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BCP Technology Transfer to Industry in the Framework of ESS

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On behalf of the STFC ESS team

PIP-II Technical Workshop – 1st – 4th December 2020

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BCP Requirement

- STFC agreed programme scope of work did not include any process developmental work
  - Plan to transfer processes from CEA Saclay to industry
- BCP process developed and defined by CEA from prototypes and INFN medium beta cavity
- Identified by STFC, ESS & CEA that industry process will be different to CEA process
  - Different set-up
  - Different acid concentration

⇨ Requirement to validate the BCP process with pre-series cavities prior to the commencement of the production cavities

- Bulk BCP required to remove 180 µm from the cavity inner surface + 20 µm light etch
- Process:-
  - Perform initial treatments on cavity H001, then cold RF test undressed
  - Iterate the processes if required on cavity H002 (and H003, and H004)
  - In parallel forming of half-cells and fabrication of dumbbells for series production was progressed

BCP Specification

1. Frame assembly, cleaned and rinsed with hand-held pressure washer and moved into the ISO 7 (or better) cleanroom
2. Degreasing and ultrasonic cleaning
   Ultra Pure Water (UPW) rinse - Resistivity > 12 MΩ.cm
3. Drying in cleanroom ISO 7
4. Weighed with the frame to enable the average surface removal obtained with chemistry
5. Assemble blanking flanges (ports and beam tube flanges including an etching control Nb sample at the coupler port)
6. Leak test of the BCP plant, pressurizing it with UPW
7. Etching in closed loop, Bulk BCP - 1st step. First etching step: 80 µm.
8. Pre-rinse cavity inside BCP loop Prompt rinsing of the cavity within 120 s after acid process stops
9. Disassemble flanges for BCP and assemble flanges for the rinsing up to resistivity > 12 MΩ.cm
10. Outer ultrasonic cleaning and rinsing of the closed cavity to enter ISO 4 cleanroom for HPR
11. Standard High Pressure Rinsing (HPR): 120 min
12. Drying in cleanroom ISO 7 or higher.

BCP Specification

13. Cavity weighing with frame (assessment of mass of Nb removed)
14. Flip the cavity orientation to guarantee etching uniformity
15. Etching in closed loop, Bulk BCP- 2nd step. Second etching step: 100 µm
16. Pre-rinse cavity inside BCP loop to Ph >5 to stop reaction
17. Disassemble BCP flanges and assemble flanges for the rinsing up to resistivity > 12 MΩ cm
18. Outer ultrasonic cleaning and rinsing of the closed cavity for entering the ISO 4 HPR area
19. Standard High Pressure Rinsing (HPR) (120 min)
20. Drying in cleanroom ISO 7 or better
21. Cavity weighing with frame (assessment of removal)
22. Cavity can exit the cleanroom
23. Remove frame
24. Frequency measurement of the 5 modes of the cavity

Vendor Validation Process

- Original BCP process qualified for 1.3 GHz cavities (XFEL)
- System required modifications to integrate the larger volume cavity
- Need to understand the etch rate
  - Acid concentration: 1 volume part HF (40 %), 1 volume part HNO_3 (65 %) and 2 volume parts H_3PO_4 (85 %) - different to CEAs
- Verification of heat exchanger capability
  - Acid is typically pre-cooled down to 5 to 7 °C before commencing etch process
  - Process typically between 12 – 15 °C
  - Acid temperature maintained below 15 °C for the whole process time
- Acid flow 10 -20l/min
- Ensure proper circulation of the acid and avoidance of any trapping of gas bubbles
- Verification of heat exchanger capability
  - Acid is typically pre-cooled down to 5 to 7 °C before commencing etch process
  - Process typically between 12 – 15 °C
  - Acid temperature maintained below 15 °C for the whole process time
- Performance witnessed by Axel Matheisen (consultant)

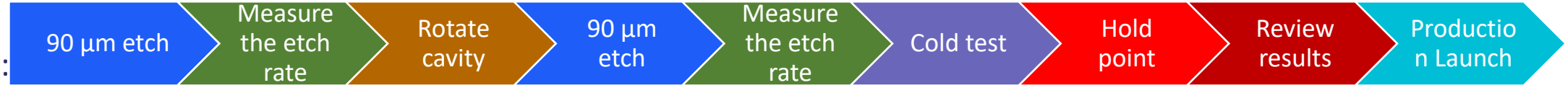
Cavity **H001**:

