Status of the ITER Neutral Beam Test Facility and the first beam operations with the full-size prototype ion source

G. Serianni on behalf of NBTF team and

contributing staff of IO, F4E, QST, IPR, NIFS, IPP and other European institutions

Consorzio RFX, Padova, Italy

Reliability of electrodeposited components for fusion application: A process evaluation of the first kind

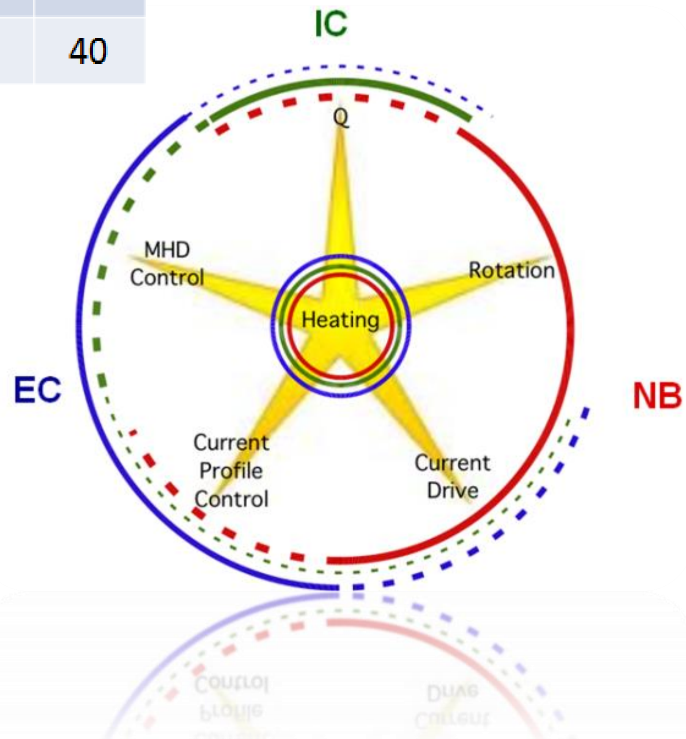
J. Joshi

Institute for Plasma Research (IPR), Gandhinagar, India

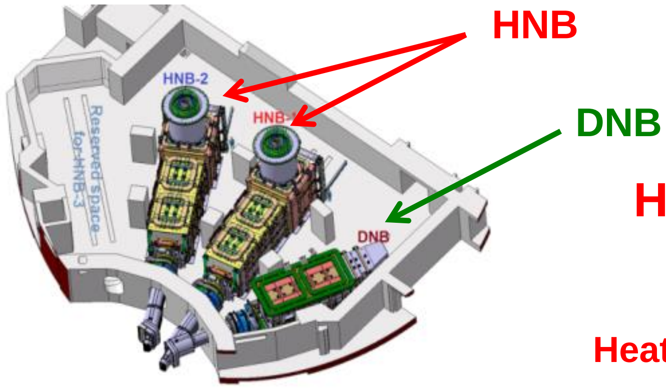
Heating systems at ITER - summary

ITER operational phase	Time line	Power requirement (MW)			
		NB	EC	IC	LH
First plasma	2025		6.7		
Pre fusion power op. 1	2028 – 2030 (mid)		20		
Pre fusion power op. 2	2032 (end) – 2034 (FQ)	33	20	20	
Fusion power op (DT)	2036 onwards	33	20	20	
Upgrade potential		50	40	40	40

EC system	IC system	NBI system
170 GHz	40-55 MHz	870 keV H^0, 1 MeV D^0
NTM, ST control, $j(\rho)$ control, EC-assisted startup	High fusion gain, ST control, wall cleaning	Bulk current drive, plasma rotation, plasma heating
24 gyrotrons (24 x 0.8 MW)	2 antennas (2 x 10 MW)	2 injectors (2 x 16.5 MW)



Neutral Beams at ITER: overview of requirements



Beams at ITER

- **Heating beam (HNB)**
  - Heating
  - Current drive
  - Plasma rotation
- **Diagnostic beam (DNB)**
  - Diagnosing He ash content (CXRS)

Parameter	HNB		DNB
Phase	HH/HHe	DD/DT	HH/HHe/DD/DT
Species	H	D	H
Injected neutral beam power [MW]	16.5	16.5	2
Beam energy [keV]	870	1000	100
Accelerated current [A]	46	40	60
Beam uniformity [%]	>90	>90	>90
Acceptable beamlet divergence [mrad]	3÷7	3÷7	3÷7
Pulse length [s]	1000	3600	5Hz; 3s ON /20s OFF

Worldwide effort towards ITER NBI

IPP test facilities ELISE & BUG

Achievements:

H: > 90% in long & short pulses

D: > 90% in short pulses
> 65% in long pulses

Wünderlich, Poster session P7

QST

R&D of high energy & long pulse beam acceleration for ITER and JT-60SA

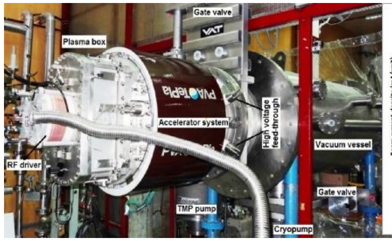
970keV, 190A/m2, 60s; 500keV, 154A/m2, 118s

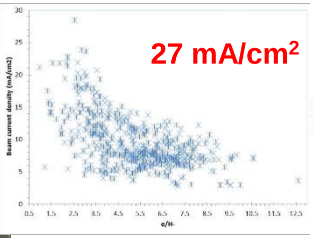
FEC 2016 Kashiwagi, session TECH/3

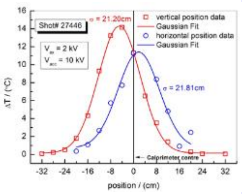
R&D accelerator for ITER

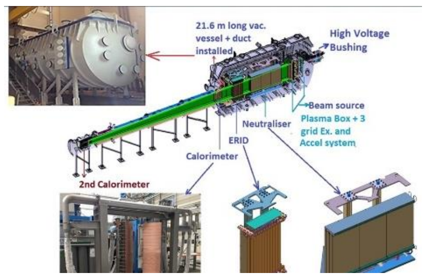
JT-60SA beam source

IPR: ROBIN, TWIN; INTF





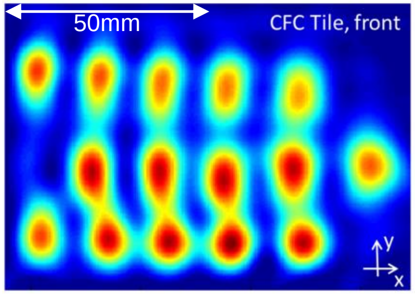


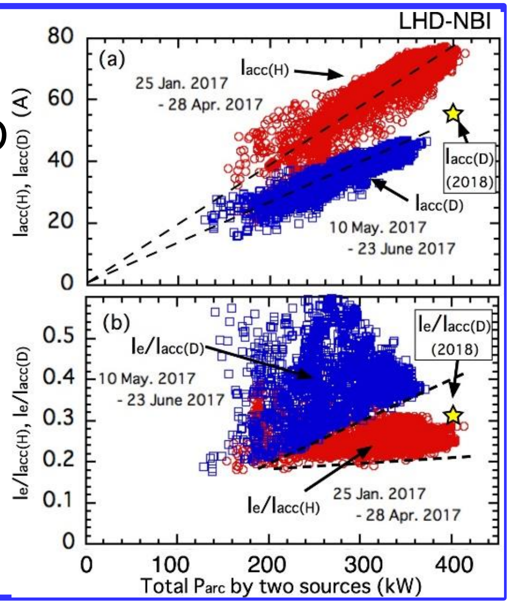


INTF: DNB prototype beam line with ~22 m beam transport path length

NIFS

NBI heating of LHD





Tsumori, session TECH/3

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Reliability of electrodeposited components for fusion application: A process evaluation of the first kind

J. Joshi

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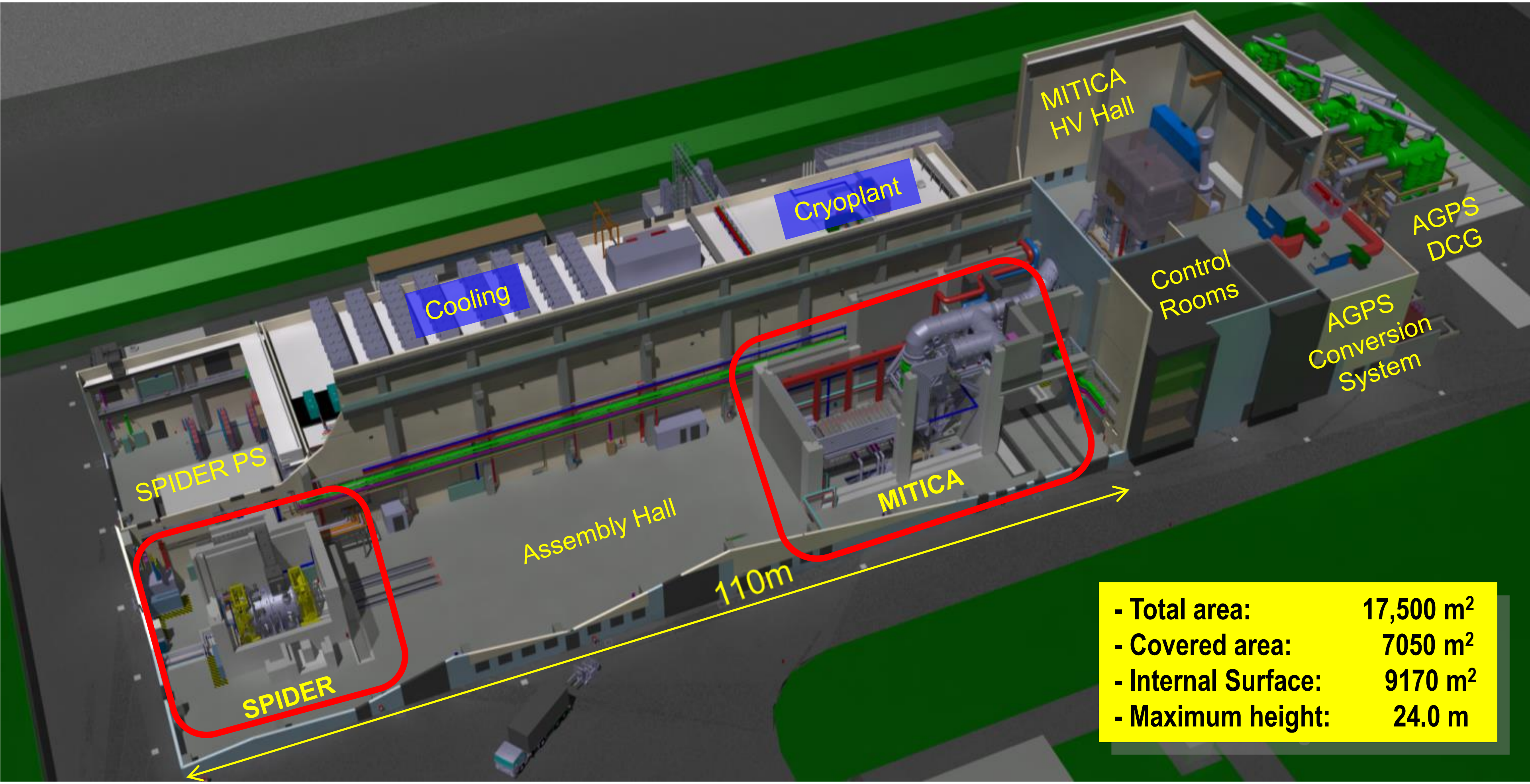
The Neutral Beam Test Facility



