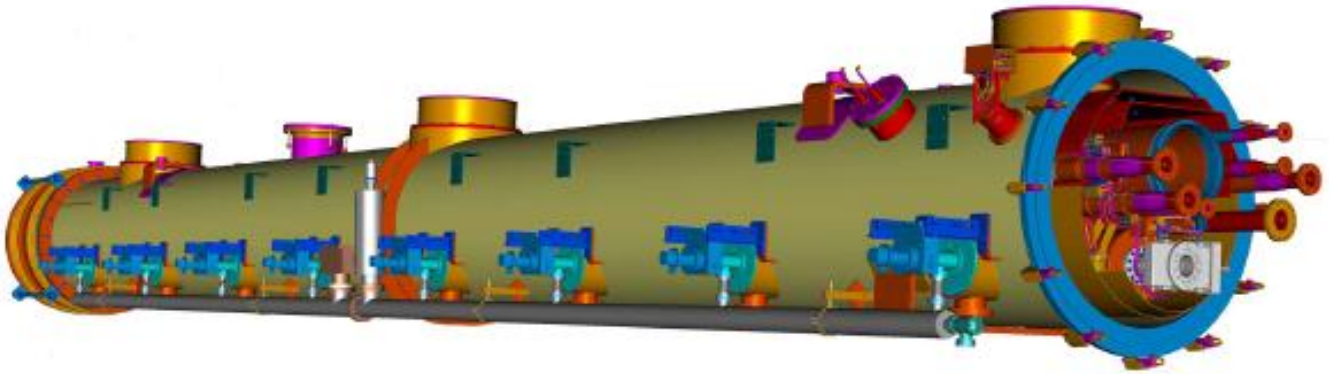
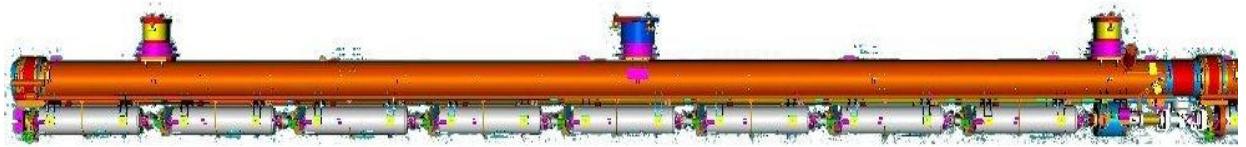
Status of E-XFEL String and Module Assembly



O. Napoly, CEA-Saclay, Irfu/SACM

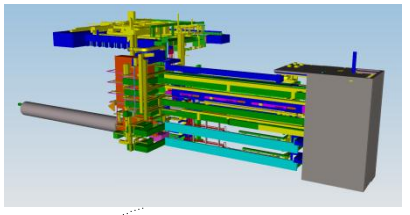
E-XFEL Accelerator 17.5 GeV

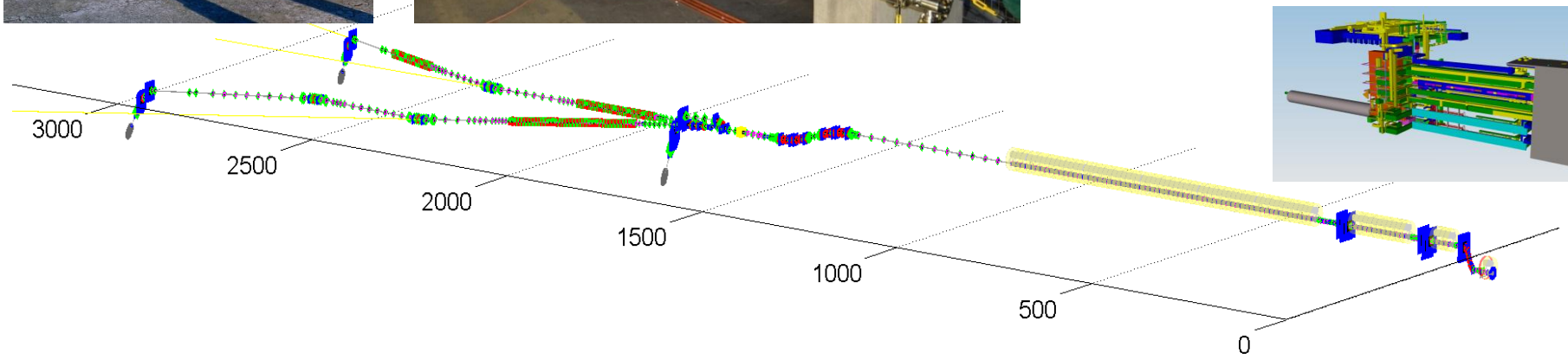
101 accelerator modules



808 accelerating cavities
1.3 GHz / 23.6 MV/m / 10^{10}

25 RF stations
5.2 MW each





CEA In-Kind Contribution

CEA contributes to the
XFEL Cold Linac construction through
String Assembly in Clean Room (WP9) and Module Assembly (WP3)

↓

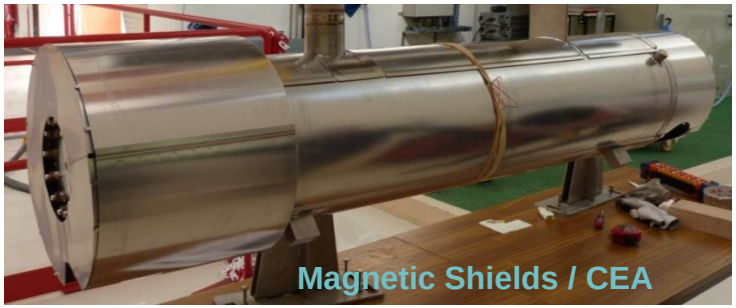
Assembly of 103 accelerator modules with 1 week throughput !
operated by an industrial contractor on the Saclay site.

Component Industrialization / Handover

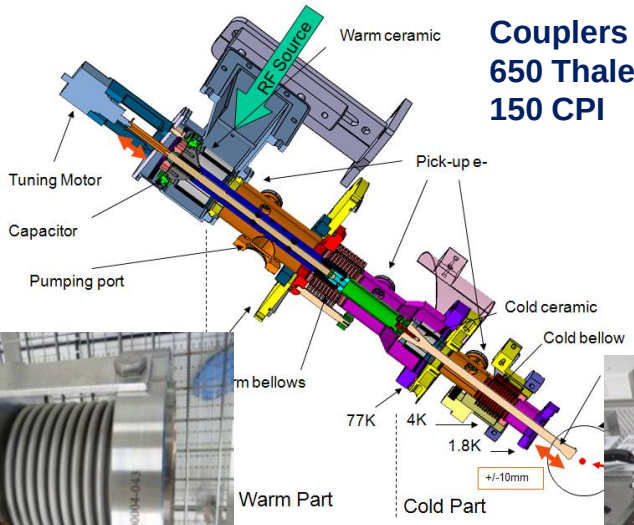
Cryo-systems

Vacuum vessels

45 from Zanon, 58 from IHEP/DESY

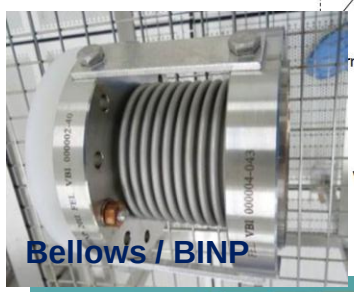


Magnetic Shields / CEA

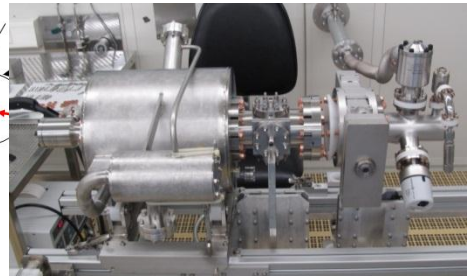


Couplers / IN2P3
650 Thales-RI
150 CPI

Quadrupole-BPM / DESY
103 Magnets / Ciemat
BPM / 72 DESY – 31 CEA
206 Gate Valves / DESY



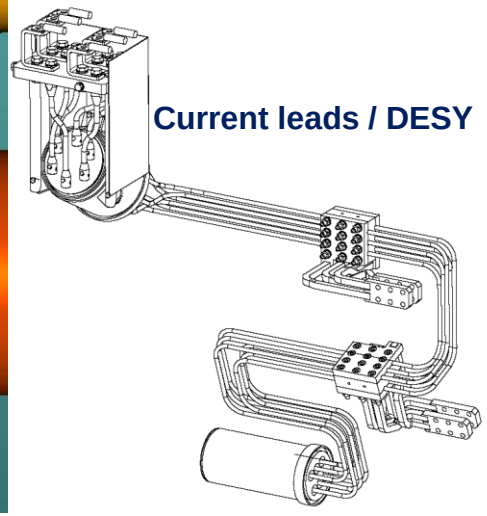
Bellows / BINP



Helium tanks / DESY
600 Zanon / 200 CNC / DESY

Tuners / DESY

800 Cavities / DESY
400 Zanon / 400 RI



Current leads / DESY

Organisation of Work Stations

The breakdown of the assembly work of 7 Work Stations aims at:

- **balancing almost equally the time occupancy of each WS,**
- **bringing the largest occupancy below 5 days**

1. **Clean Room Cold Coupler Area** (IS04-CC-WS1)
   - Cold coupler assembly (x8)
   - Leak check of caity-coupler connection (+RGA)
2. **Clean Room String Assembly Area** (ISO4-SA-WS1, ISO4-SA-WS2)
   - String connections (1 gate valve + 8 cavities + 1 Qpole unit)
   - Leak check of string and N_2 venting (+RGA)
3. **Roll-out Area** (RO-WS1, RO-WS2)
   - HOM adjustment, magnetic shielding, T-sensors (x6)
   - Tuner assembly (x8), coupler 4K and 80 K shields
   - 2 Ph-tube welding, NCT (LT, PT, RT)
   - Cold-mass/string connection
4. **Alignment Area** (AL-WS1, AL-WS2)
   - Cavity and quadrupole fine alignment (~100 µm)
   - Welding of 8 mm LHe filling line (x9)
   - Tuner and piezo electric tests
5. **Cantilever Area** (CA-WS1)
   - Welding of 4K and 70 K shields, 4K and 79 K super insulation
   - Cable routing and insulation, Quad current lead
   - Insertion into vacuum vessel and cold mass alignment
6. **Coupler Area** (CO-WS1, CO-WS2)
   - Warm couplers + coupler pumping line + leak checks (8 connections + coupler vacuum)
   - Cabling of flanges A (x8) and flange D
   - Quadrupole current lead connections and welding
   - Final leak check of cavity vacuum + final pumping
7. **Shipment Area** (SH-WS1, SH-WS2)
   - Control operations (RF frequency)
   - End-caps closing, N2-insulation
   - CEA-Alsyom “acceptance test”
   - Loading

Assembly Procedures

- The preparation, assembly and control work are described in **179 procedures**, 'Fiches d'Instruction', 'used' by the operators.