- Consider repeat of H001 process or progress to 90 µm etch

Cavity **H002** release:

- Review etch rate consider 2 x 45 µm or 90 µm etch

H003 and **H004** release:



Cavity validation process

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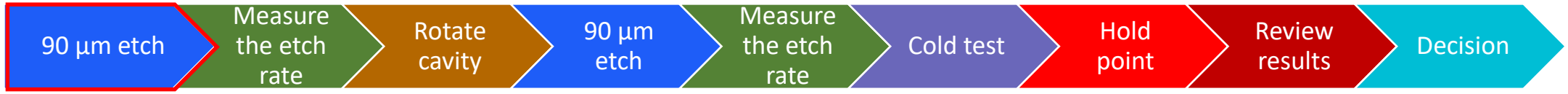
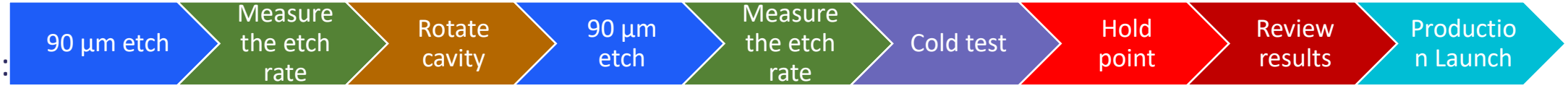
Cavity **H002** release:



- Review etch rate consider 2 x 45 µm or 90 µm etch

H003 and **H004** release:



Cavity validation process

Review Criteria

Parameter	'Full' pass similar to prototype data	Limited pass but 'review' if:	'Fail' if:
2K Q_0 @ 1 MV/m	>2 x 10^{10}	Review if <2x10^{10}	No fail condition
2K Q_0 @ 19.9 MV/m	>1.45 x 10^{10}	5 x 10^9 < Q_0 <1.45 x 10^{10}	<5 x 10^9
Max E_{acc}	>19.9 MV/m	>19.9 MV/m	<19.9 MV/m
Field emission / X-ray		If early on-set of X-ray, review	No fail condition
Actions:	Release all pre-series cavities to processing	**De-bug of cavity** *If root cause analysis suggests:* "Local" cavity problem: - Release next cavity / cavities - Re-treatment of cavity Process problem: - Review processes and modify if required	**De-bug of cavity** Review processes and modify if required Consider re-test of cavity before release of cavity / cavities

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High-beta data, RI prototypes

