Australian National University

14 UD Tank Opening Report

#127

1st February – 23rd February 2017

Team leader	P. Linardakis
Report compiled by	P. Linardakis, N. Lobanov
Tank crew	S. Battison, B. Graham, J. Heighway, P. Linardakis, N. Lobanov, B. Tranter, D. Tsifakis, T. Tunningley.
Gas handling	J. Bockwinkel, J. Heighway, L. Lariosa, B. Graham, B. Tranter
Electronics Unit	N/A

Department of Nuclear Physics
57 Garran Road
Research School of Physics and Engineering
The Australian National University
Acton ACT 2601

Contents

1 Reason for tank opening

This tank opening was scheduled maintenance operation, although the machine was exhibiting issues with terminal voltage.

After completing conditioning on the low- and high-energy ends in June 2016, a conditioned voltage of 1.095 MV/unit was achieved (14.97MV equivalent for entire machine).

By early August, the 14UD was conditioned up to 15.1 MV. During LINAC operation, the 14UD operated at 14.3-14.5 MV in October-November 2016. On 14th November, the scheduled last day of the LINAC run, a big tank spark occurred. It caused continuous X-rays at about 13.5 MV and many hours were required to re-condition the machine to 14 MV.

AMS attempted to condition the 14UD and managed 14.3 MV on 6th Dec 2017. The machine did not behave very well, exhibiting voltage dips and big sparks. AMS continued using the machine, however the operation voltage slowly degraded to 13.5 MV with sparks happening at less than 13 MV.

NRD group attempted to use machine in early January at about 13MV with S and Ca beams. The group gave up measurements on 7th Jan as machine did not provide required voltage.

AMS continued at operation at about 13 MV till 27 January 2017. The group reported unstable voltage and experienced frequent sparks. On 27th January, a big spark made the 14UD very unstable. The machine displayed high loading at low input current and sparks happening at very low voltages of 11 MV. AMS had cancelled their run under those conditions.

The 14UD diagnostic test before this tank opening revealed the following:

- With all units live, the CPO signal became unstable at above 8.5 MV.
- With 9 units shorted at the HE end of the machine, the CPO instability occurred at 2.8 MV.

These preliminary results indicated that the possible fault was developed in the high-energy sections adjacent to the terminal and that it could be an open circuit in the resistive chain which was bridged via unstable corona with applied voltage.

Furthermore, a pre-tank opening series of RGA scans showed small traces of SF_6 in the acceleration tube vacuum space. A representative scan result is shown in Figure 1.