- The first set of draft procedures was written by CEA, during the Prototyping phase at DESY and Saclay, in English and appended to the Call for Tender Specifications for Industrial Operator selection

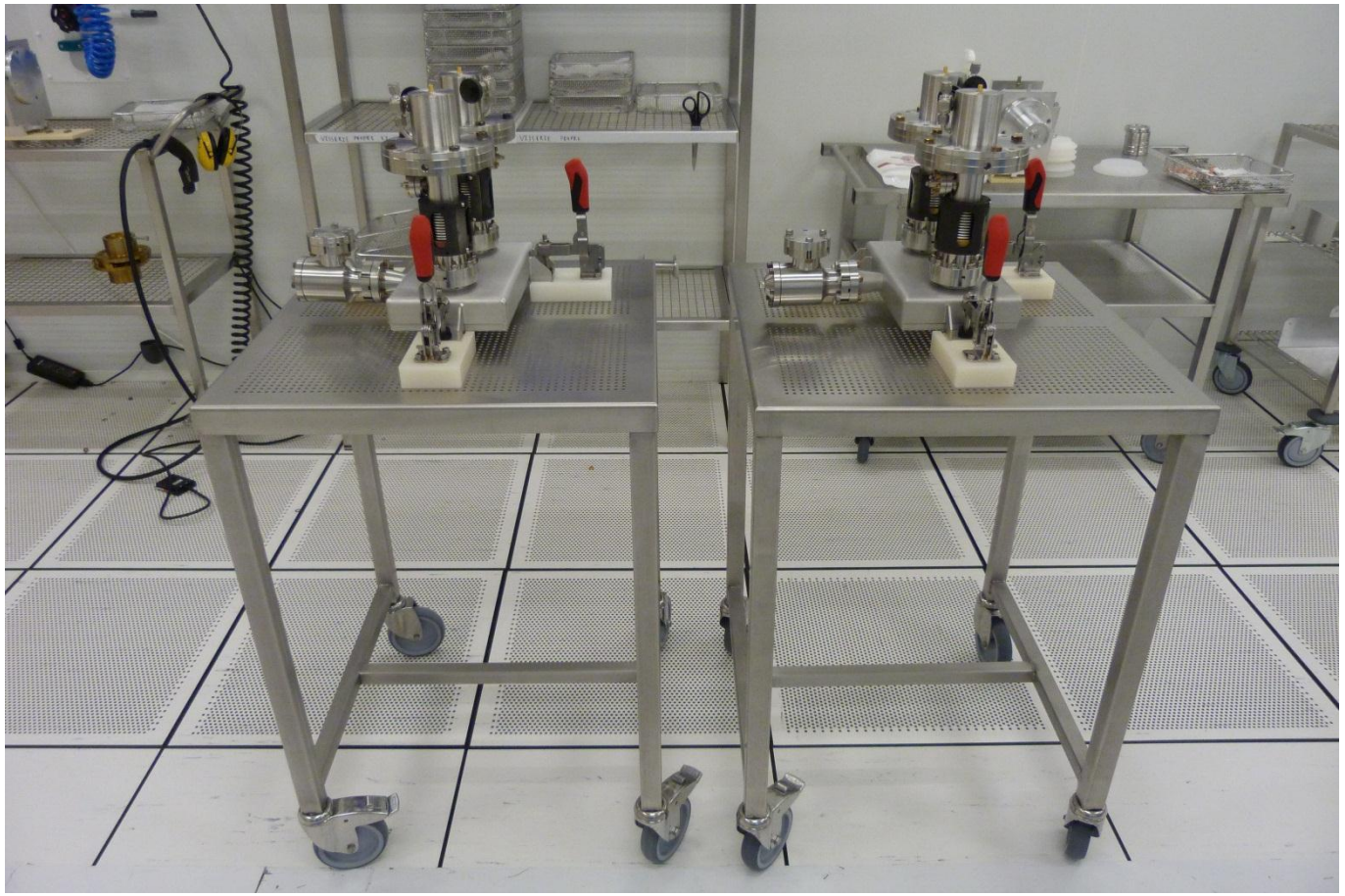
- Alsyom, the selected Industrial Operator, was in charge of updating these procedures during the Pre-Series phase (3 modules) and to translate them in French for their usage during the Series production phase.

- This took much (much) longer than expected ! **166 are final.**

Productivity may still gain from improvement of small tools

Productivity may still gain from improvement of small tools

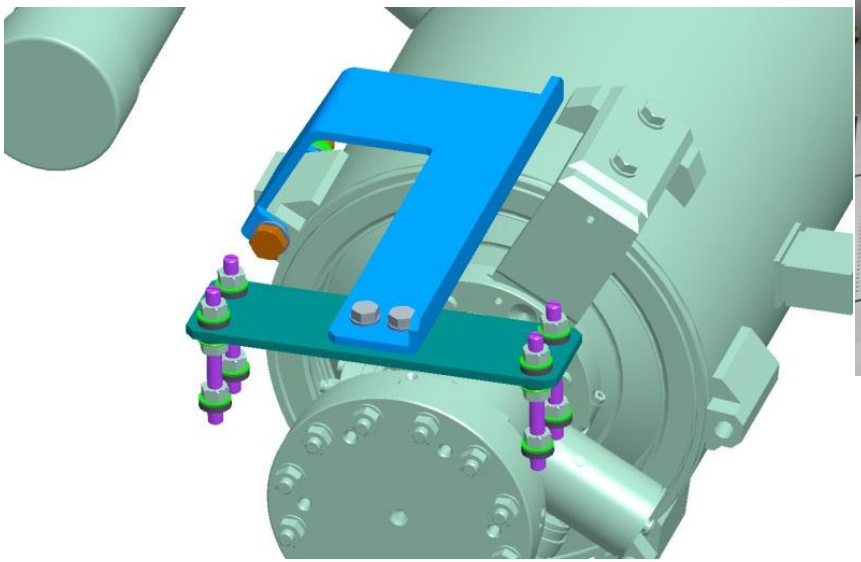
Transfer carriages for cold coupler pairs and coupling box

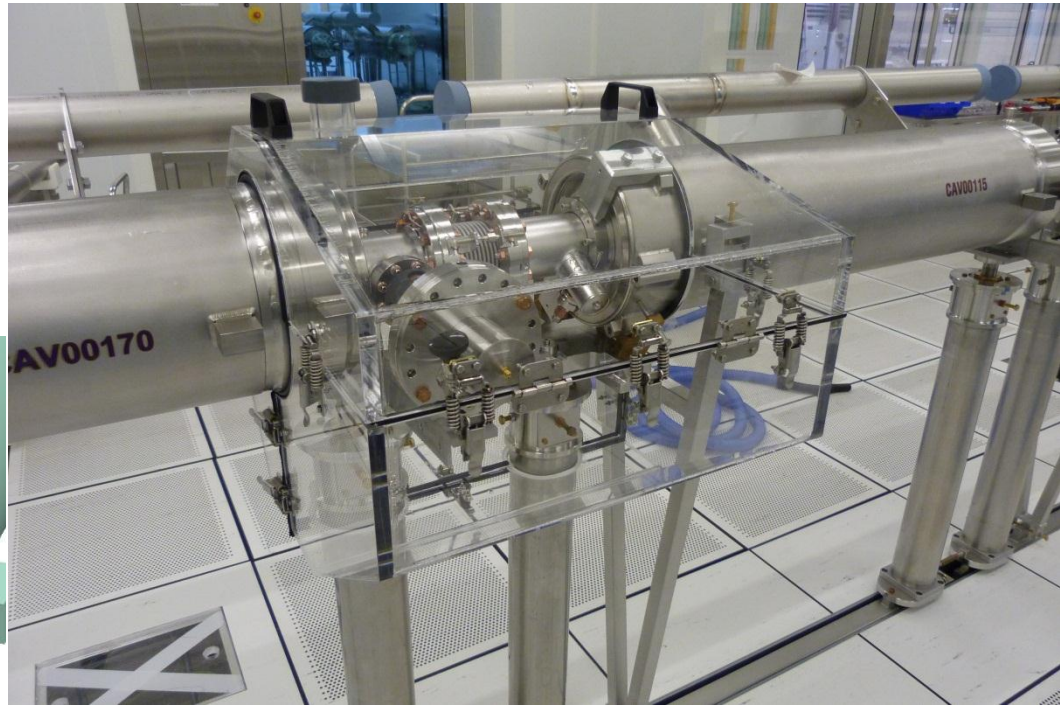


Two more examples, in use:

1) Pre-fabricated et reusable devices for the leak-check of the cavity string connections → 3 units fabricated and in use.

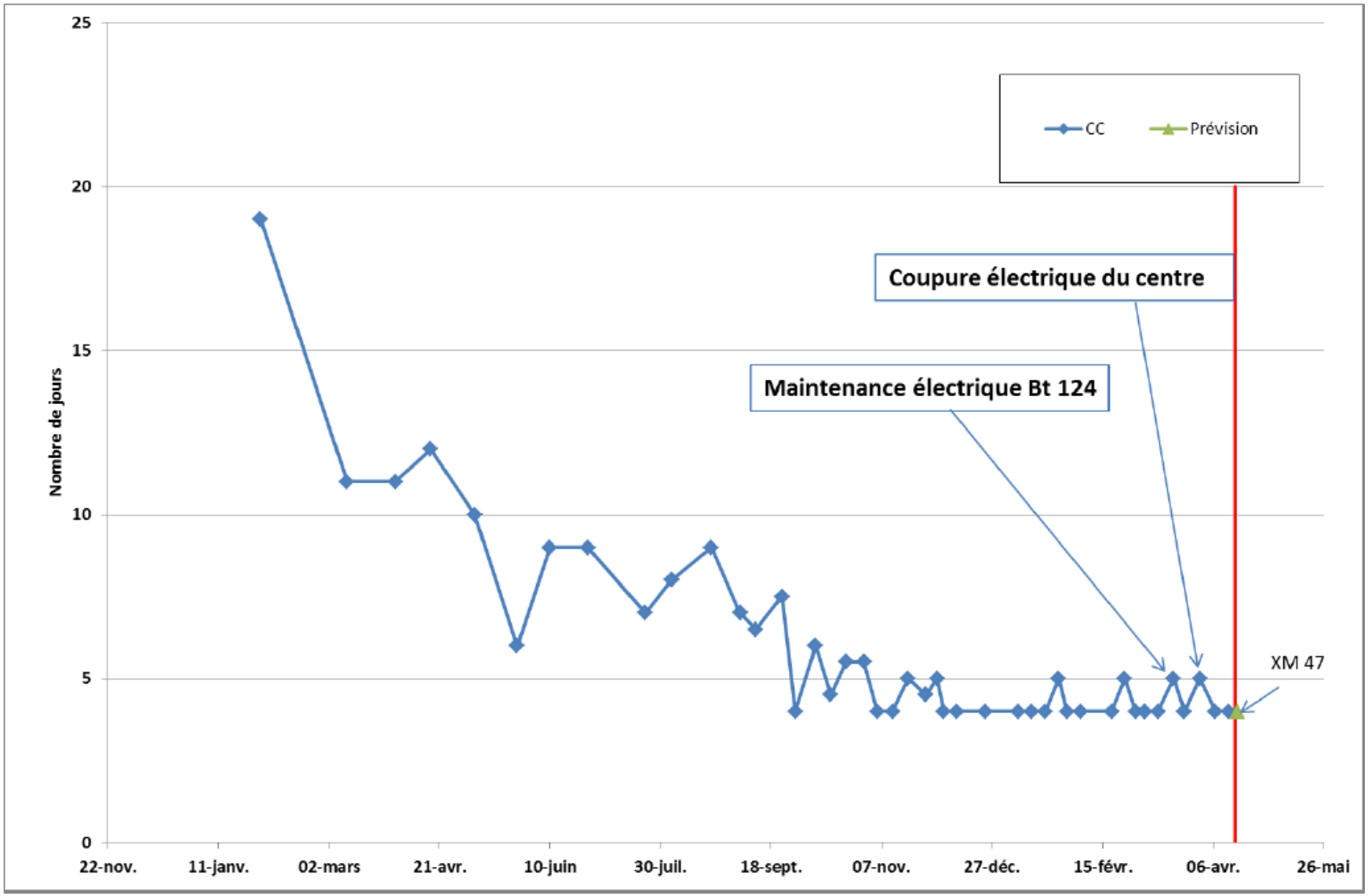
2) Realization of gate valve support for its assembly on Cold-Coupler workstation:
Design and fabrication taken over by Alsyom, used for XM22.