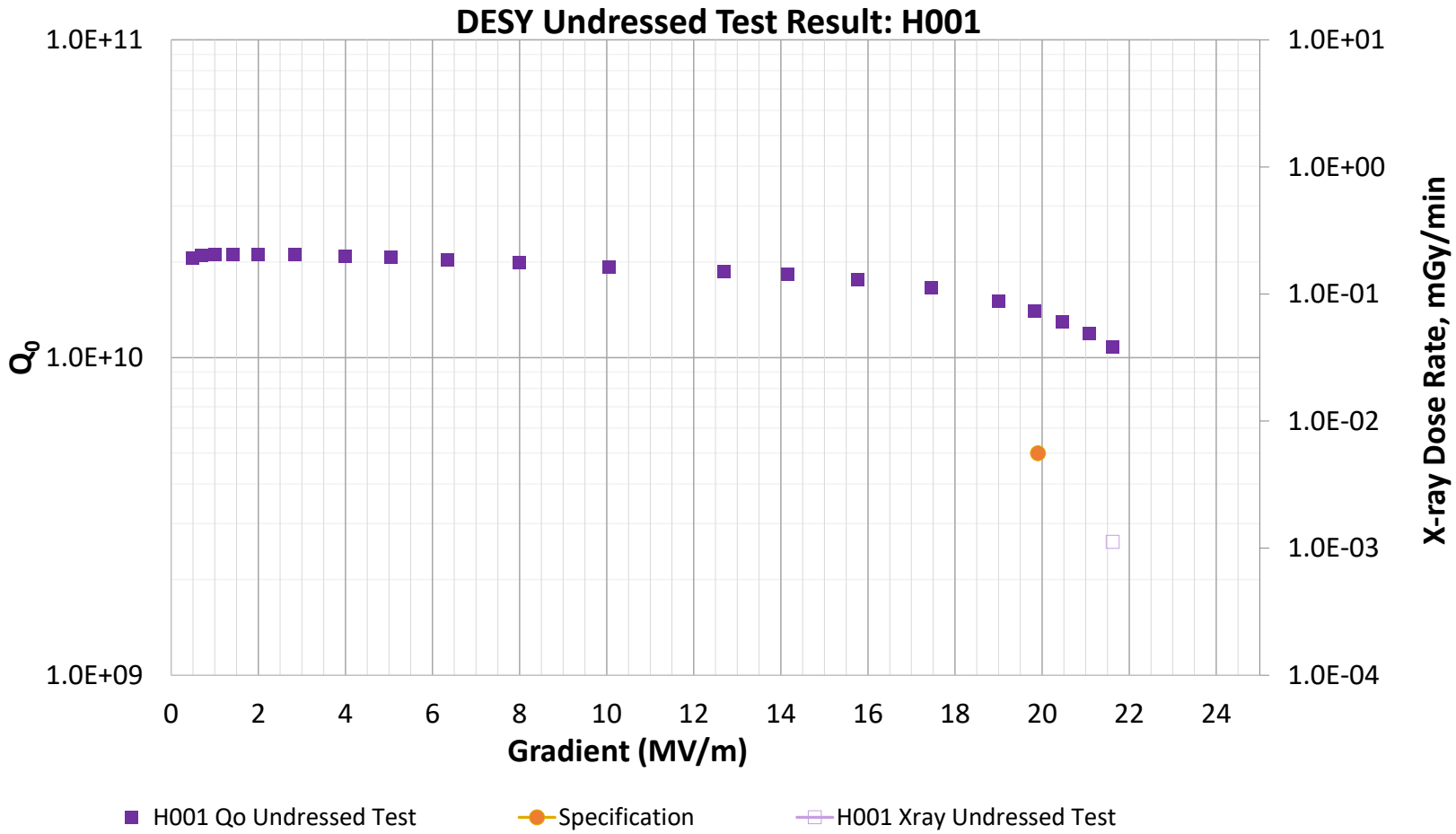
Cavity #	Q0 @1MV/m	Q0 @ 19.9MV/m	Max Eacc [MV/m]	Q0 @Max Eacc
HB02T	2.50E+10	1.60E+10	22.7 (Power limited)	1.03E+10
HB04T	2.50E+10	1.90E+10	21.4 (Quench)	1.80E+10
HB05T	2.57E+10	1.90E+10	24.6 (Power limited)	1.20E+10

ESS Specifications : Q_0=5E9 @19.9MV/m

De-bugging guide (Courtesy of Axel Matheisen)

Criteria		Assessment
• Q_0 low • No field emission	First test	Check cavity for Q decease during cold test
		Check mode spectrum during cold to identify if Q_0 is limited by a local problem
		Redo HPR and retest
	Still poor after retest	Optical inspection by camera
		Redo 20 µm BCP with STFC people on place
• Q_0 ok • Limited by field emission	First test	Check mode spectrum during cold to identify cell that limited by a local problem
		Redo HPR and retest
		Optical inspection by camera / check surface damages
	Still poor after retest	Grinding if needed
		Redo 20 µm BCP with STFC people on place
• Q_0 ok • No field emission • Quench before specification limit	First test	Check mode spectrum during cold to identify cell that limited by a local problem
		Install T sensors of cavity for localisation of defect
		Redo 20 µm BCP and HPR
	Still poor after retest	Install T sensors of cavity for localisation of defect
		Optical inspection by camera
		Grinding if needed
		Redo 20 µm BCP and HPR

Undressed Pre-series Cavity Test: H001



Undressed Test

- Gradient and Q_0 specification achieved
- Radiation observed above 21 MV/m
- Criteria met