- Total area:	17,500 m^2
- Covered area:	7050 m^2
- Internal Surface:	9170 m^2
- Maximum height:	24.0 m

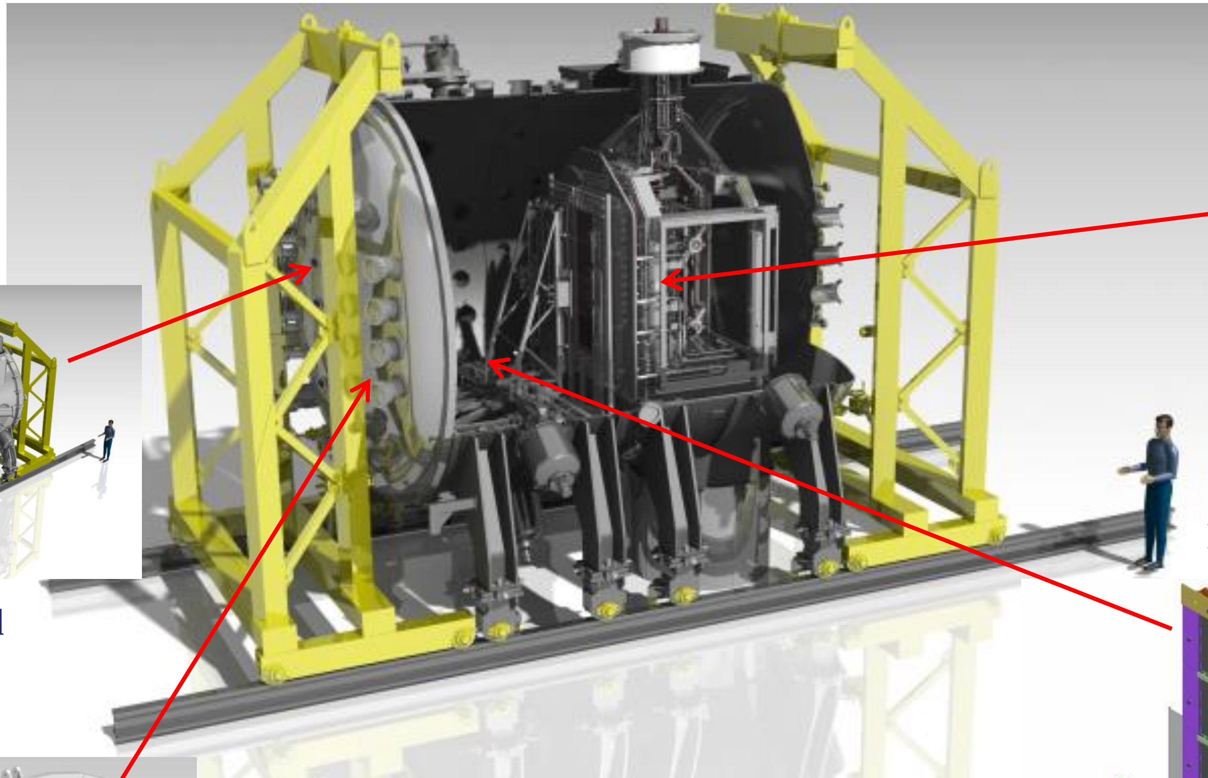
NBTF hosts the two experiments: the negative ion source **SPIDER** and the 1:1 prototype of the ITER injector **MITICA**

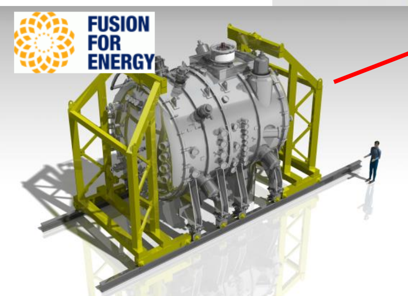
Each experiment is inside a concrete biological shield against radiation and neutrons produced by the injectors

Thanks to these shielding the assembly/maintenance area will be fully accessible also during experiments