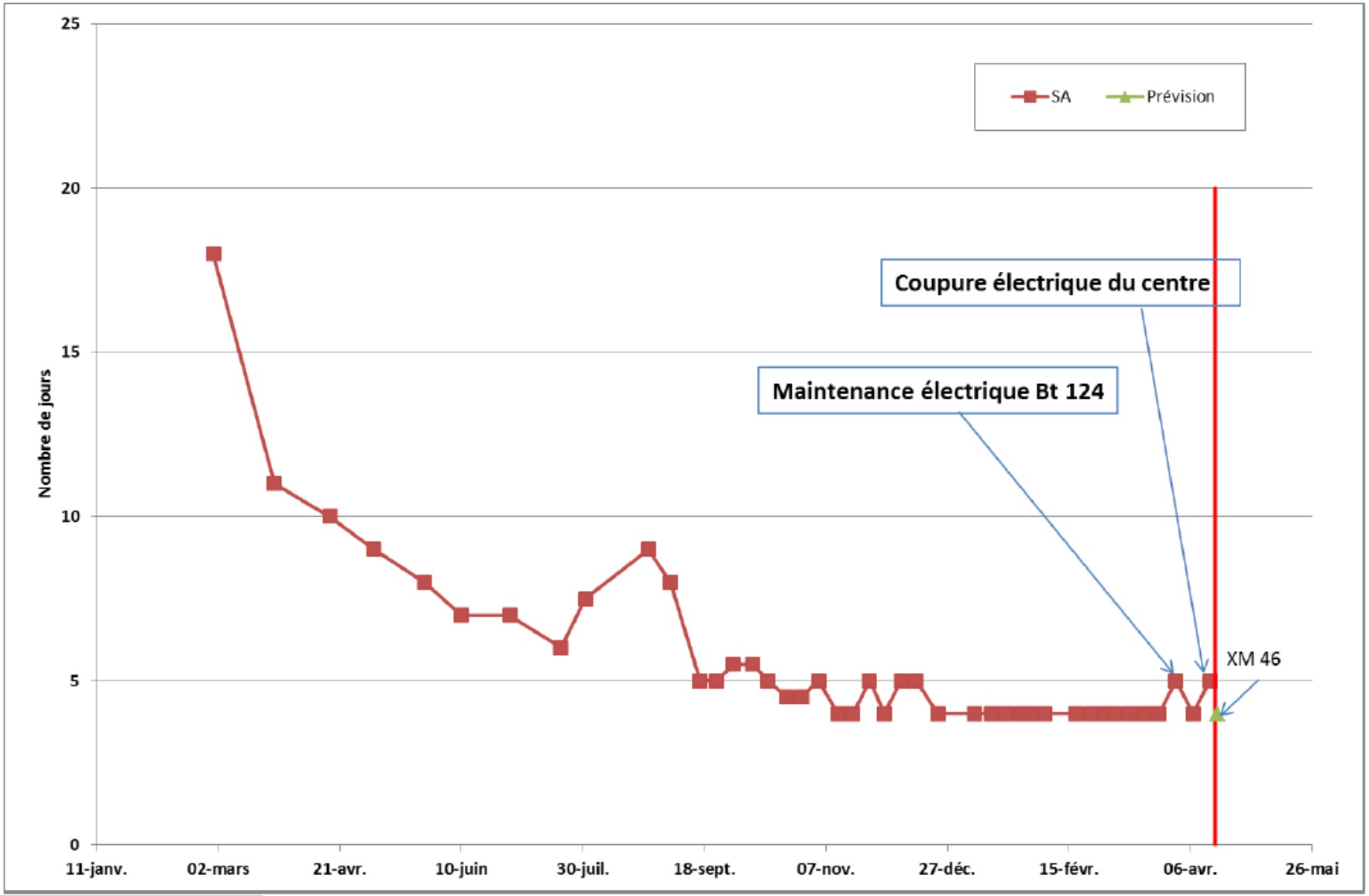


Inter-cavity connection leak-check box, including cold coupler connection, and pre-existing HOM flanges