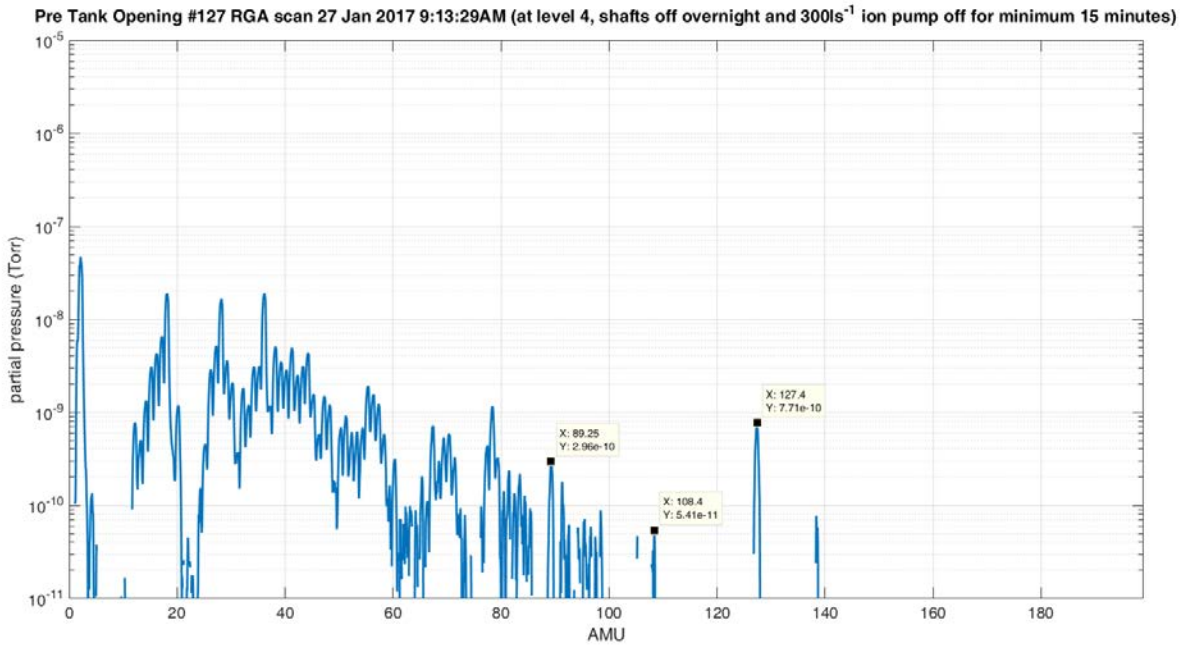

Figure 1 Pre tank opening RGA scan on 27th January. Results were similar on a repeat scan on the morning of 30th January.

2 Summary of work

2.1 1/2/17 Wednesday

- The SF_6 was pumped from the 14UD into the storage vessel.
- The porthole doors were opened, and the fresh air ventilation system was run overnight.

2.2 2/2/17 Thursday

- Gas tests showed the atmosphere within the 14UD was OK and compliant with the Confined Space regulations and was safe to enter.
- Platform was deployed and tool and lighting setup loaded on.
- Performed initial 30kV HV entry test. Here is the list of problems:
  - Unit 3 tube 1: 7.6µA current (higher than expected 7.2µA)
  - Unit 4 tube 3: 7.2µA current but unstable. There is also some “slag” on the bottom casting near the post resistors.
  - Unit 5 tube 4: blown resistor lead
  - Unit 10 tube 1: 7.4µA current (slightly high)
  - Unit 12 tube 3: 7.4µA current (slightly high)
  - Unit 13 tube 4: 11µA current (slightly high for an 8-gap tube)
  - Unit 14 tube 2: 7.6µA current
  - Unit 15 tube 1: 4.7µA current (low)
  - Unit 15 tube 2: 3.6µA current (low)

  - Unit 15 tube 3: 5.4µA current and sparking. Blown resistor lead on tube gap 1
  - Unit 20 tube 2: single spark on post B every time you probe.
- Wiped down column using 20ml of RBS into 10l of water. As per recent tank openings, the distribution of breakdown products seems to be toward the low-energy end. We speculate if the mechanical movement in the high-energy end due to the chains and shafts acts to distribute the breakdown products further away from the column. Interestingly, the pH of the wash water after wiping down the column was somewhere between 5 and 6.5 (measured with a 0-14pH test strip)

2.3 3/2/17 Friday

- Ran chains and shafts. Chain 3 is noisier than the other two, but we seem to remember that from last time as well. Other than that, it all sounds OK.
- Track marks were observed on the shafts in unit 15 and unit 17.
- Infinitron measurements began and finished in about four hours. Results were:
  - Posts
    - Unit 3-4 8 gap: uneven
    - Unit 10: below 9/10 8 gap: uneven (first tube in unit 10)
    - Unit 14: posts corresponding to bottom two tubes: uneven
    - Unit 15: 2nd from bottom: uneven
  - TUBES
    - Unit 5-6: 8 gap: open circuit
    - Unit 6: tube 1: very uneven
    - Unit 12: tube 1: uneven
    - Unit 15: the whole unit (all four tubes): 4 is open circuit, others uneven
    - Unit 22: tube 3: minor imbalance (maybe leakage in ceramic)
    - Unit 26: tube 1 and tube 2: possible microbreak