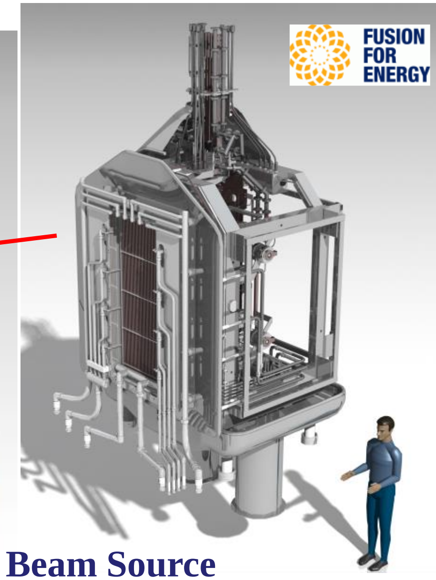
SPIDER mechanical components

Vacuum-insulated beam source

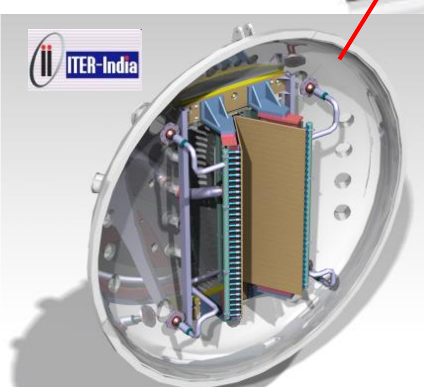




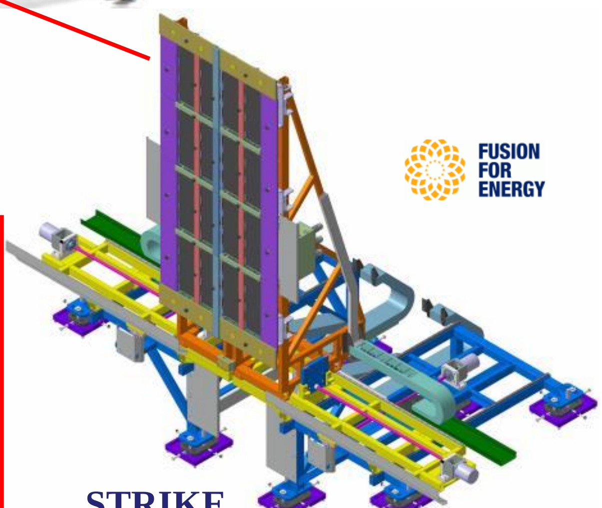
Vacuum Vessel



Beam Source



Beam Dump

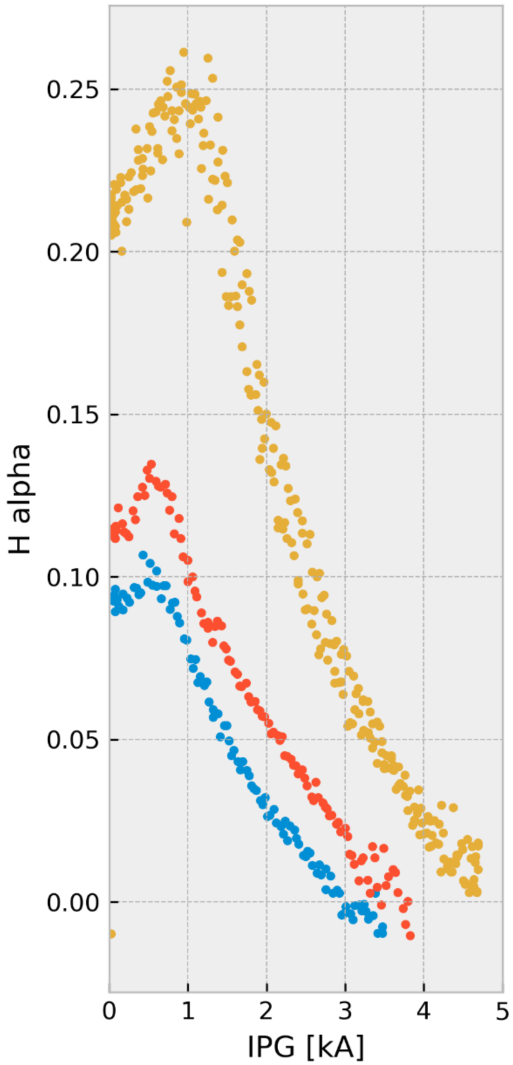


STRIKE
High resolution calorimeter

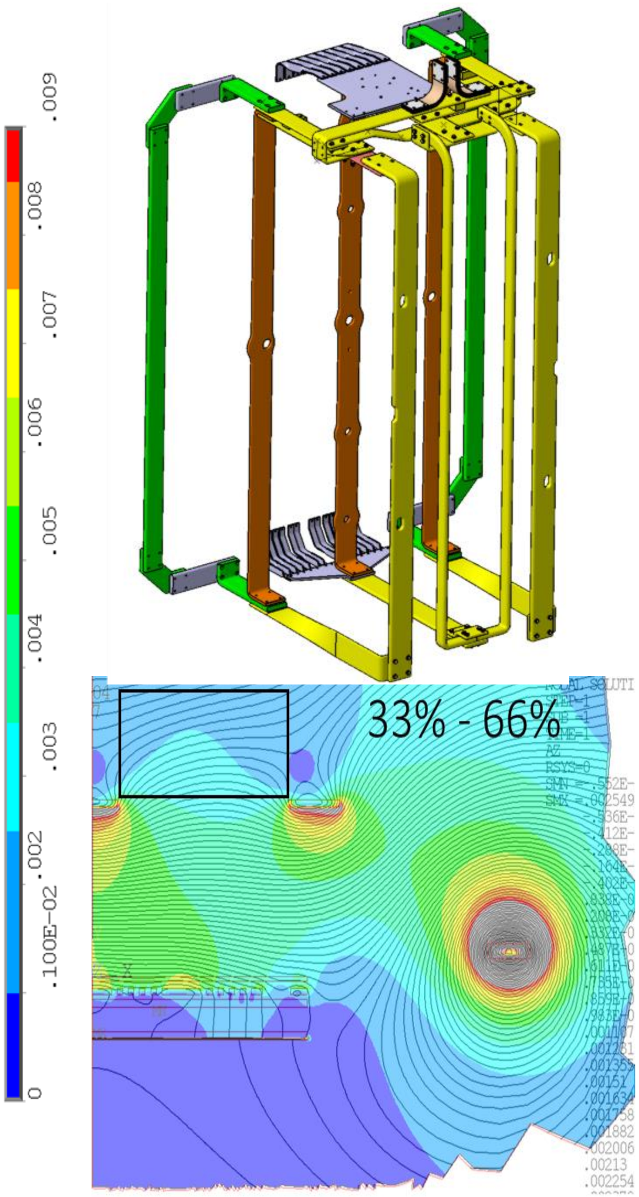
	Unit	H	D
Beam energy	keV	100	100
Maximum Beam Source pressure	Pa	<0.3	<0.3
Uniformity	%	±10	±10
Extracted current density	A/m²	>355	>285
Beam on time	s	1000	3600
Co-extracted electron fraction (e^-/H^-) and (e^-/D^-)		<0.5	<1

Effect of magnetic filter field

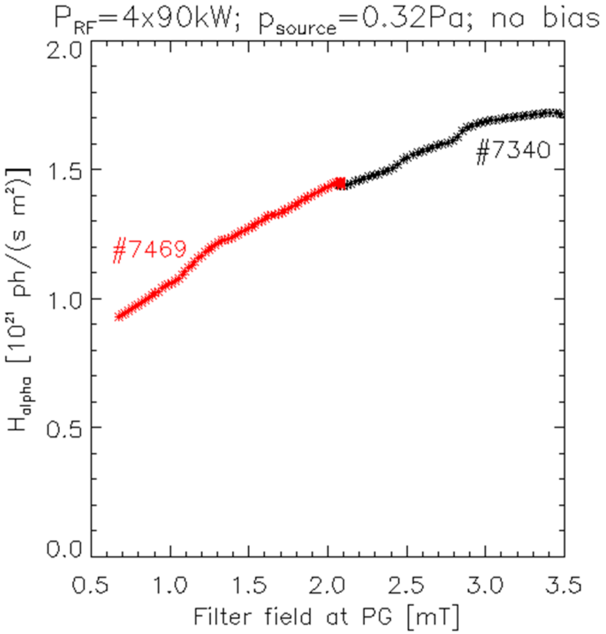
- Quenching of plasma with increasing filter field

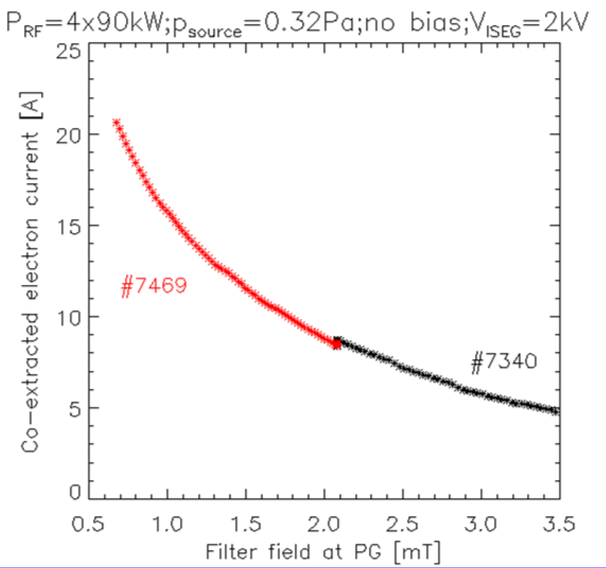


Improved magnetic filter field



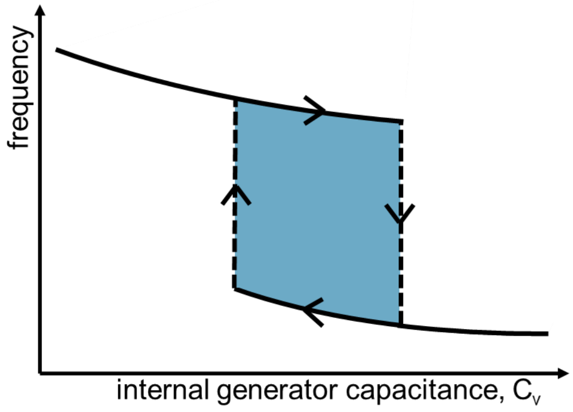
- H_{alpha} signal in drivers increases with magnetic filter field
- Co-extracted electron current slightly decreases with magnetic filter field
- Beam current is almost unaffected



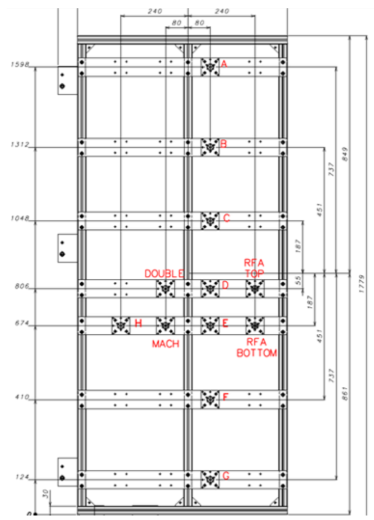


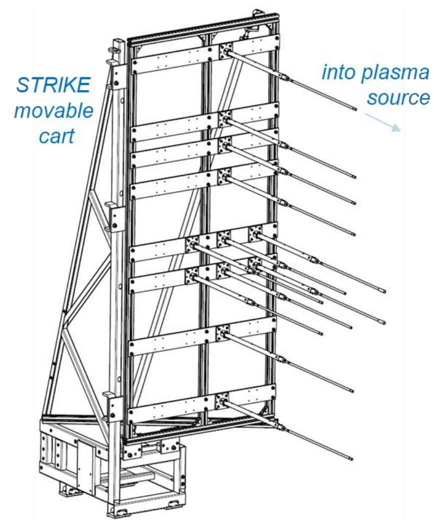
SPIDER RF system

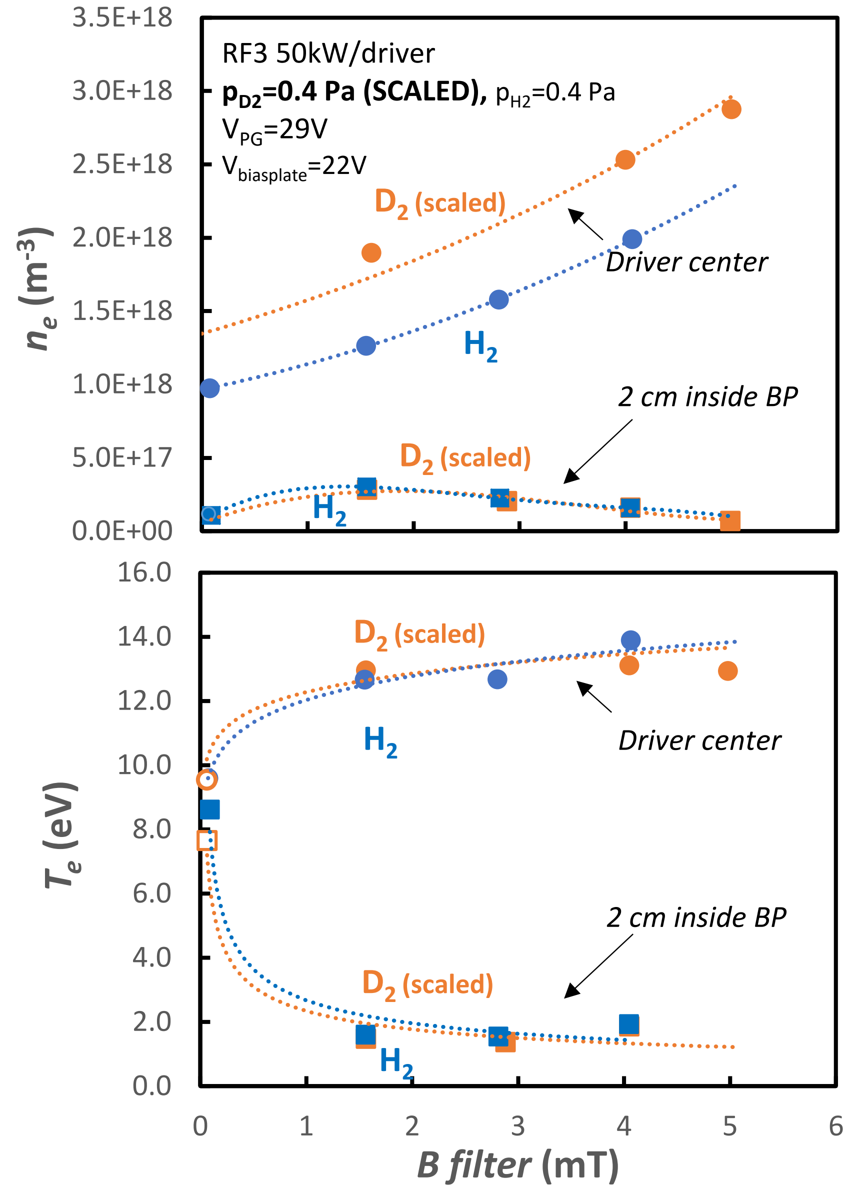
- SPIDER RF generators:
  - pair of power tetrodes in push-pull connection; variable capacitor C_v to tune operating frequency
- RF power limit identified:
  - power transfer depending on equivalent load impedance
  - sudden frequency flips near impedance matching
    - RF power constrained, as observed in other facilities
- Short term strategy:
  - feedforward control of C_v capacitor
  - development of model reproducing different behaviours of RF generator to:
    - support SPIDER operation and analyse its performances
    - help in achieving nominal performances
  - experimental investigation of different matching network parameters
- Longer term strategy: replacement of tetrode-based oscillators with solid-state amplifiers