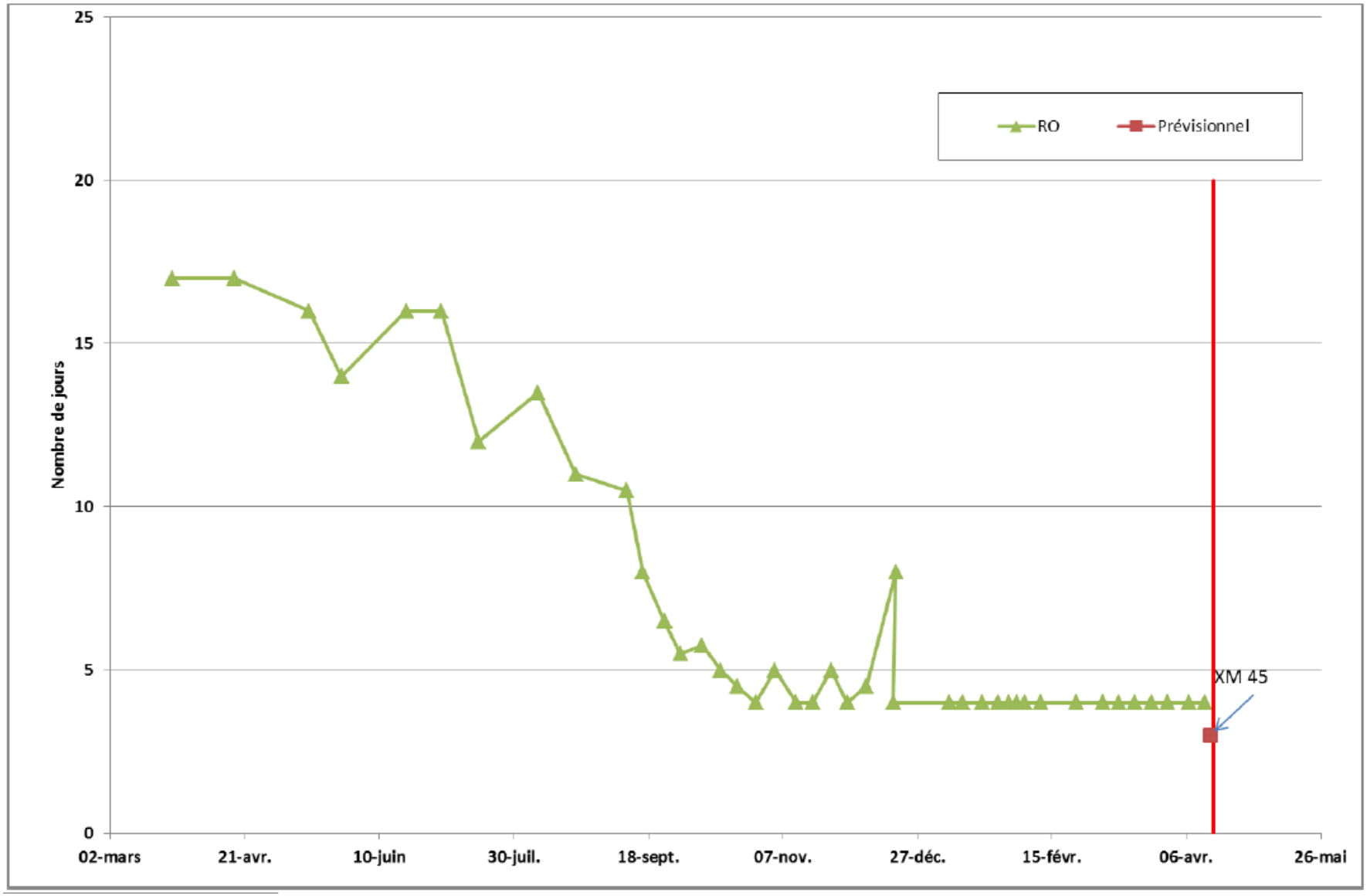
Throughput at Cold Coupler WS



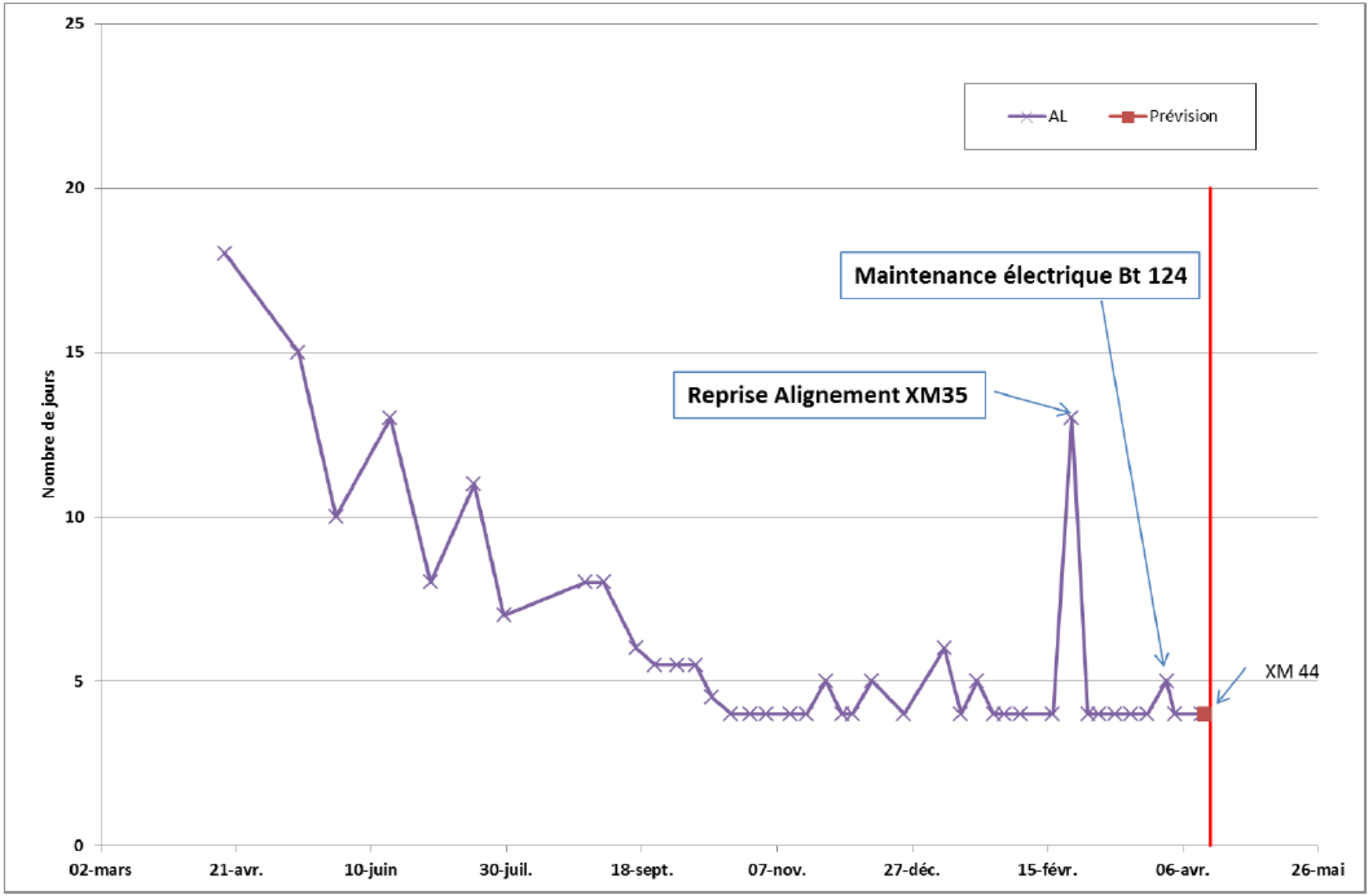
Throughput at String Assembly WS



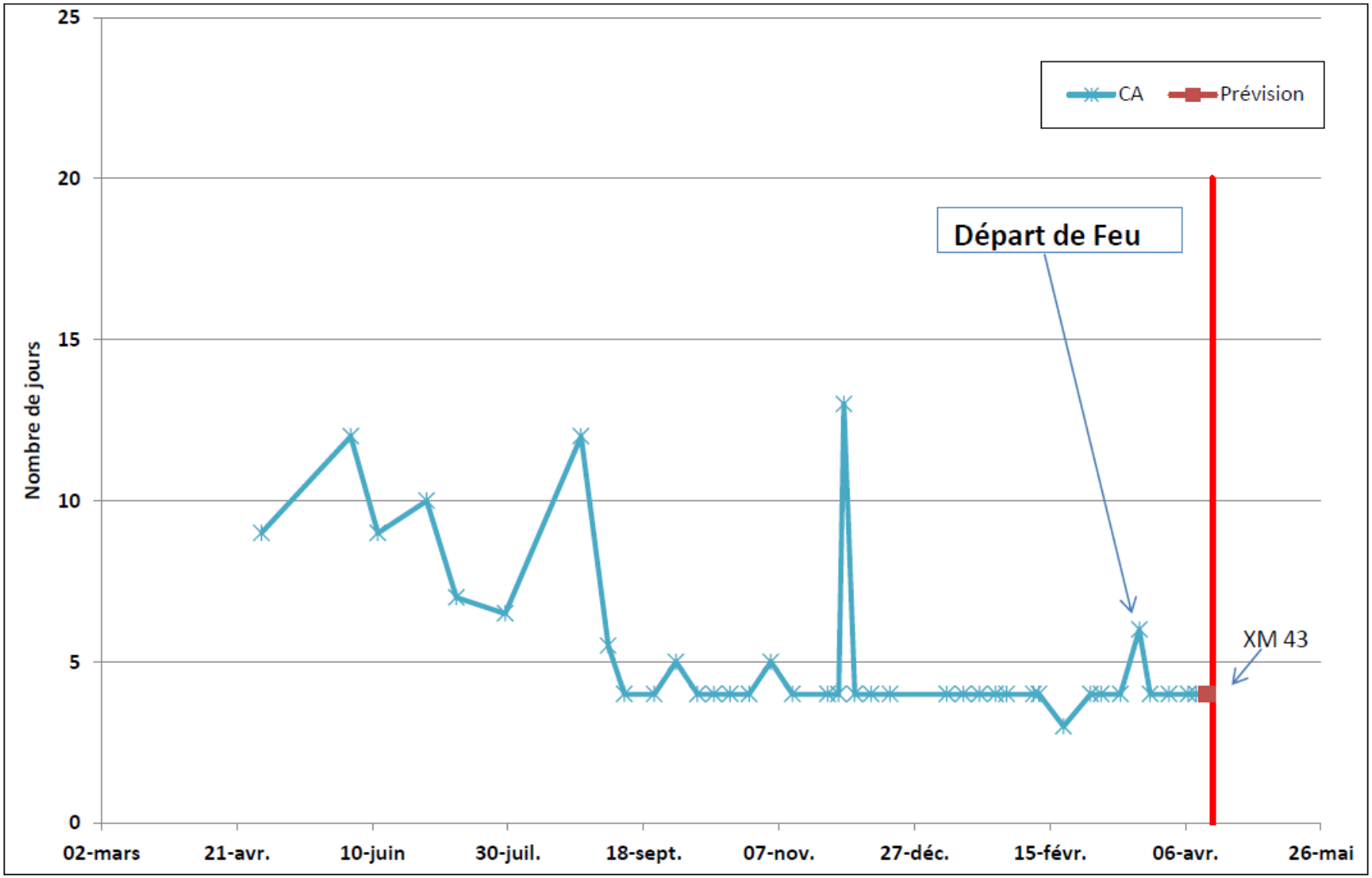
Throughput at Roll-out WS



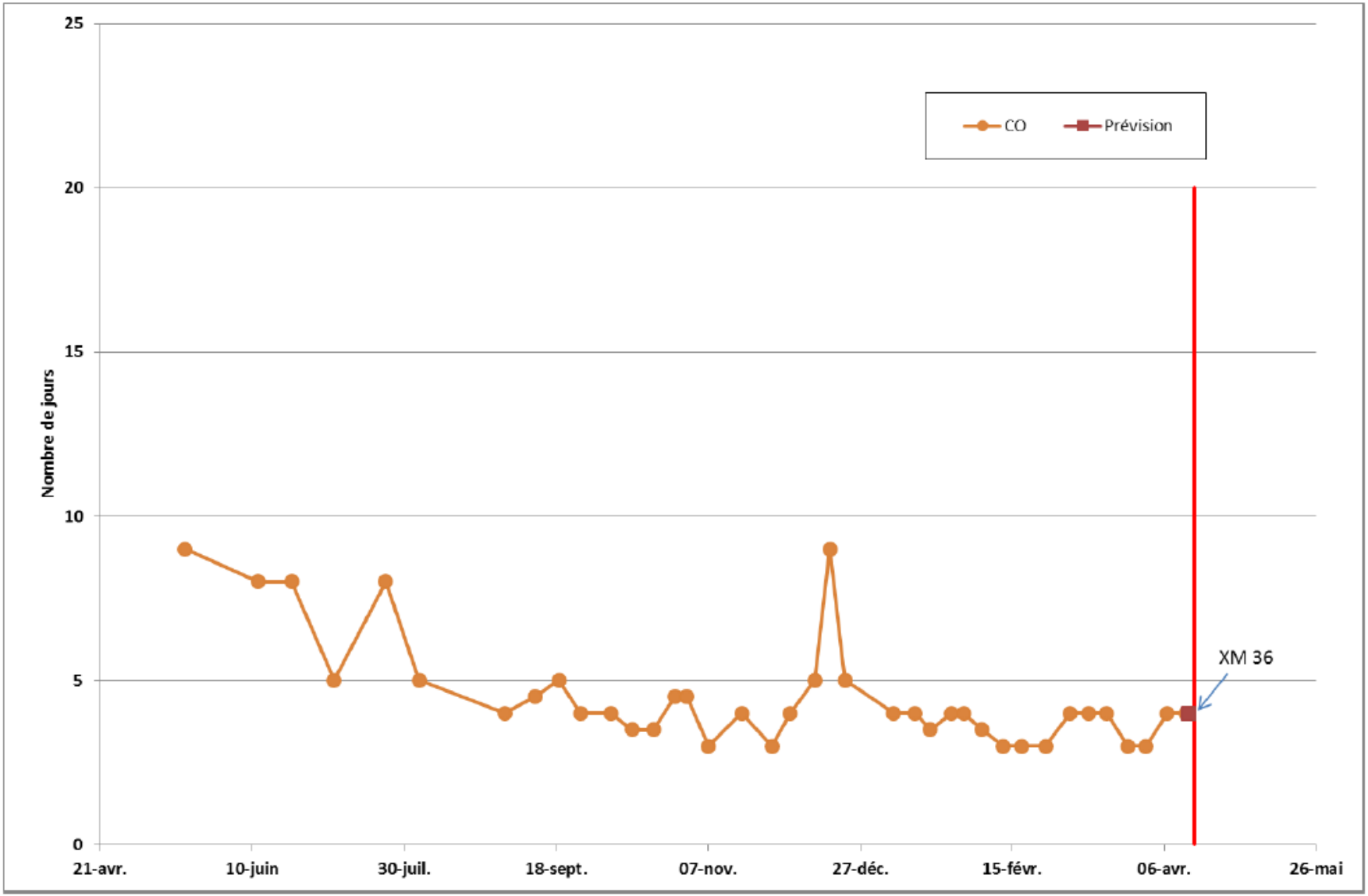
Throughput at Alignment WS



Throughput at Cantilever WS



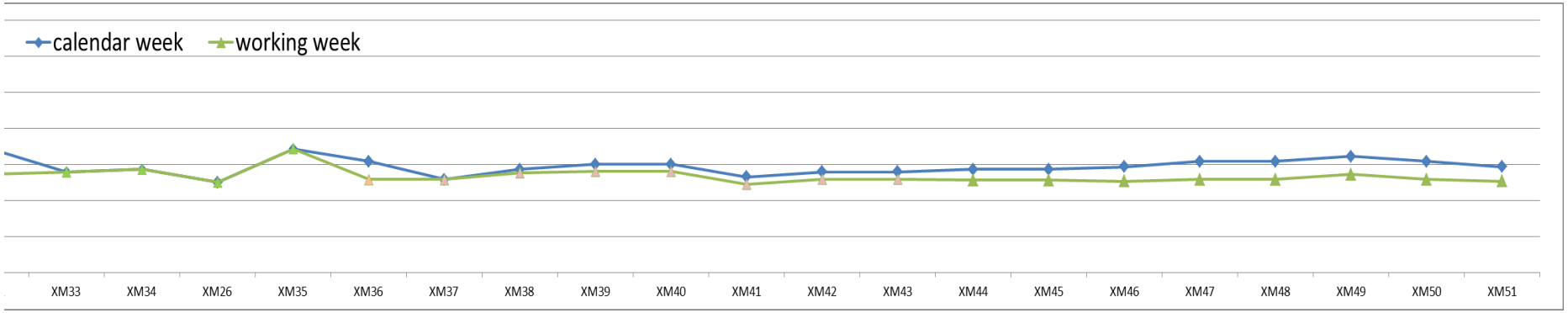
Throughput at Warm Coupler WS



Cryomodule Asssembly Time

7 weeks = 7 x 5 working days was reached mid-October 2014 with XM15

$\Rightarrow$ the design of the Assembly Infrastructure was sound

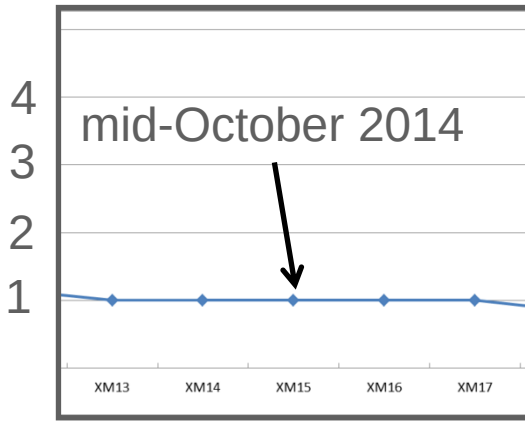


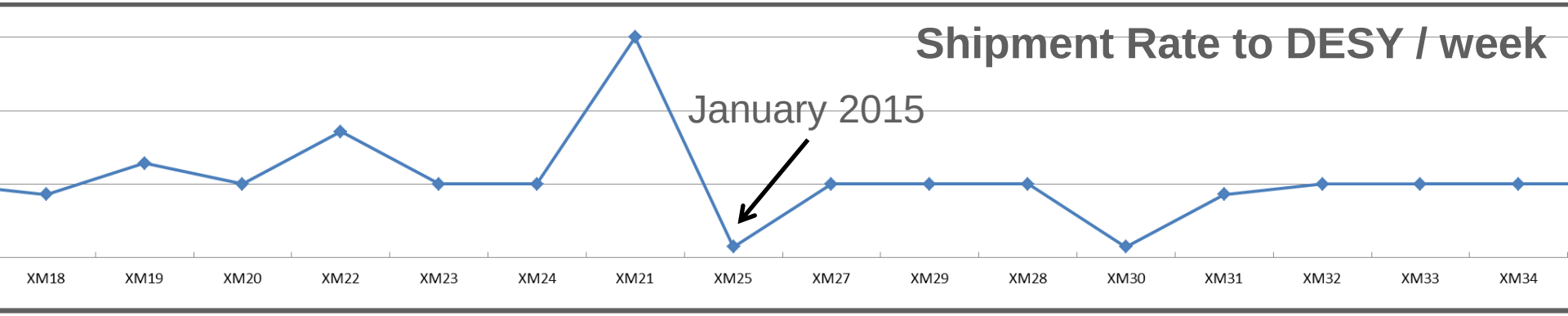
7 x 4 working days was reached on 5 January 2015 with XM25

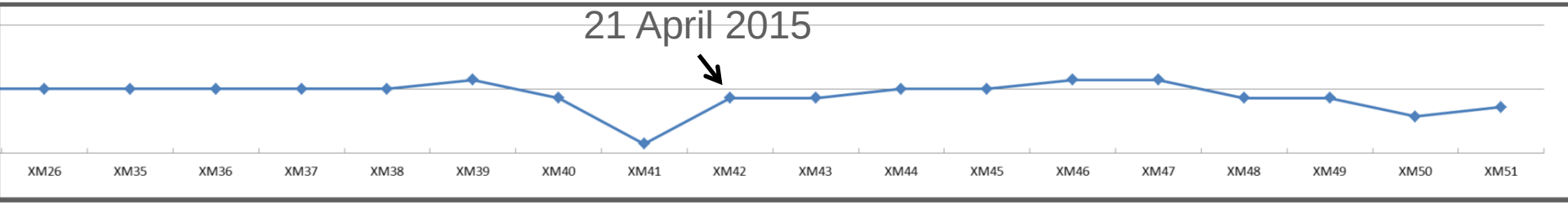
This accelerated production is needed to close the XFEL tunnel mid-2016

CEA to DESY Cryomodule Delivery

- As of April 22, 2015: **45 out of 103 modules shipped to DESY**.
- Throughput of 4 days started in 2015 : from January 5 till April 21, CEA delivered 18 cryomodules (XM25 to XM42) in 69 working days (69/4=17,25).