2.4 6/2/17 Monday

- Installed new corona needles
- Inspected unit 15 and found aside from broken resistor lead on tube 3, gap 1, there are charred resistor assemblies all over the post. Also, most of the stringer mounting screws are loose and in fact stringer two is completely missing, broken at both ends. The broken stringer was eventually found, intact, at the bottom of the tank.
- Problem with unit 4 post gap 3 top resistor. The spark gap was touching the shield electrode and is likely the source of the pool of slag mentioned earlier.
- Unit 3, tube 1 gap 1 top spark gap electrode collapsed onto the lower electrode. Showed leakage across gap of 7µA@5kV. The electrode could be screwed back tight and retesting showed all is now good.
- Unit 5 tube 4 (8-gap) gap 5 top resistor ball ended resistor lead failed at ball. Banana plug was fused into resistor nut preventing disassembly, so new resistor assembly was installed. Gap 1 resistor nut and lead was a bit dirty but basic cleaning was all that was required.
- Unit 10 was retested (HV and LV tests) and was found to be fine.
- Unit 14 tube 2 takes a while to settle on HV test and get sparking from in the terminal or below. May be masked by all the open resistor circuits in unit 15 at the moment. Need to retest.

2.5 7/2/17 Tuesday

- Repeated 30kV HV tests on unit 14 tubes 2 and 3 with HV applied to non-terminal end this time. They seem to be fine. Had a problem with the LV tests and did not repeat.
- Opened the terminal.
- Prepared to remove terminal foils but were hampered by a saturated vacsorb pump

2.6 8/2/17 Wednesday

- Removed terminal foil stripper for repopulation
- Entered the bottom of the tank and cleaned up the oil
    - Noticed some flakes of ceramic near post B side. Inspected post Bs all the way up the machine except for those covered by the terminal spinnings, but did not find a source. There may be a crack on unit 24 post B gap 17.
    - Measured leg clearances
        - Chain 1: 70 mm
        - Chain 2: 77 mm
        - Chain 3: 70 mm
- Started trying to track fault with terminal cup (would not read negative currents)
- Removed motor coupling for high-energy shaft

2.7 9/2/17 Thursday

- Tracked problem with the terminal cup not reading negative currents to the AQV253H PhotoMOS relay (see tank opening report #118). Positive currents were OK, since this is the “relay off” default behaviour. Due to some surprising foresight, there was a spare AQV253H PhotoMOS in the cupboard. This popped straight into the IC socket and all works again.
- Checked the brush contacts on the terminal pulley wheels.
- Inspected the high-energy shaft motor and found that it has a 0.85mm axial misalignment.
    - Since the bolt clearance holes are tight, a neck/waist was cut into the bolts to allow for some lateral movement and hence alignment
    - There doesn’t seem to be any scope for movement since the stand offs are hard up against a lip edge on the motor.

2.8 10/2/17 Friday

- Inspected the high-energy shaft motor and how to best modify the mounting so that there can be some adjustment.
- Started to clean and inspect units 1 to 3. Need to check some resistor lead in unit 1 when we have the tools on board. Found some small shards of something metallic in the unit 1 top casting.
- Reinstalled stripper foil assembly in the terminal. Attempted to pump out stripper space but were hampered by the vacsorb pump…again.

2.9 13/2/17 Monday

- Unit 1 tube 1 gap 3 resistor replaced to fix broken banana plug end

- Unit 3 tube 4 gap 7 to resistor lead replaced
- There are some strange marks on the unit 7 shaft (which are not track marks)
- Prepared Hi-Cube pumping system to pump down the terminal foil stripper. Having some issues as in standard form, you cannot pump with only the diaphragm pump (to rough) and the turbo pump gets too much load.
- Reinstalled foil stripper motor
- Checked N_2 stripper gas pressure and it's 0.24barg (c.f. 0.25 barg at installation during tank opening 125)

2.10 14/2/17 Tuesday

- Pumped out terminal foil stripper vacuum space with Hi-Cube system. Works well when you start the diaphragm pump separately. Achieved a pressure of about 2 Torr before starting turbo pump. Turbo had no problems starting up and we were quickly down to <10mTorr after opening the large main valve (after pumping for a bit through the needle valve). Left system to pump for a few hours. Base pressure according to the gauge reached 4mTorr. Weisser valve was then opened with minimal disturbance to tube vacuum pressures. After Hi-Cube system turbo slowed to a stop, it was removed and the cap over the Weisser valve mechanism replaced.
- Installed spacers in the high-energy shaft motor mounts in preparation for alignment. Clocked motor to less than 0.1 mm axial alignment and less than 0.2 mm perpendicular to axis.