Source characterisation



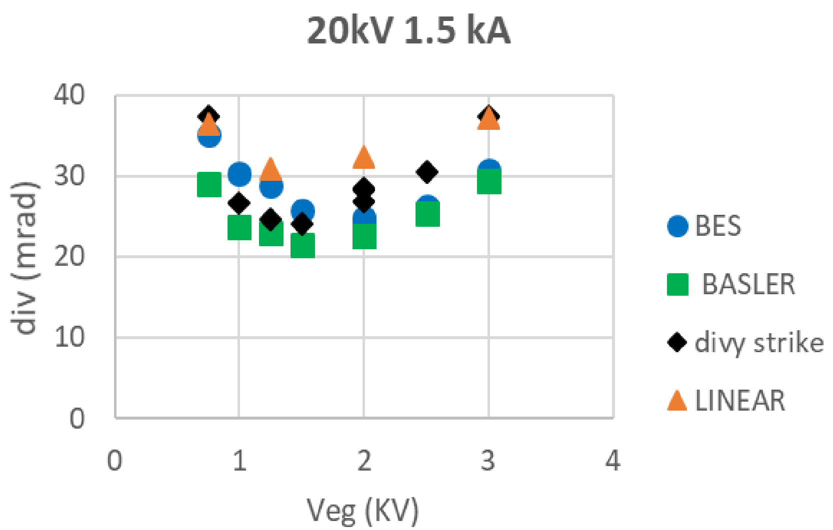




- Measurements inside driver and in extraction region
- Filter field scan in D_2 and H_2
  - Electron density increases with filter field in driver and decreases in extraction region
  - Electron temperature decreases with filter field in extraction region
  - Electron density higher in D_2 inside drivers

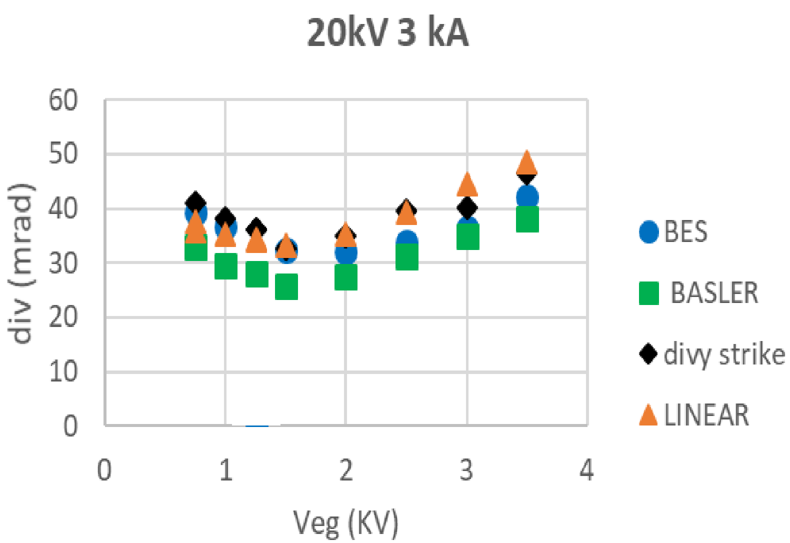
Comparison of divergence measurements

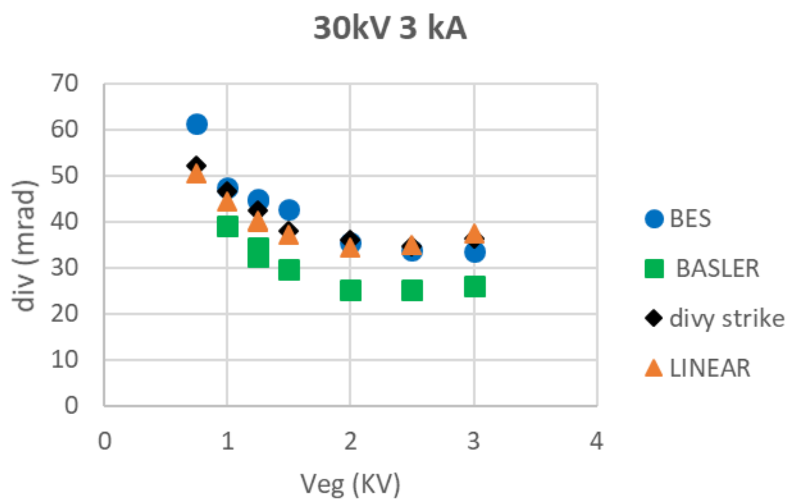
- Values and trends are similar despite different principles of operation



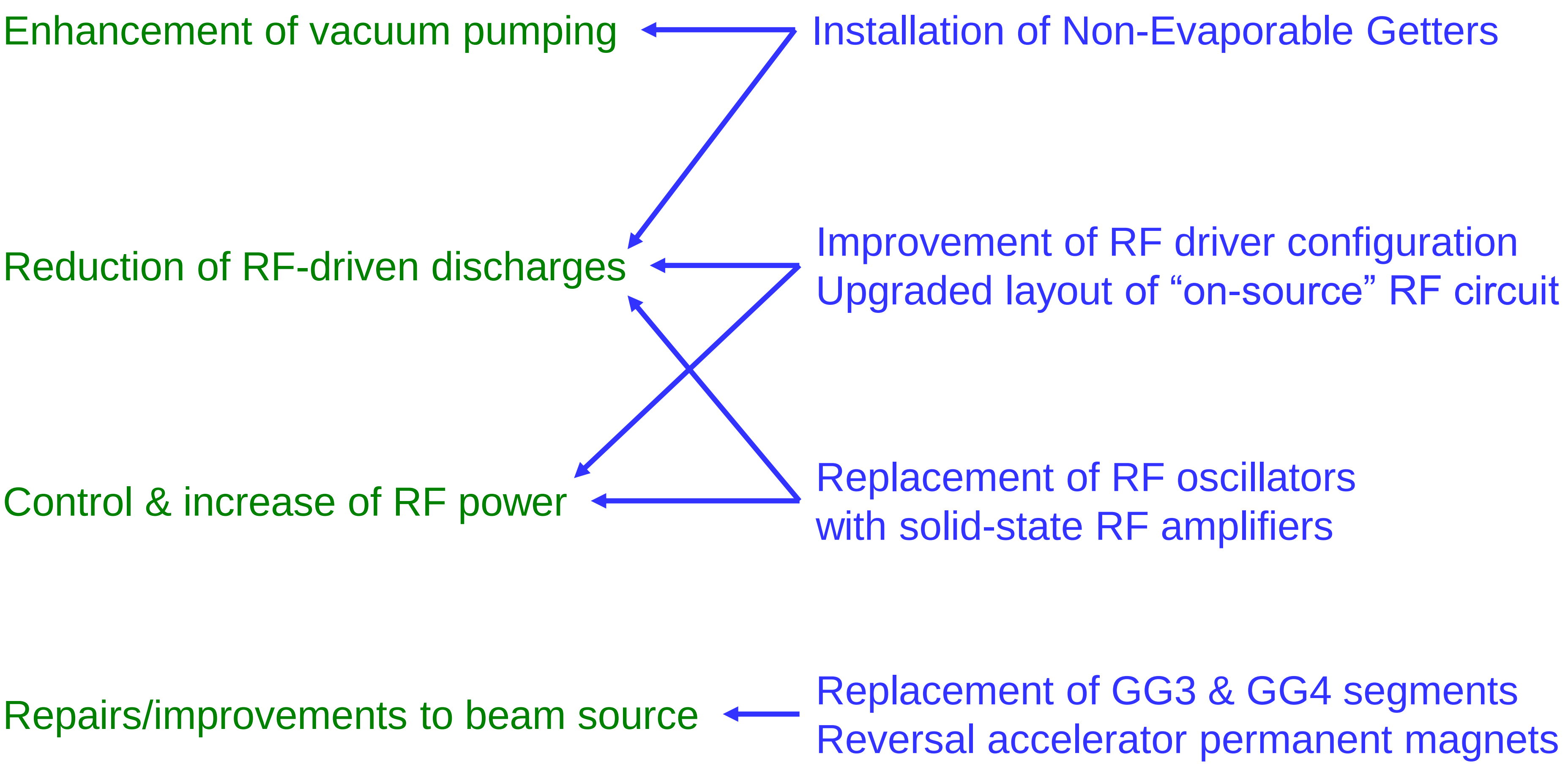
- Divergence increases with magnetic filter field