- If we maintain the 4 day throughput (so-called *acceleration of production)* XM100 will be delivered around 20 April 2016.
- The accelerated scheme is robust: it has already absorbed major incidents.







Quality Control

Quality Control consists in:

1. Inspecting the incoming components
2. Controling the assembly work in person
3. Documenting the controls and non-conformities

Until end of 2014, the quality control group of Alsyom was too small (3 people) in such a way that Documenting and Incoming Inspection was performed in priority. CEA took the major part of the Assembly Work Controling, essentially during pre-defined ‘Hold Points’.

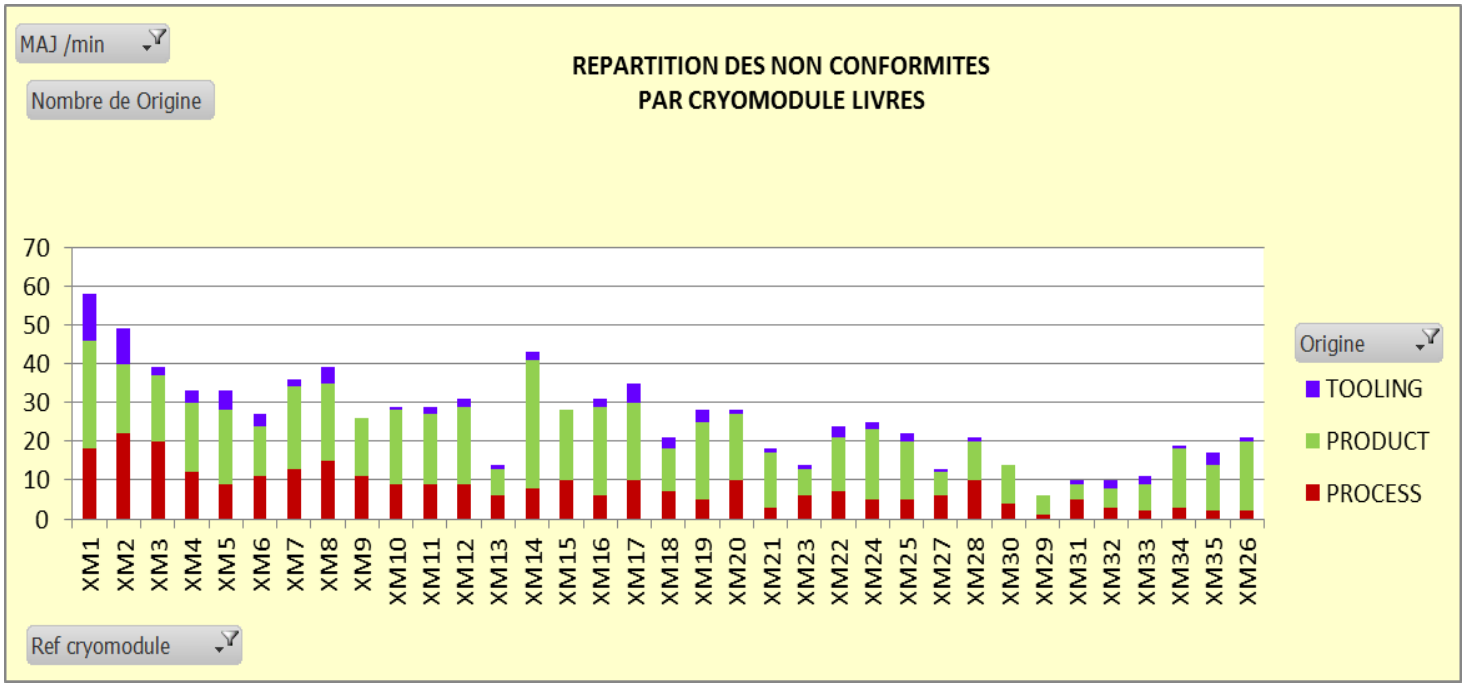
The ‘every day’ or ‘random’ controls were too few and this led to many mal-fabrication, most of them recorded at DESY before or during cryomodule cold test !

In November 2014, the quality control group of Alsyom was increased to 5 people which, together with the better organisation, covers the need of QC.

Quality Control: Non Conformities

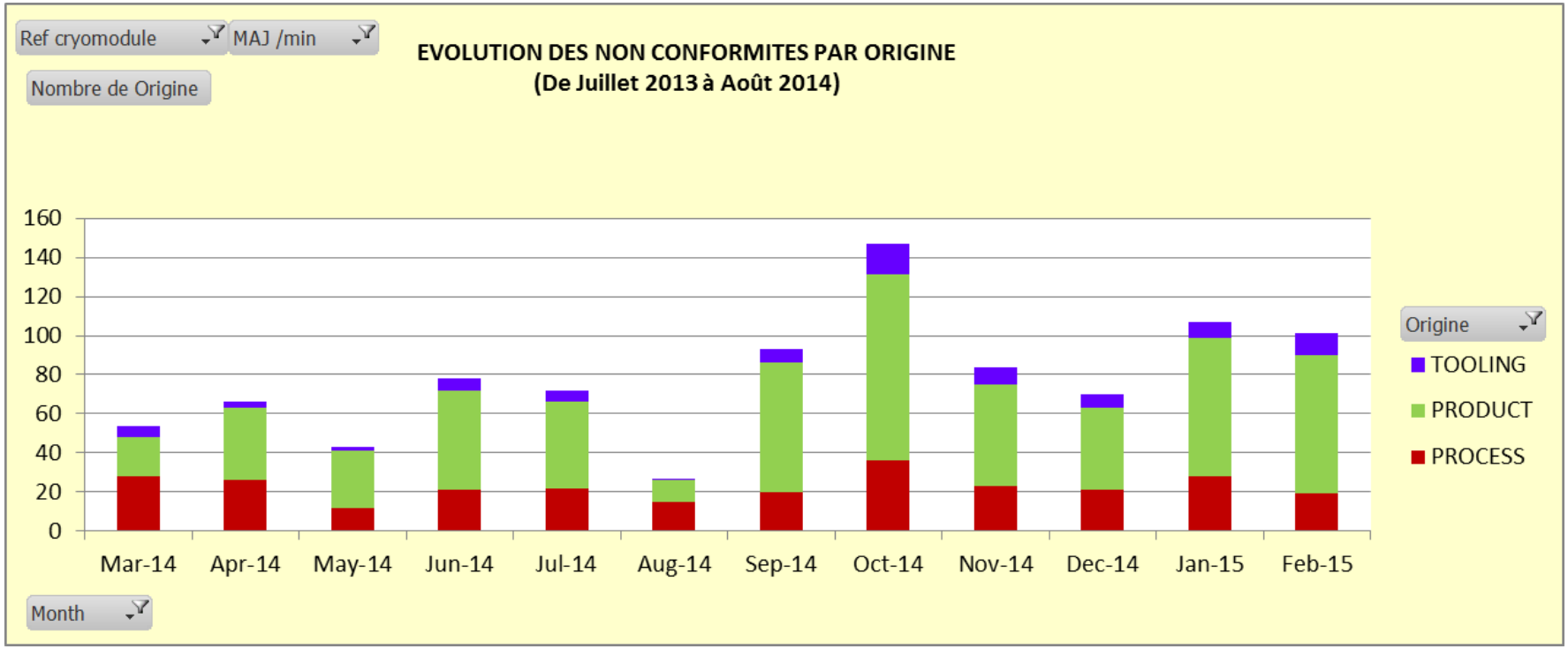
Non Conformities recorded by Alsyom fall into 3 categories:

1) Tooling and assembly equipment, from CEA and DESY (pump stations) (TOOLING)
2) Accelerator components (PRODUCT)
3) Assembly operation (PROCESS)



Quality Control: Non Conformities

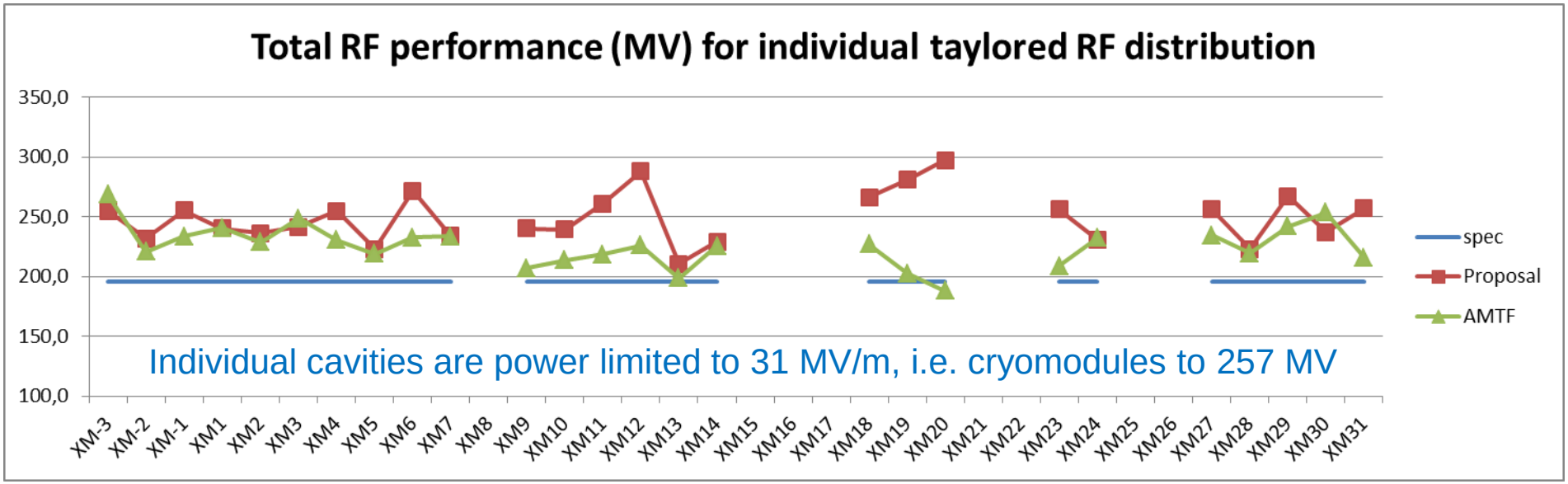
The number of Non Conformities is NOT going down.



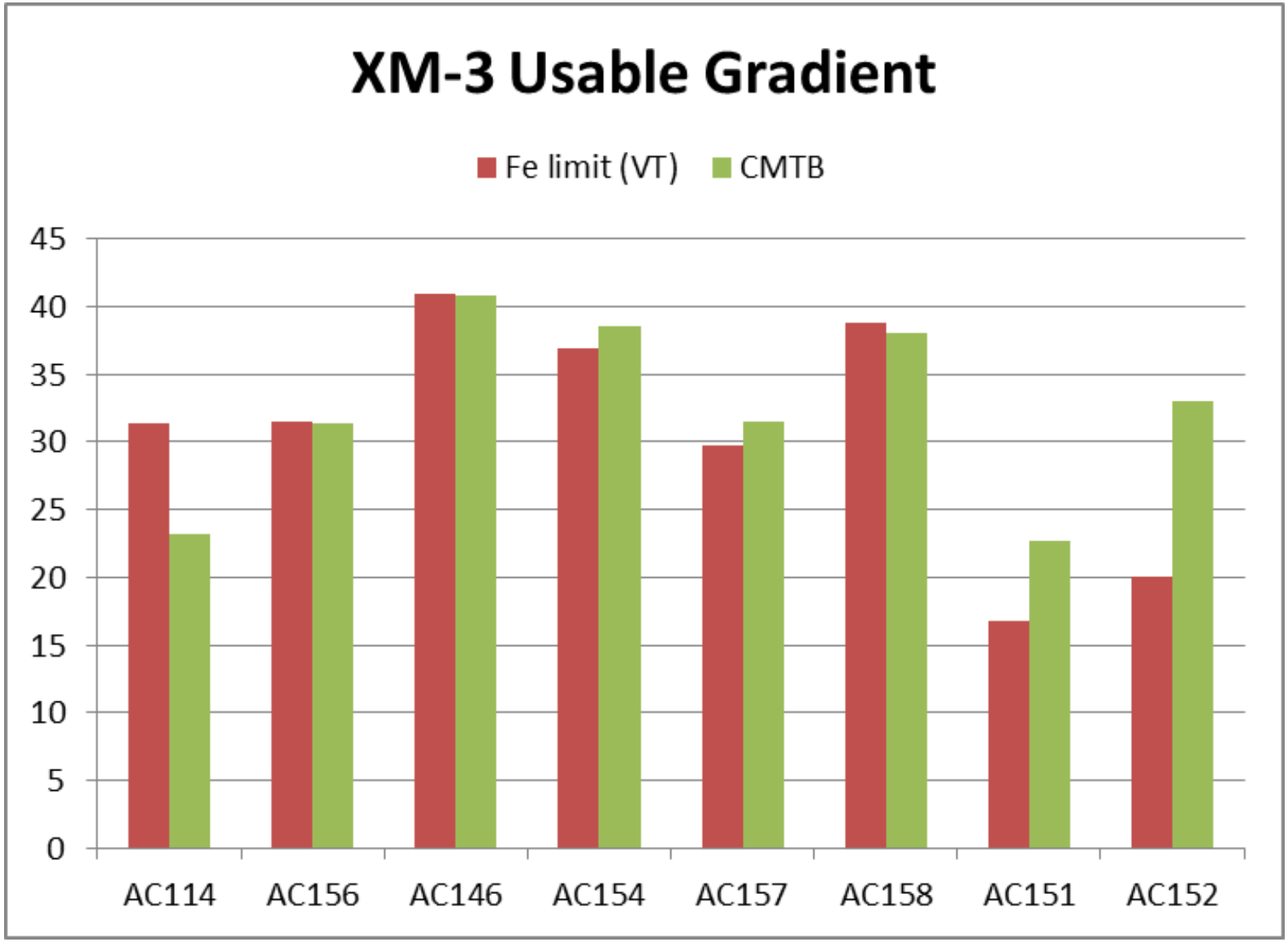
But, with better and more efficient detection at Incoming Inspection, the impact of PRODUCT NC on the module assembly has considerably decreased, compared to when many NC were discovered ‘on the fly’.

Cryomodule Performance

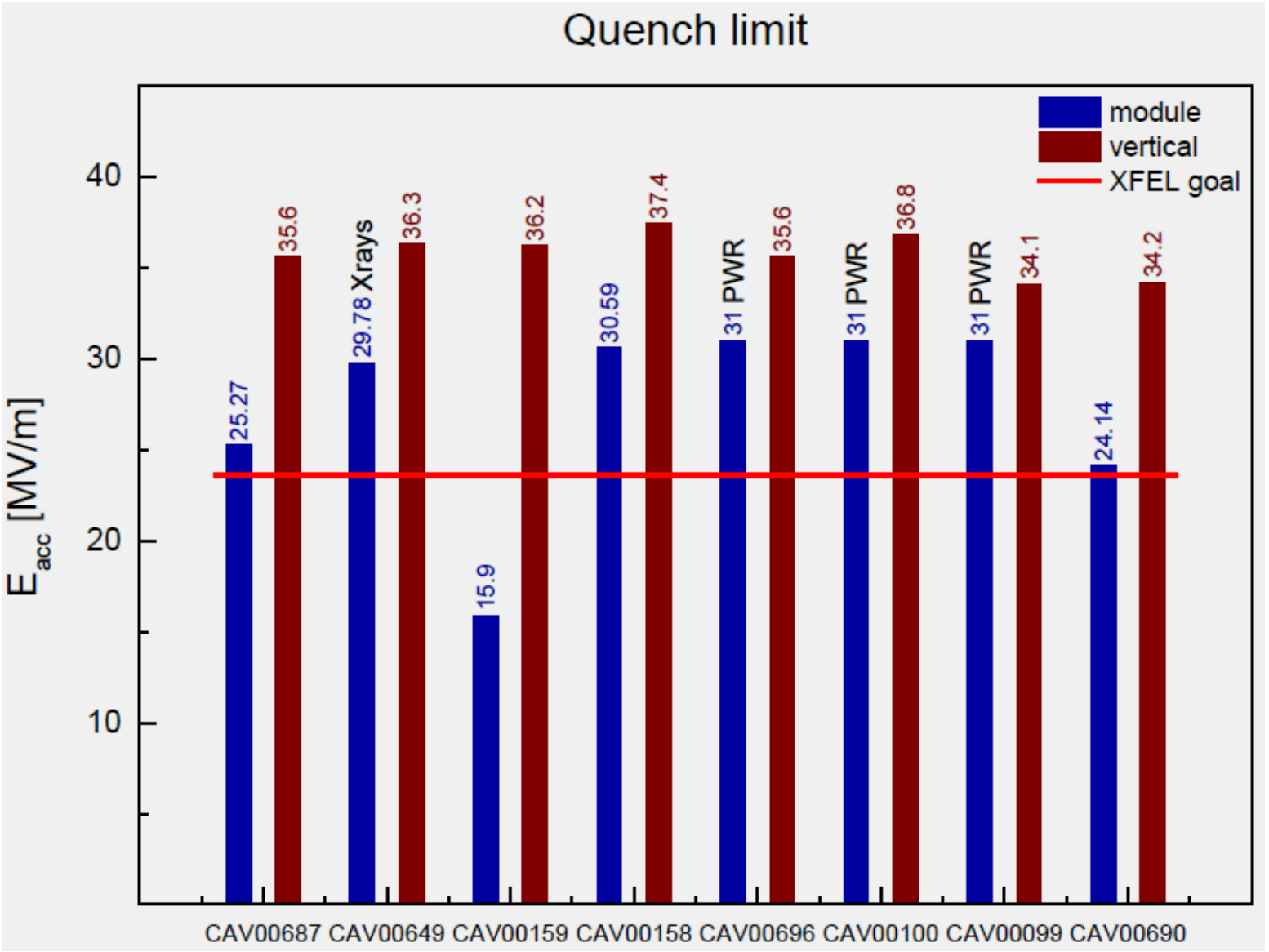
- All tested modules are on XFEL specs (195 MV per module), on average 15 % above specs (27.2 MV/m).
- Some very important cavity gradient degradation have been recorded, e.g. on XM19. Modules XM-3 and XM30 are the two exceptions.