⇨ H002 released for processing

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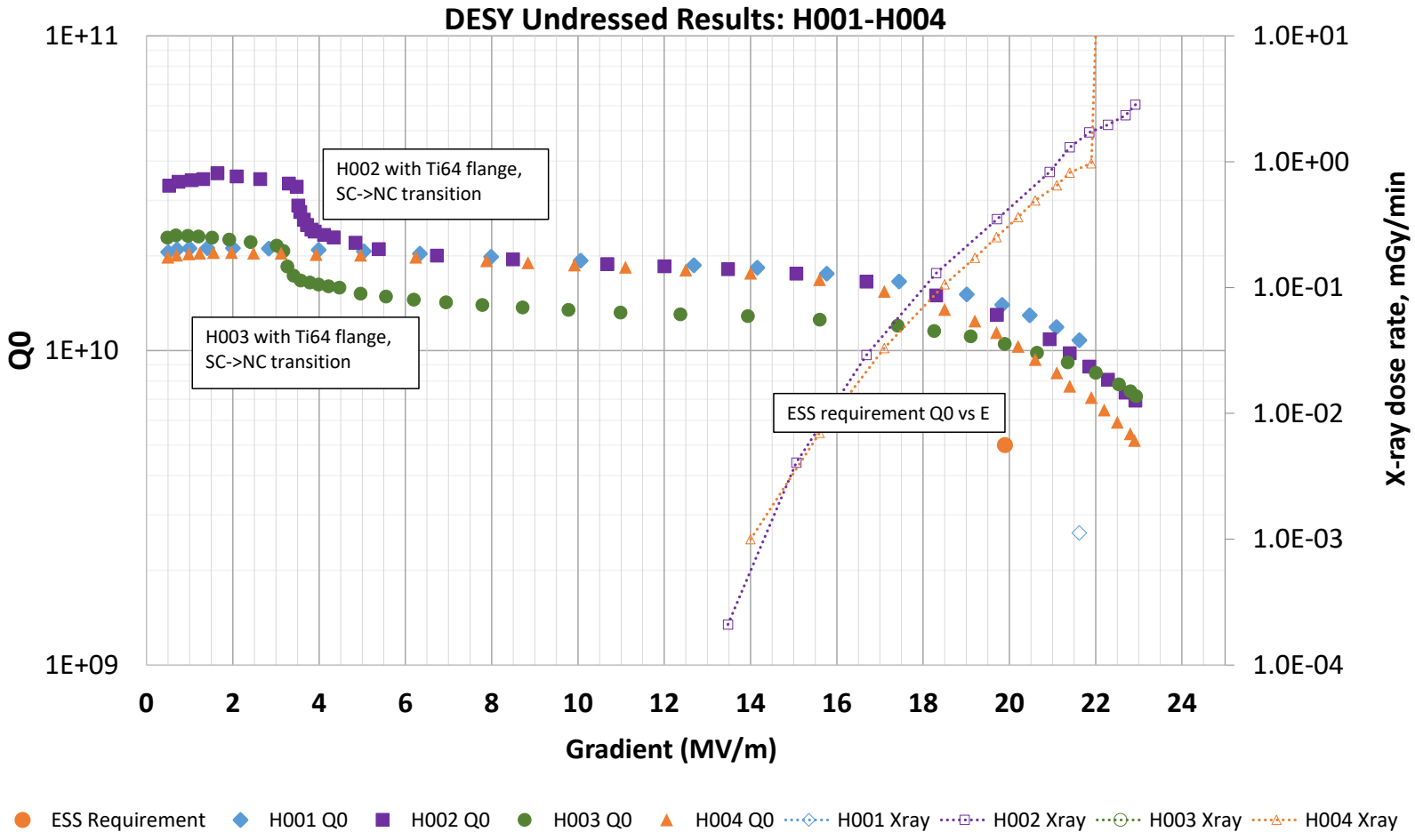
Undressed Pre-series Cavity Tests



H002, H003, and H004:

- Gradient and Q_0 specification achieved
- H002 radiation observed
  - Cause identified to be incorrect seating when undergoing HPR
- H003 no radiation observed
- H004 radiation observed
- Criteria met