- Optimal voltage ratio ~10





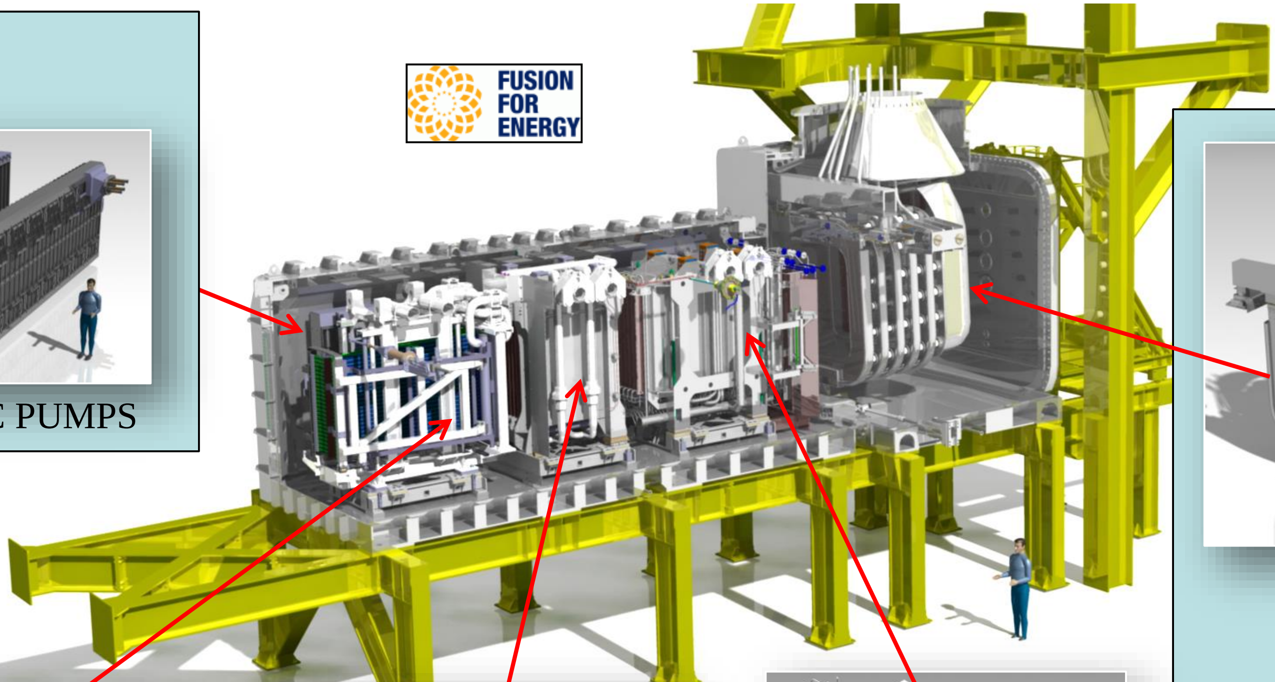
Improvement of main SPIDER plants During major shutdown from mid-2021