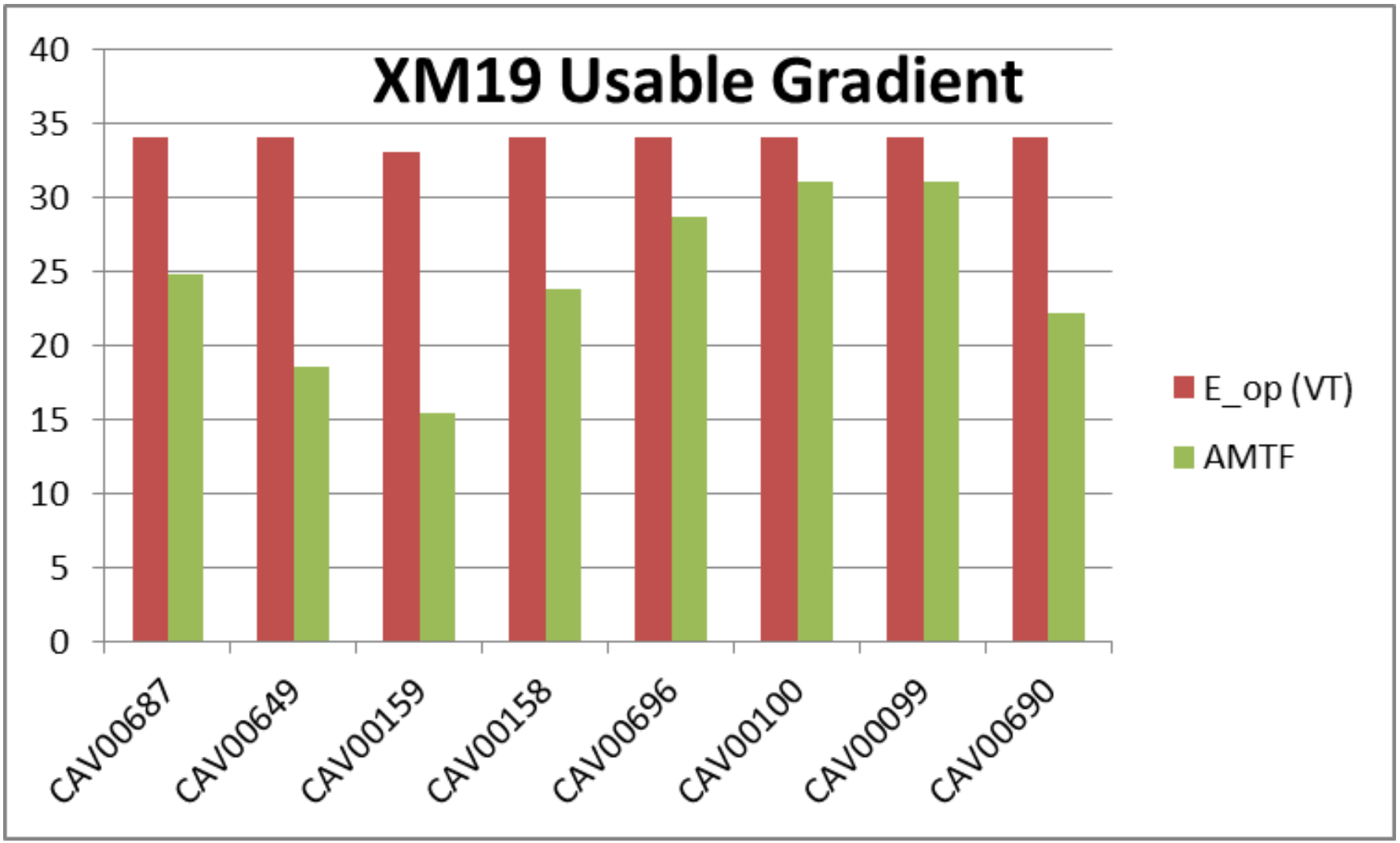
Cryomodule Performance : XM-3



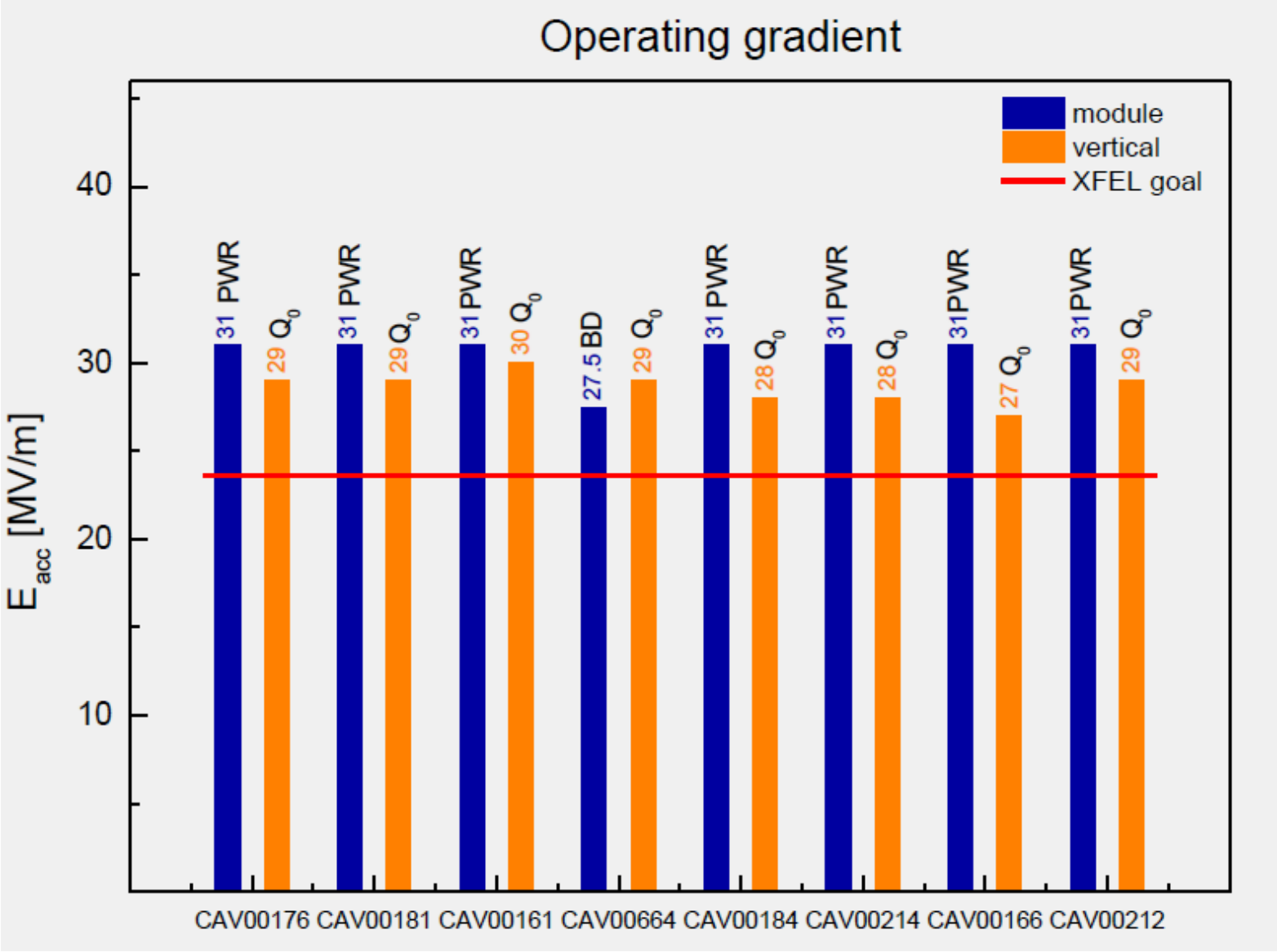
Cryomodule Performance : XM19



Cryomodule Performance : XM19



Cryomodule Performance : XM30



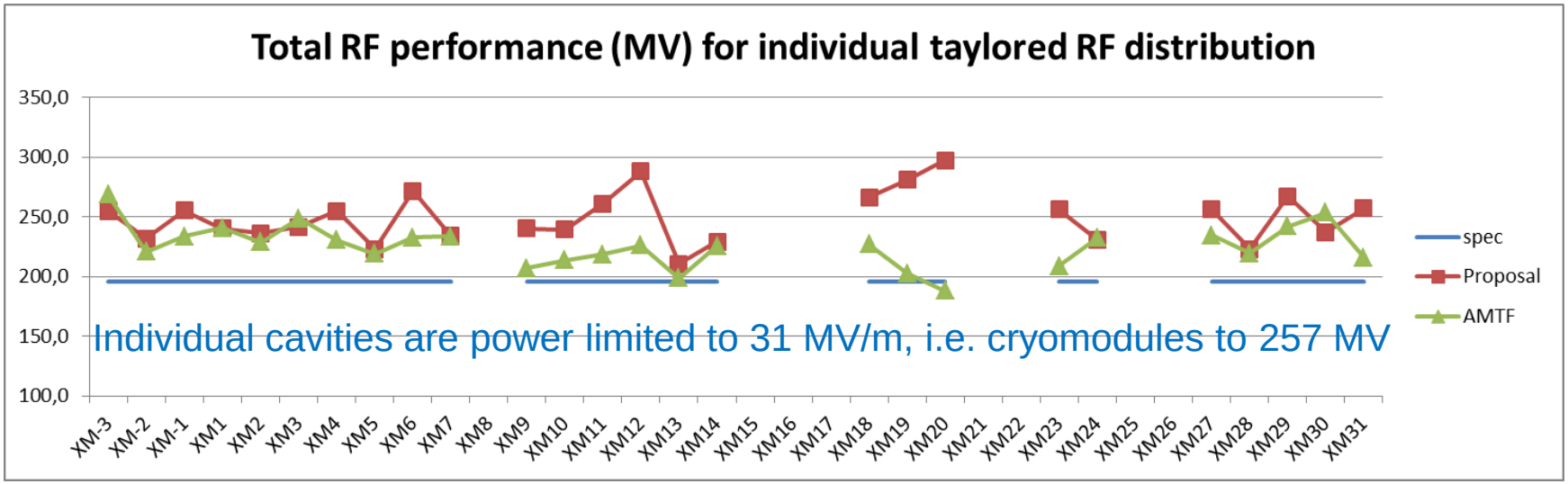
About Cavity Degradation

CEA and DESY are working on understanding the causes of cavity degradation after module assembly.