⇨ Process released for production cavities

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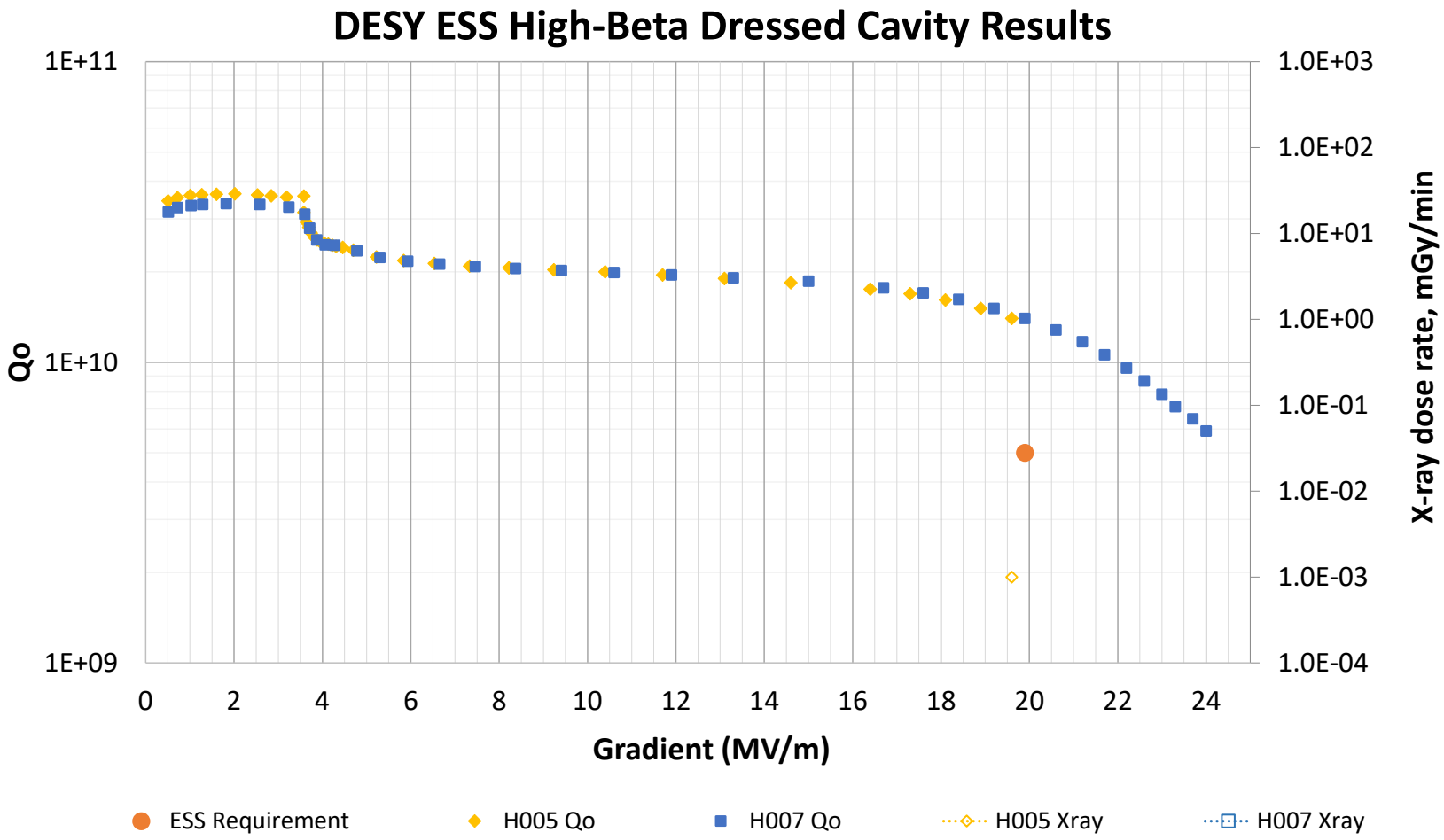
Non-Conformance Reports

- Production cavity issues:-
  - Water resistivity too low on 4 cavities (Between 12 – 13 MΩ.cm)
  - Acid temperature exceeded 15 °C on 7 cavities
    - Issue occurred in the Summer and has improved
    - Maximum allowed increased to 16 °C, but the target is still 15 °C
  - Acid drain time was exceeded on 2-3 cavities
    - Reviewed valve opening operation

⇨ Monitoring continuing

Dressed Production Cavity Tests



H005 and H007:

- H007 specification achieved
- H005 hard quench at 19.8 MV/m
  - Radiation observed

