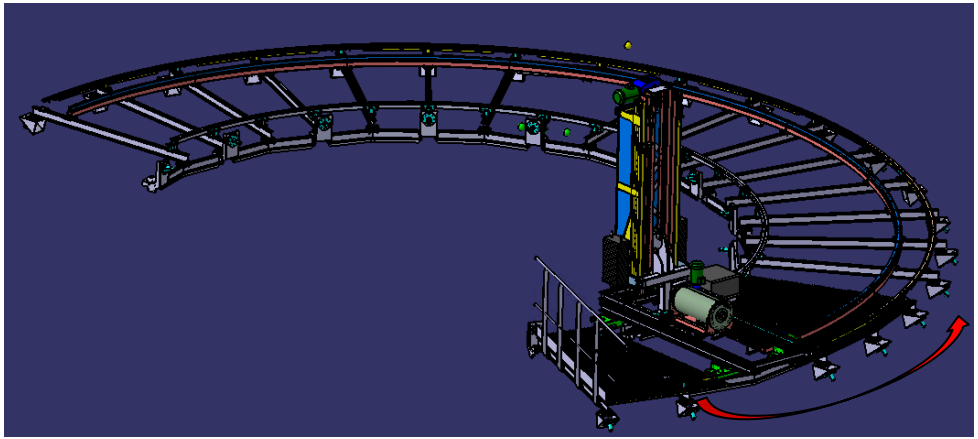
Back-up

Why IBED hot water discarded

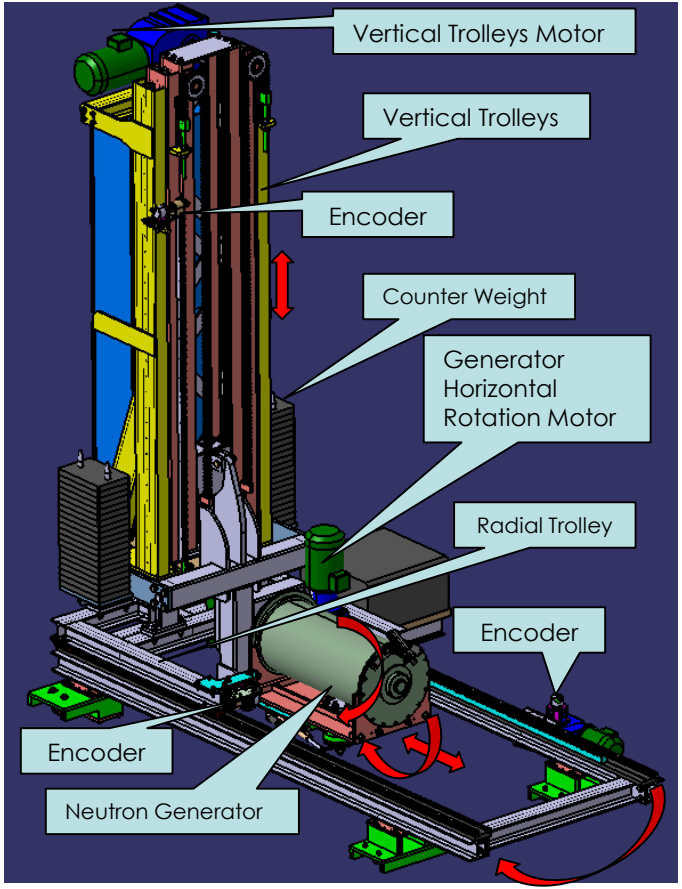
- Early integrated commissioning start (with machine in non-complete configuration)
- Double TCWS commissioning (without and with 3 DCs installed)
- Double TCWS valves calibration (2 weeks procedure)
- NG and electronics cooling difficult
- All components, including RH tool compatible with high temperature
- Long times required to fill up + heat up circuits → then cool down and drain