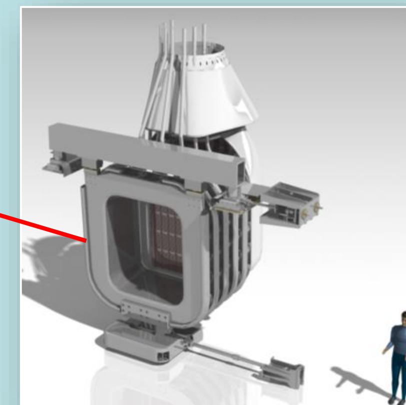


MITICA in-vessel components

OPE-307

CRYOGENIC PUMPS

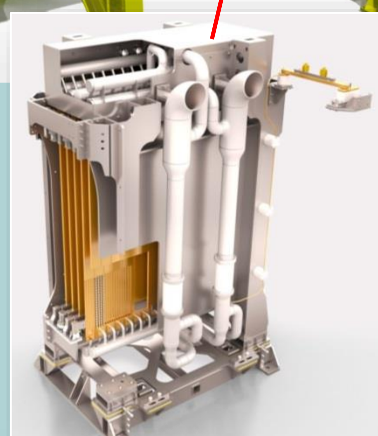




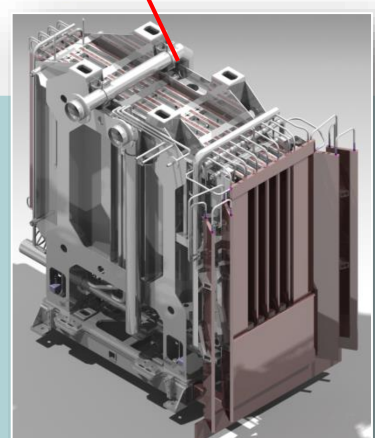
BEAM SOURCE

OMF-605

CALORIMETER



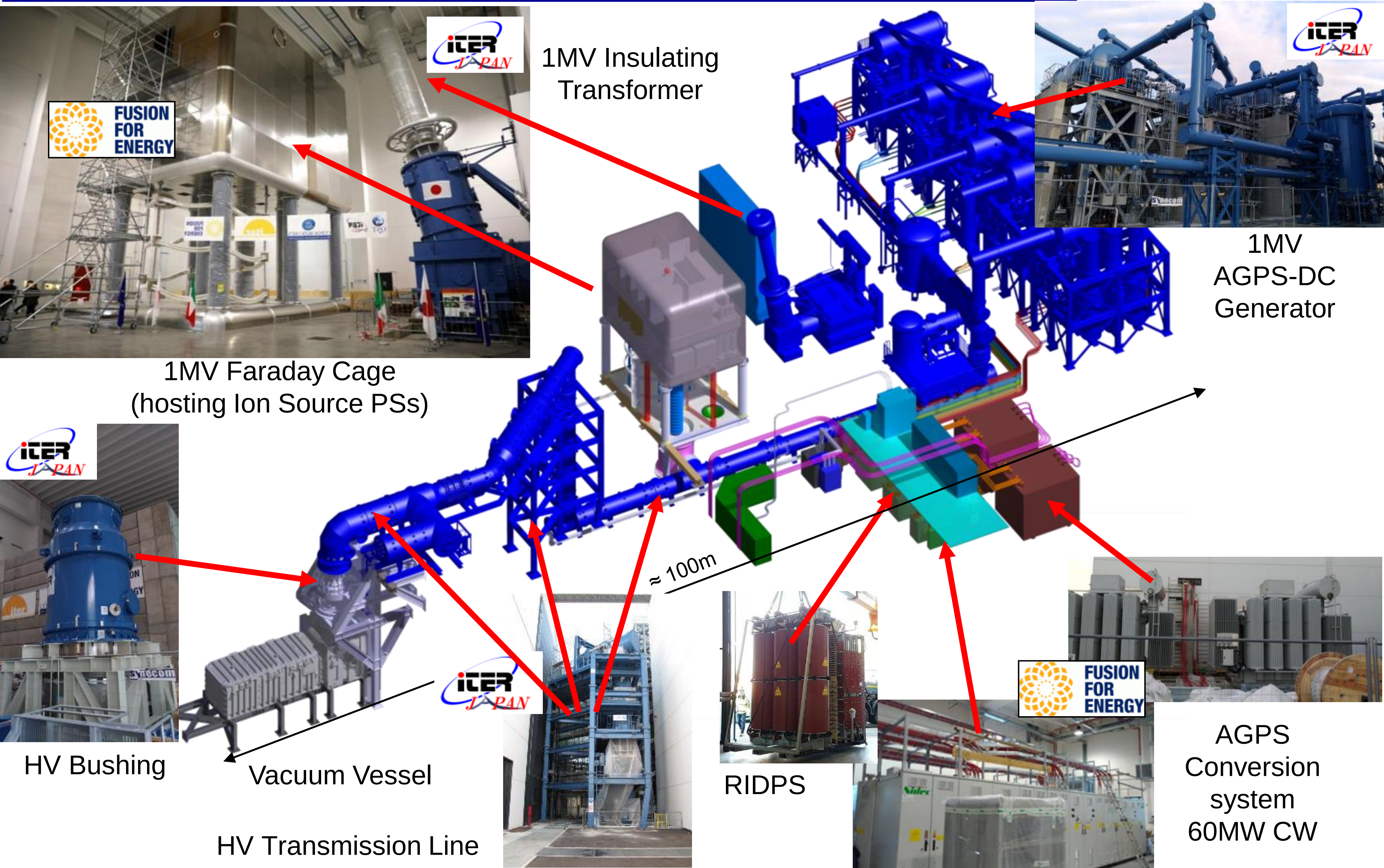
RESIDUAL ION DUMP



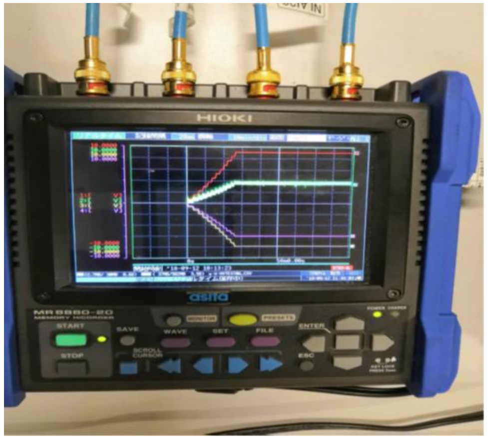
NEUTRALIZER

OMF-795

MITICA Power Supplies



AGPS-DCG insulating tests

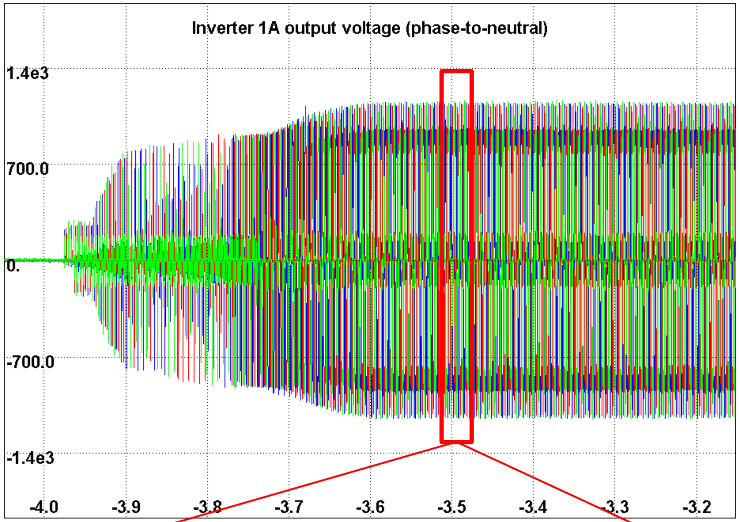


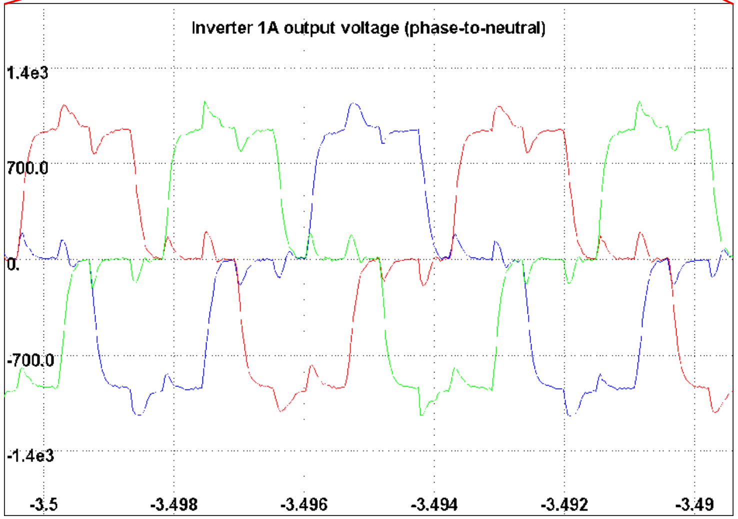
1st STEP 1200kV-1 HOUR

2nd STEP 1060kV-5 HOURS

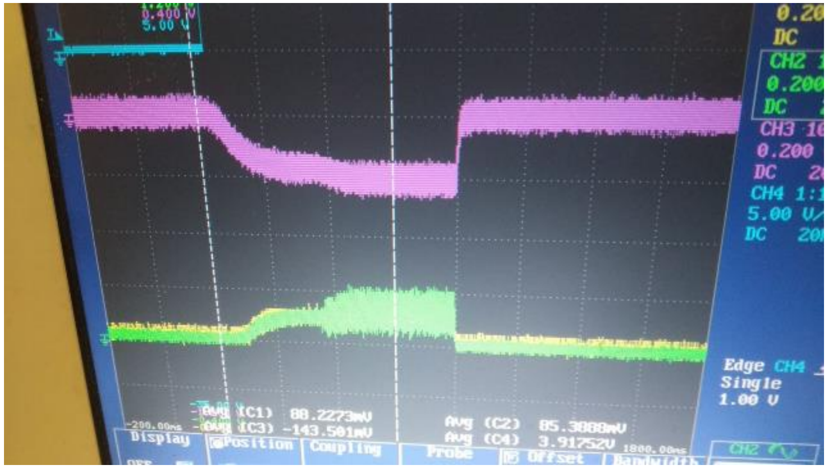
- The insulation tests were performed in successive steps, each time adding a new part of the system provided by a different DA
- The process was long and lasted about 1.5 years. The overall insulating test was successfully completed in Nov 2019

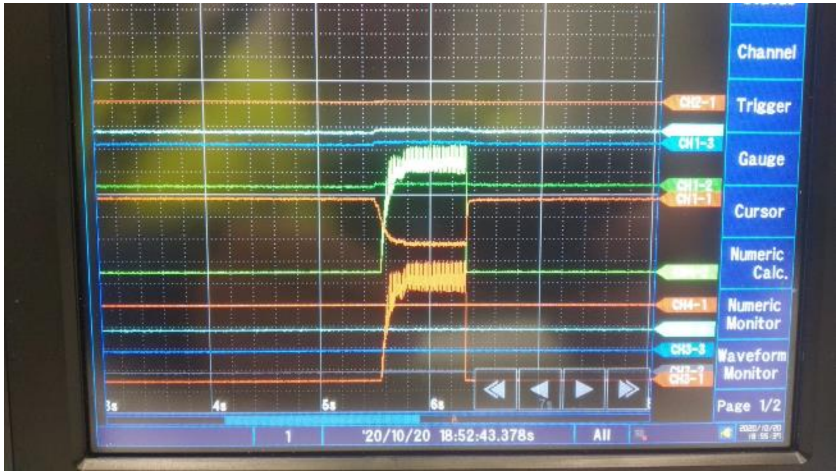
AGPS integrated tests





Converter output voltages





AGPS output voltage and current

MITICA Beam Line Vessel

Delivery on site and installation of the MITICA BLV

- Installation and SAT completed in Q1 2020 just before the Site closure for some weeks due to the Covid-19

Conclusions and lessons learnt

- **MITICA**
- Construction nearing completion; commissioning of plants well advanced. All injector mechanical components in procurement phase; to be delivered in 2022-2023
- 1MV power supply system successfully subjected to insulation tests up to 1.2MV for 1 hour
- Power integrated tests just started (delay by COVID-19) using modified organisational structure
- High voltage holding tests in vacuum planned using MITICA facility and electrostatic mock-up of Beam Source

SPIDER

- Operating since ~3 years, producing interesting results
- In 2020, experimental plan delayed due to Covid-19. First Cs operations postponed to 2021
- RF-induced discharges on rear side of source
  - Cause: residual vessel pressure
  - Temporary solution: partial masking of grid apertures ⇨ operation possible
  - Final solution: increase pumping speed & capacity ⇨ long shutdown required
- Difficult RF control; limited RF power per generator
  - Solution: replacement of RF oscillators with solid-state amplifiers ⇨ long shutdown required
- Mid-2021, long shut down to improve source and plants to increase SPIDER performances

Contribution ID: 1319

Reliability Of Electrodeposited Components For Fusion Application: A Process Evaluation Of The First Kind

Jaydeep Joshi
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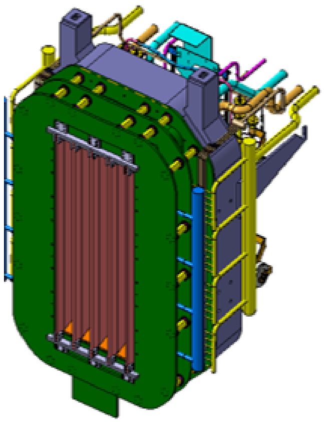
Gandhinagar, India
jaydeep.joshi@iter-india.org

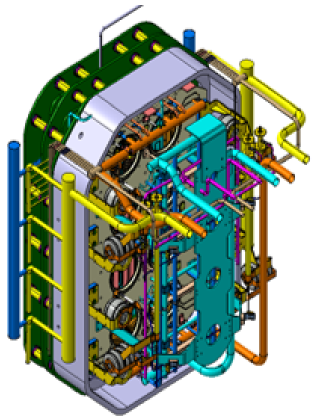
Contents

- Background
- Need, methods adopted and goal
- Implementation
  - Adhesion test
  - Hardness test
  - Optical microscopy
  - ‘All deposited’ tensile test
  - Immersion ultrasonic testing
- Summary

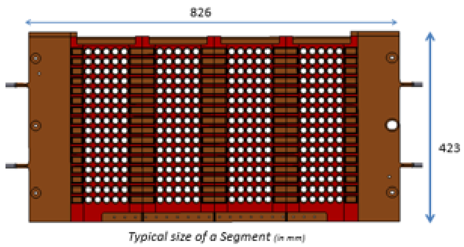
Background-need for the ED process evaluation

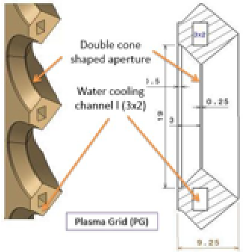


Accelerator
(1.4m x 2.2m x 0.4m)



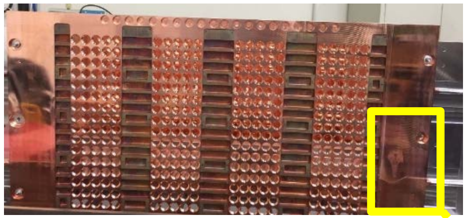
RF Based Ion Source with 8 RF drivers
(1.5m x 1.9m x 1.1m)





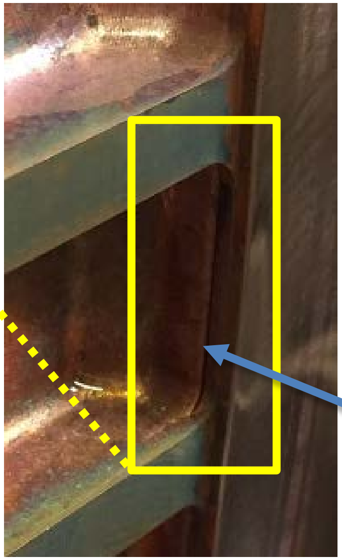
Configuration of the ‘angled’ PG segment of DNB Source (Right picture shows the c/s of cooling channels, to be closed by ED)

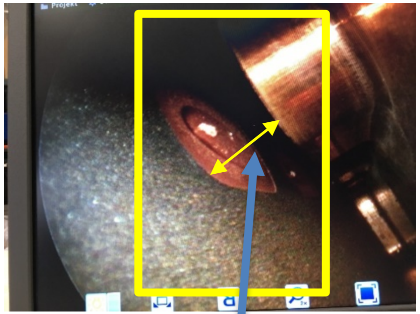
One segment out of four (tested in parallel) has failed and that was ED in different bath…



‘As manufactured ‘angled’ PG segment of DNB- Failure during the Hot Helium Leak Test (150 C and >25bars)

(Area of failure is highlighted by yellow)





Separation of the ED layer from the base is seen here

Example of ‘a good ED bond’

Need→ Methods→ Goal

Need for the ED process evaluation:

- No recommended procedure / historical database for carrying out an assessment of the bond integrity for electrodeposited surfaces
- No codes are presently available to qualify the process compatibility for the operational requirements including application at around 150 C.