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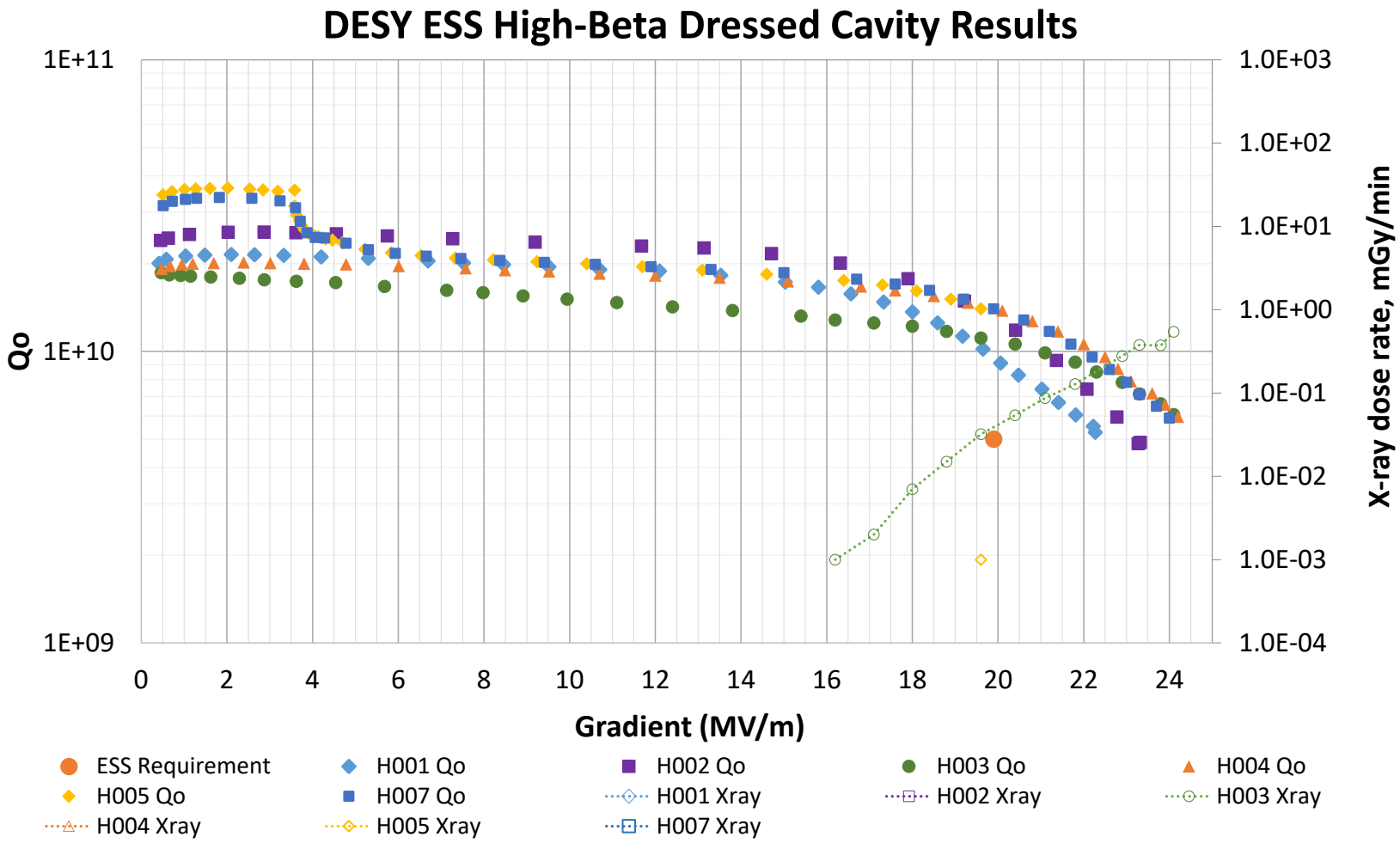
Dressed Production and Pre-Series Cavity Tests



H005 and H007:

- H007 specification achieved
- H005 hard quench at 19.8 MV/m
  - Radiation observed

Pre-series and Production cavities:

- H003 radiation observed after He jacket installation and additional BCP
- H008 and H009 on test at present
  - High radiation levels observed

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Summary and Discussion

Summary

- Pre-series cavities all met gradient and Q_0 performance
  - No issues with Q disease witnessed
- Radiation levels observed on H002 (HPR issue) and H004

⇨ BCP process qualified with 4 pre-series cavities

- Production cavities released
- Statistical sample low!

⇨ Reliant on the experience and capability of the vendor

- Testing of production cavities just commencing

Discussion

- PIP-II – Plan to have only 2 pre-series cavities

⇨ Qualification of processes more difficult (Electro-polishing and N-doping)

- Manufacturing process/capability needs to be reviewed as soon as possible
- Need to fully understand knowledge and experience gained from the prototype cavities