1st remark: one module is worth > 1 M€ and 200 MV. We lost about ¼ M€ on XM12 and ½ M€ on XM20. This cost is worth investing in in-situ (AMTF) diagnostic and in-situ repair (better conditioning).

2nd remark: about 80% of cavities are reproducing or improving their VT performances: module integration is based on a sound process. Causes ?

3rd remark: a smaller but significant number of cavities improve their gradient after module integration.



About Cavity Degradation

The gradient degradation is presumably du to contamination of the cavity RF surfaces. Contamination can occur by two processes:

1) External contamination of cavity volume
2) Internal contamination of cavity volume

1st process: **External contamination** may have 3 causes:

a) **Clean room air**: idle ISO5-ISO4 clean rooms are worth 'ISO0': permanent counting at nights monitors cleanliness

b) **Operator behavior** : hands-on cavity connections and bad preparation work is a highly probable cause of contamination. DESY and CEA performed two audits of clean room assembly. No major faults were detected but some procedures needed a reminder. Also, the connection of the gate valve to cavity is difficult, particularly on the CC workstation.

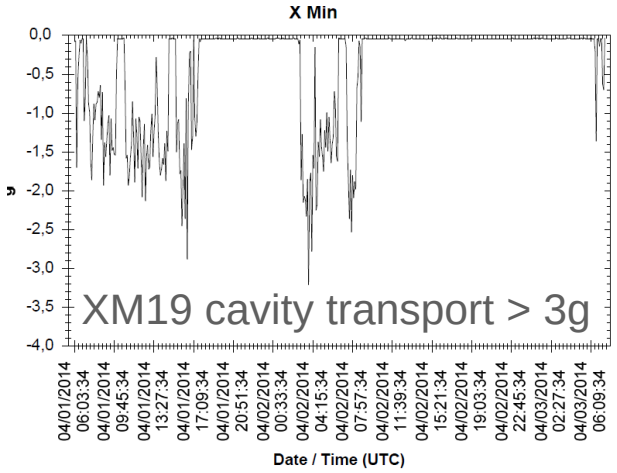
c) N2 Flushing (10 l/mn) and **N2 venting** (3 l/mn): venting systems release 10k particulates / mn in open air, but in-cavity tests measured less than 10 particulates / mn on realistic conditions of cavity venting. Systematics ??

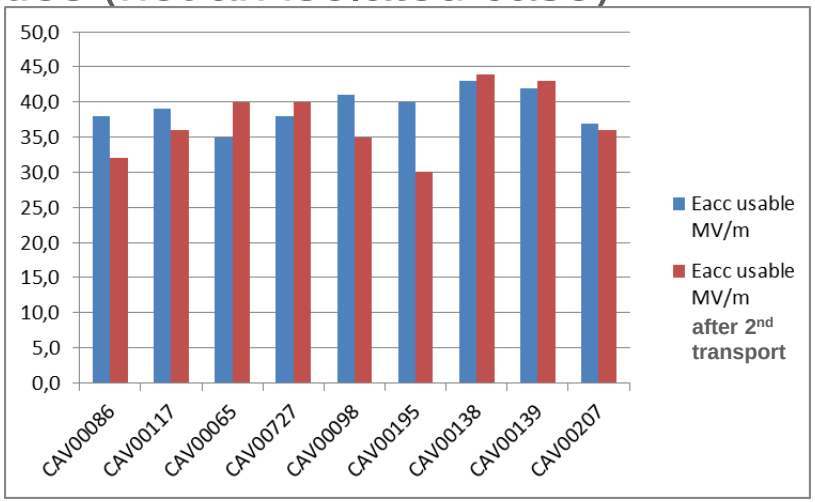
About Cavity Degradation

2nd process: **Internal contamination** may have 3 causes:

a) **Particulates migration**: metallic particulates are inevitably present or produced in the RF-free volumes around flanges. The 'art' is not to move them using controled slow venting and slow pumping, and avoiding vibration. Flushing with clean N2 is questionable from this point of view.

b) **Vibrations**: 'Sticking' theory predicts that particulates stick to the surface when cavity is under vacuum ⇒ cavity and cryomodule transports are done under vacuum. Vibrations are recorded: the case of XM19 and XM26 cavities (not an isolated case)





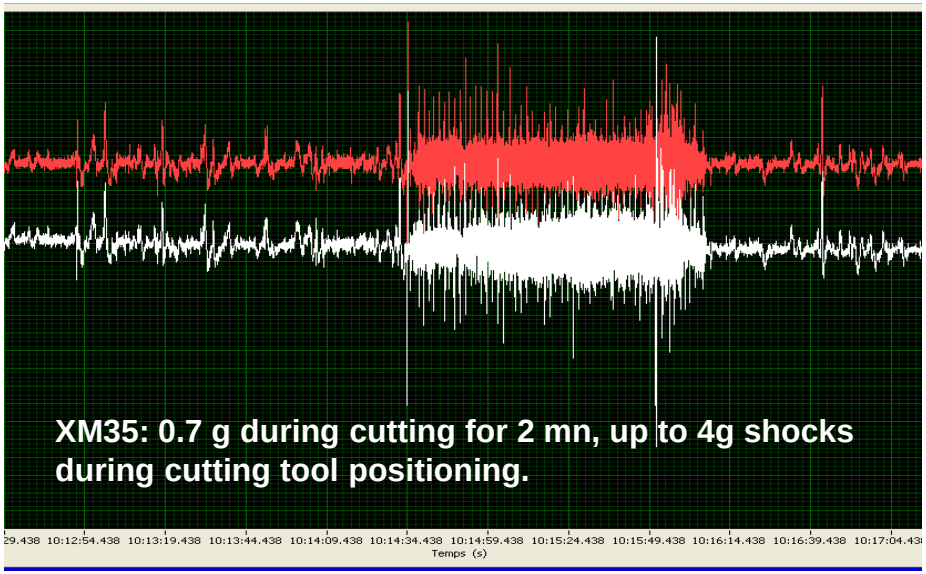
XM26 cavities have been shipped back to DESY and tested a second time in VTC

About Cavity Degradation

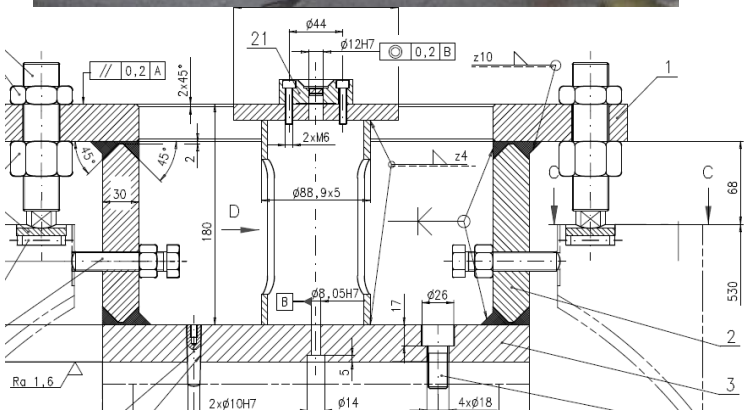
2nd process: **Internal contamination** may have 3 causes:

b) Vibrations: vibrations occurs also during the '5 assembly weeks' outside of the clean room when the string is vented.

e.g vibrations during cut-out of Ti tubes of the 2K 2-phase line along cavities



e.g hammering of 6 dowel pins on the cold mass

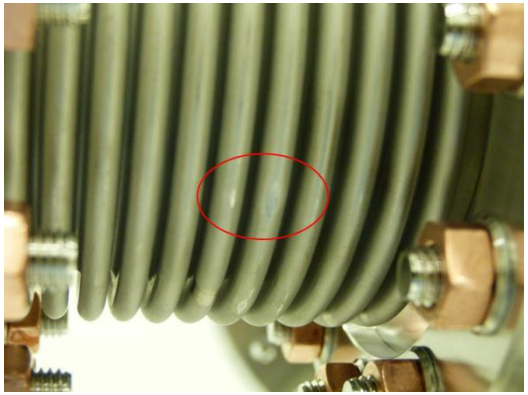


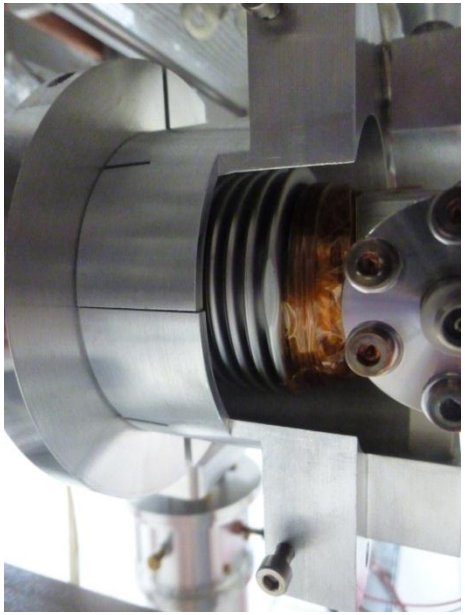
The maximum acceptable acceleration levels remains unknown to us.

About Cavity Degradation

2nd process: Internal contamination may have 2 causes:

b) Particulates creation and migration: copper coating flakes on intercavity bellows and coupler Cold External Conductor are particularly suspected.





Conclusions:

1) several suspects were interrogated but the culprit is still loose ☺ ☹
2) ILC could help in conducting some assembly and RF tests.

Conclusions

1. Cryomodule Assembly is almost inevitably on the critical path of the acceleration contruction project, once the component production reaches steady state.
2. The difficulties of coupler production and assembly have been underestimated
    1. Unlike cavities, coupler production was discontinued (in Europe) and vendors lost their know-how
    2. Coupler assembly is the most complex operation: about 8 couplers (both cold part and warm part) have been destroyed du to bad manipulation and/or bad assembly
3. The XFEL village infrastructure and people will be used for ESS cryomodules, and are adapted for mass production of a substantial fraction of the ILC cryomodules (~2000).