Methods adopted:

- Adhesion Strength
- Hardness measurement
- Optical Microscopy
- Immersion Ultrasonic Testing
- All deposited sample tensile testing

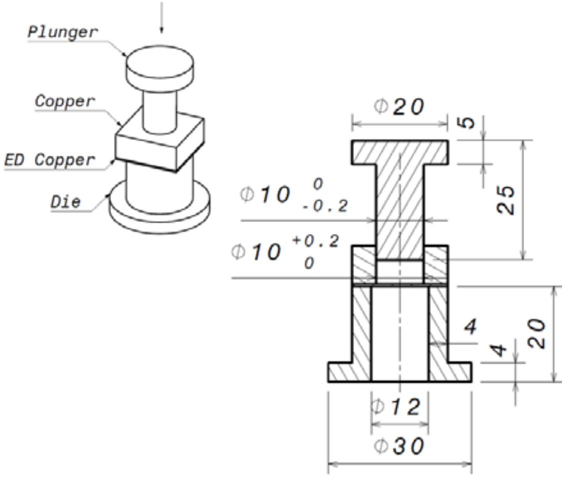
Samples were drawn from three different bath (including the one in which the failed segment was deposited)

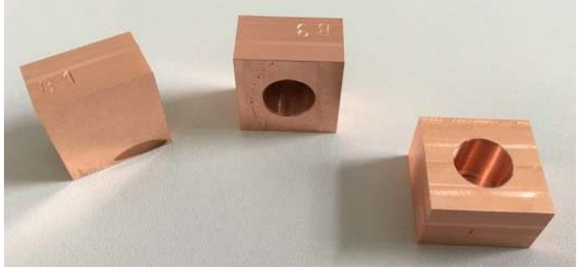
Goal:

- To assess the compatibility with respect to the functional environment
- To arrive at the recommended procedure for process evaluation

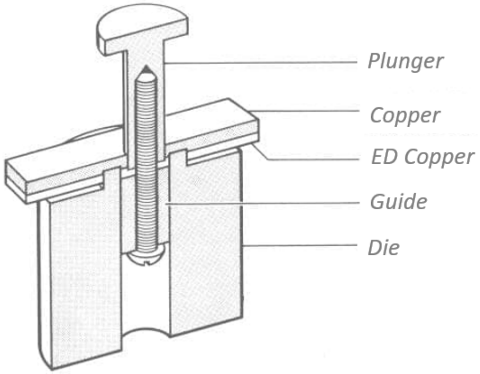
Implementation (1/2): Adhesion Strength

Adhesion Strength:
Push Test

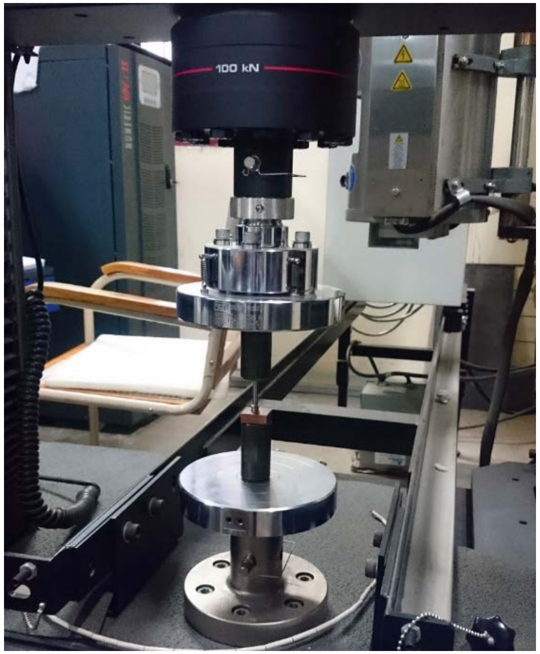




Adhesion Strength:
Modified Ollard Test

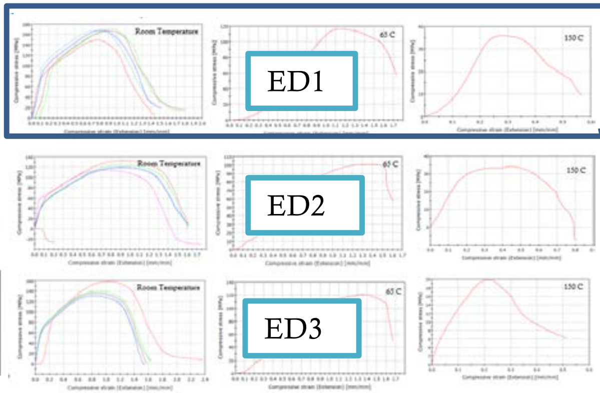


Testing in-progress in the
Universal Testing Machine



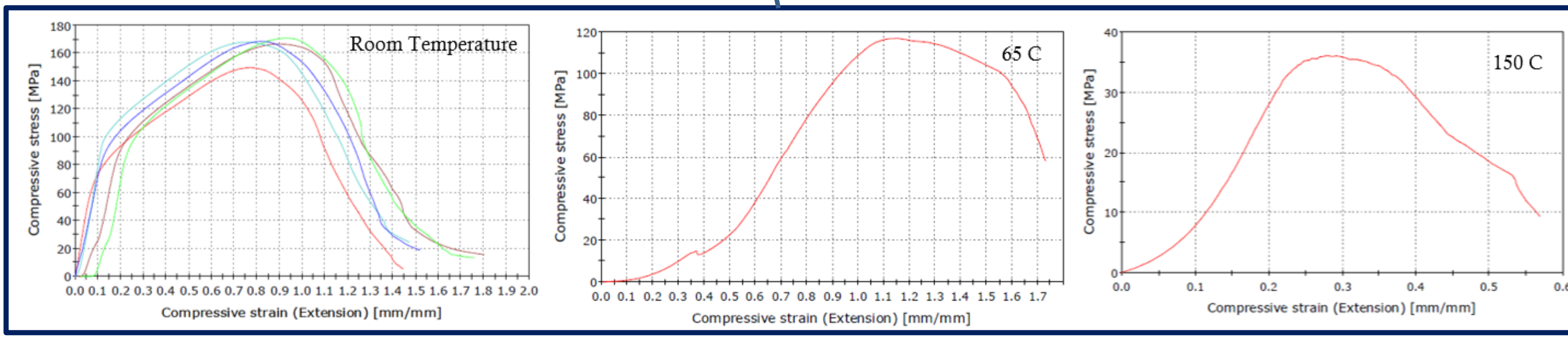
Implementation (2/2): Adhesion Strength (Push Test)

Push test samples after testing



Observations:

Specimens	Adhesion Strength @ 25 C (MPa)	Adhesion Strength @ 65 C (MPa)	% Change for 65 C	Adhesion Strength @ 150 C (MPa)	% Change for 150 C
ED 1 (Bath-1)	165	117	29 %	30	82 %
ED 2 (Bath-2)	123	100	18 %	41	66 %
ED 3 (Bath-3)	140	122	13 %	34	75 %



Note:

Based on the location of the failure for Modified Ollard test, it was inferred that:

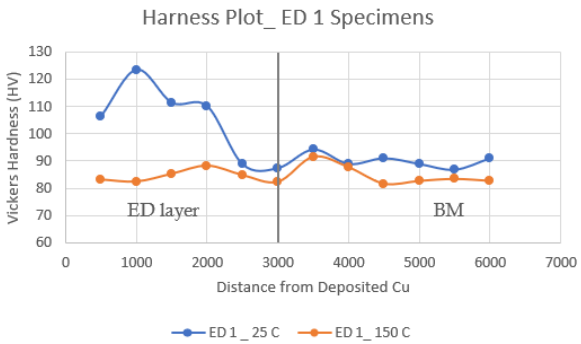
- load of the plunger was actually resisted by the base material rather than the intended CuED layer
- the failure is mainly due to the stress concentration rather than the plunger loading.

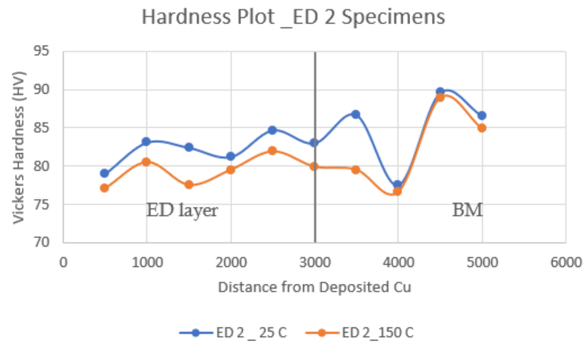
→ The test configuration of the Modified Ollard test is not suitable and reliable for the present application.

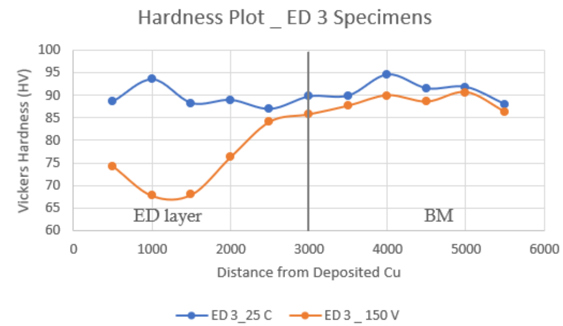
Hardness Measurement

- Vickers microhardness measurements was carried out at (1) transverse cross section and (2) on the deposited surface.