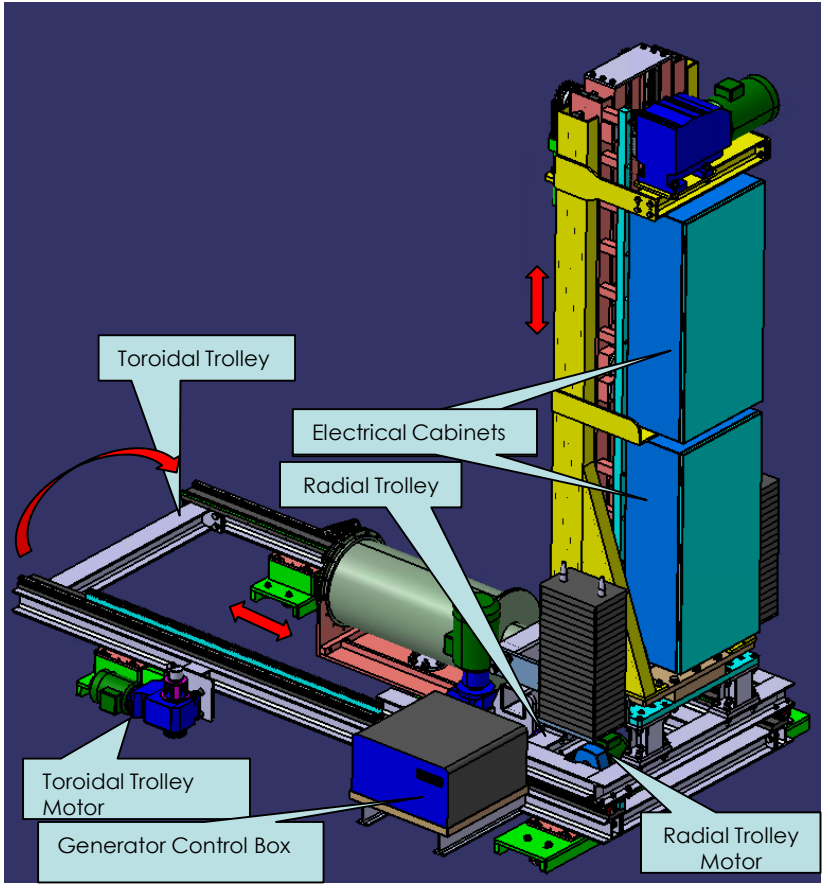
Campaign 1 – Complete view of the Tool and Its environment





Campaign 1 – Neutron Generator Deployment Tool





Performances:

Toroidal: Speed max 250 mm/s, rotation axis = Tokamak Axis, Power 0,25 Kw
Radial : Speed Max 150 mm/s, stroke 1900 mm, Power 0,12 Kw
Vertical: Speed Max 375 mm/s, stroke 6000 mm, Power 3 Kw
Generator Horizontal Rotation : Angular Speed Max 6°/s, Stroke -90° +20°, Power 0,55Kw
Generator Vertical Rotation: Stroke +/- 45°, Electrical Jack Force : 1200N

Campaign 1 - Planning

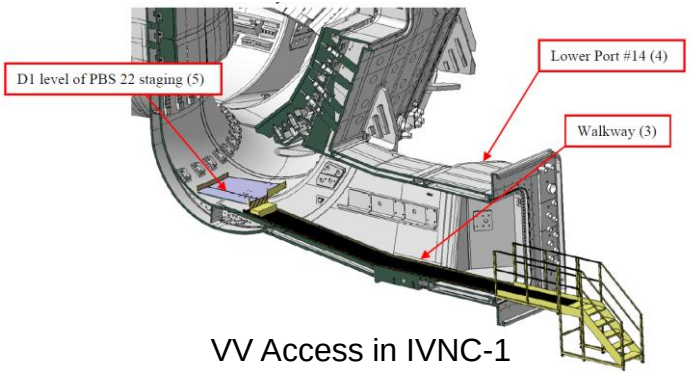
Context:

- End of Assembly Phase II, Long Term Maintenance
- Before the start of PFPO-1 Phase
- DCs installation – all installed except for the ones in front of LP14

Calibration sequence:

1. 55.BV components assembly (Access: LP14) → 3 days
2. Commissioning activities + IBED Circuits filling → 1 day
3. Irradiation → TBD
4. Decay time + IBED draining → TBD
5. 55.BV components disassembly → 3 days

- The VV will be a Be environment in this phase



VV Access in IVNC-1

Campaign 1 – Constraints and Challenges

Main challenge: schedule

- Required partial commissioning activity of TCWS (3 DCs are not installed)
- Assembly of 55.BV components in Be environment
- Activation after irradiation
- Careful placing in ITER Assembly and Commissioning Plan

Campaign 2, 3 and following - Planning

Context:

- Long Term Maintenance – Assembly Phase III, before PFPO-2
- Long Term Maintenance – Assembly Phase IV, before FPO
- Between Fusion Operation Campaigns

Calibration sequence:

1. RH Port(s) removal → 1 month
2. RH Tool Assembly + IBED loops filling→ <1 week
3. Irradiation → weeks (TBD)
4. RH Port re-insertion & re-commissioning + IBED drain→ 1.5 month

2.5 months required to remove, re-insert and re-commission RH port!

This activity can in principle be performed in parallel with others

Campaign 2, 3 – Constraints and Challenges

- These calibrations will be performed in high ionizing radiation fields
  - All components shall be rad-hard

- Schedule:
  - Despite the use of an agile RH Tool, these campaigns will be extremely expensive in terms of time