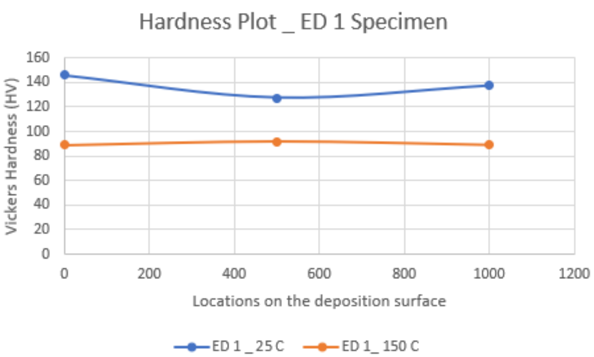
Hardness Measurement @ Transverse cross section

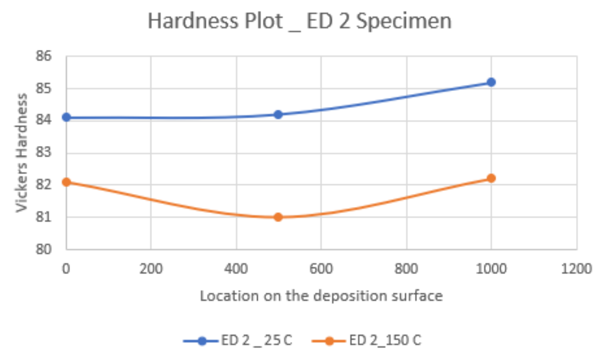


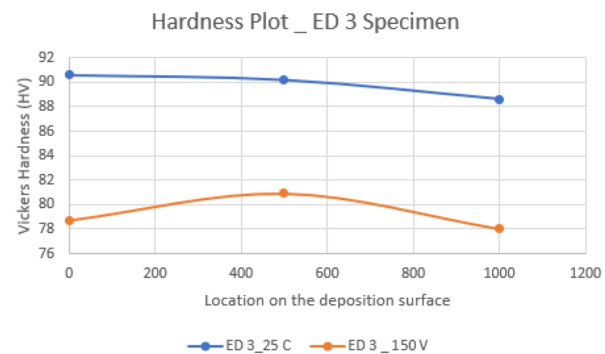




Hardness Measurement @ Deposited Surface







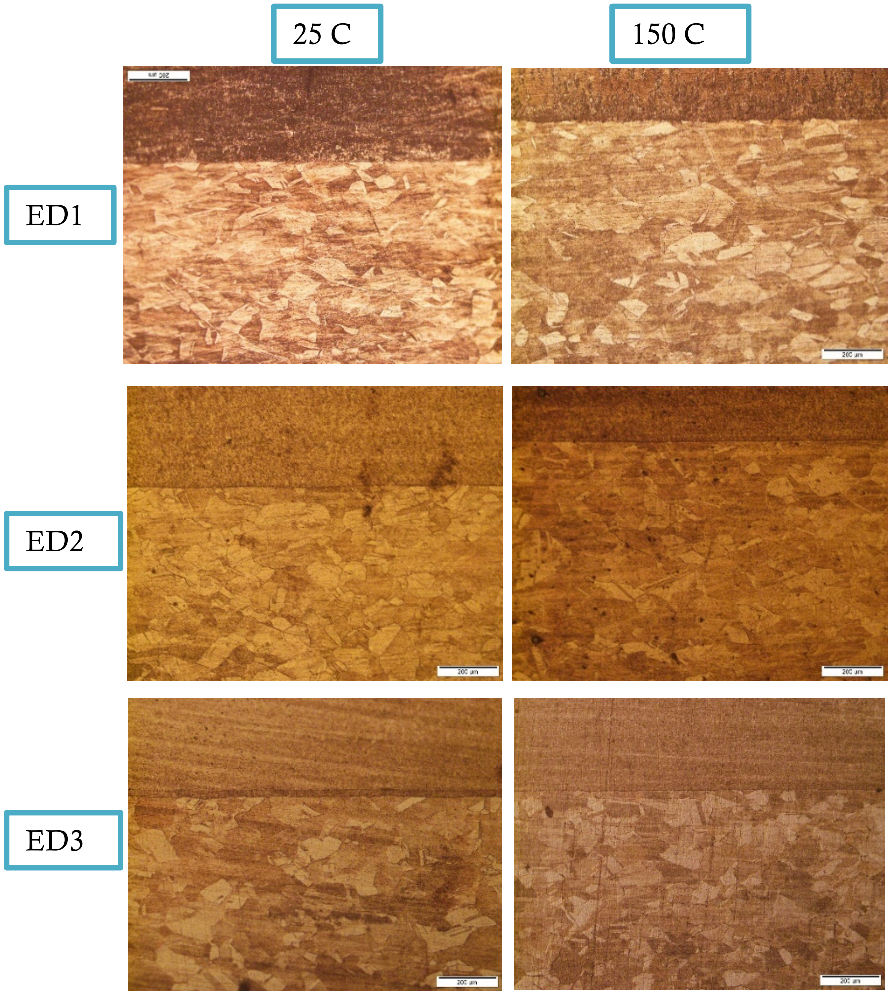
Observations:

- Results concur with adhesion strength test (Reduction in the hardness (HV) of the ED layer with the increase in the temp.
- Different bath has different resistance to the indentation against the externally applied load

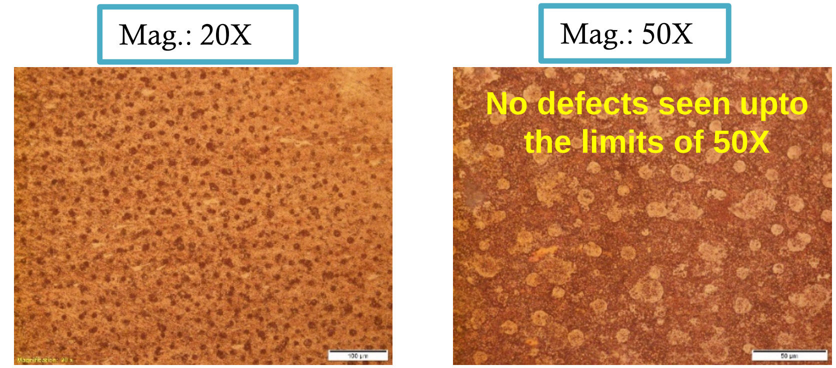
Optical Microscopy

- Microstructural assessment was carried out at (1) transverse cross section and (2) on the deposited surface.

Optical microstructure @ Transverse cross section



Optical microstructure @ Deposited Surface



Observations:

- Base material- equiaxed grains, a typical microstructure of copper material.
- No effect on the base material microstructure upto 150 C.
- Grain size are in ranging from 70 – 80 microns.
- ED, being an atomic layer by layer deposition technique, a combination of fine fibrous and lamellar structure has been observed
- No pin hole defects observed on the ED surface (normally they are the major cause of concern in the ED), associated with the required deposition time for the activation and deposition to happen.

‘All Deposited’ Tensile Testing

- Reduction in the adhesion strength and hardness values at the increased temperature (150 C) makes it important to study the all deposited samples mechanical properties at 150 C for high temperature application requirement.
- Tensile testing of the deposited samples was carried out at 25 C and 150 C, for samples from different bath .

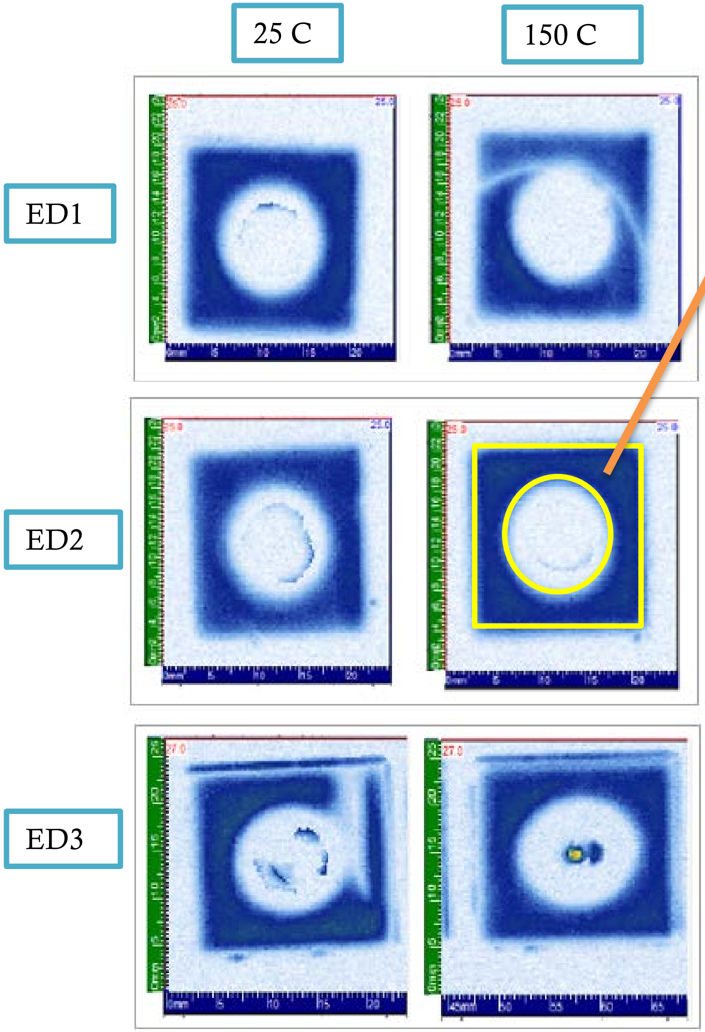
Condition / bath	25 C (MPa)	150 C (Avg. of four tests) (MPa)	% Reduction
ED 1	235	181	23%
ED 2	304	217	28%
ED 3	304	220	27%
Raw Material	290	241	16%

Observations:

- Results confirm the reduction in the strength with the increase in temperature.
- There is reduction of ~ 22 – 28 % in the tensile strength value at 150 C for all the ED specimens, while the raw material has the reduction of ~ 15%.
- → Guideline to the designer to incorporate the suitable safety margin while designing the electrodeposited components. .

Immersion Ultrasonic Testing

- In order to check the interlayer between the electrodeposition and base material, immersion ultrasonic examination with C-Scan technique has been performed.



Area of interest between the yellow boundary (white shade circle is punctured area due to previously conducted adhesion test and this area to be ignored).

Facility for performing Immersion UT examination at IPR

Observations:

- C scan results confirm that there is no de-bonding presents in the samples, for both temperatures.
- The result also confirms that the reduction in the adhesion strength at high temperature is not associated with the de-bonding at the interlayer.

Summary

- A process has been established in form of experiments where ~20 samples, from different baths, have been subjected to tests to evaluate and obtain a statistical variation in the quality of the bond at room as well as at elevated temperature of 150 C.
- Test results shows the variation in the bond strengths is highly dependent on the bath quality
- The results also establish that (1) it is mandatory to qualify the ED process according to the functional parameters and (2) it is equally important to qualify EACH bath, to ensure a reliable application of ED process for the actual components.
- Recommendation of the qualification process is as follows; (1) carrying out and interpreting the specially designed push test for samples (2) Co-relating the strength with the hardness parameters (3) study of microstructural characteristics and (4) application of process on production pieces.

Thank You

with acknowledgement to M/s PVA, M/s RI, their subcontractors, HHFT and TBM lab of IPR