2.11 15/2/17 Wednesday

- Reinstalled high energy shaft coupling
- Reinstalled and clocked shaft into unit 28
- Refilled chain oiler reservoirs
- Helium leak tested all flanges in the terminal and acceleration tube flanges in unit 19 and unit 20 (those where the tubes were replaced in tank opening 126)
    - No leaks were detected from a base leak rate of 6.9×10^{-9} mbar·l/s
    - The base leak rate was left to improve and after about 100 minutes, the base leak rate was 2.6×10^{-9} mbar·l/s. The tests were repeated and no leaks were found.
- Tested all terminal function while powering terminal from mains and 110V transformer. All functions were good so, the shielded boxes were shut in preparation for closing the terminal.
- Cleaned pellets on all three chains with acetone (avoiding the nylon links).

2.12 16/2/17 Thursday

- Closed the terminal
- Continued with clean and close from unit 11 to unit 15
    - Unit 13 had multiple issues including
        - Several burnt resistor leads
        - Loose stringer 3 at tube end
        - At least 3 burnt banana plugs
    - Unit 15 had many parts requiring rebuild
        - Stinger 1 was loose at post end, replaced with resistor type mount

        - New stringer 2 installed with resistor type mount at post end
        - Stringer 3 was loose at post end, but retightening was enough
        - All internal facing post resistors replaced with new tested assemblies
        - Three tangent facing post resistors replaced because of dirty spark gaps

2.13 17/2/17 Friday

- Reinstalled and clocked shaft into unit 15
- Continued with clean and close from unit 16 to unit 22
    - Unit 16 stringer 3 was loose at the post end but tightened OK without modification
    - Unit 17 post gaps 4, 6, 10 and 12 all had blackened banana plugs and sockets. Replaced leads and resistor assemblies.
    - Unit 18 post gap 6 bottom resistor was replaced.
    - Unit 18 tube 3 bottom gap had bad resistor nuts
    - Unit 19 tube 2 gap 1 top resistor had a loose mounting tag
    - Unit 19 tube 2 gap 11 bottom resistor had a loose mounting tag

2.14 20/2/17 Monday

- Clean and close form unit 23 to unit 28
    - Unit 27 post end of stringer 1 was loose.
- Helium leak test in all units from 1 to 28 and in the bottom of the tank. No leak found from a base leak rate of $1.4\text{-}2.0\times10^{-9}$ mbar·l/s.
- Re-rung up to unit 22. Occasional issue with ring screws found. They were replaced.

2.15 21/2/17 Tuesday

- Re-rung remaining units
- Blew down column and reinstalled casting covers
    - There was some metallic debris found in the unit 11 bottom casting in the section with the shaft bearing.
- Performed 30kV HV test. Found:
    - Missing resistors in unit 15! Oops.
    - Unit 8 tube 3 7.6-8.0µA@30kV. Checked all resistors and gaps but there is nothing obvious. There are some marks on the ceramic of post D gap 4, but even after cleaning, there was no difference in current. Reversing polarity of the applied HV so that the 30kV is applied to the grounded end of the column results in a current of 7.2µA.
    - Unit 5 tube 8.0µA@30kV but which resolved itself after we pulled everything apart to check resistors and ceramic insulation gaps.

2.16 22/2/17 Wednesday

- Could not trace issue with unit 8 and will need to live with it.
- Wipe down of column with clean water.
- Unloaded majority of tools on platform at level 2
- Vacuumed platform and bottom of tank

- Performed tank close checks
  - Had an issue with the static breakdown voltage test.
    - We had breakdown at 6kV, which is too low.
    - Two issues were identified which were the spacing of the suppressor side inductor on chain 2 and some sparking on one of the suppressor voltage stand-offs.
    - Corrected chain 2 suppressor side inductor spacing

2.17 23/2/17 Thursday

- Removed affected suppressor voltage stand-off and polished the aluminium metallic parts (there were signs of breakdown).
- Repeated static breakdown voltage tests and now reached 7kV, which will do.
- Proceeded with remainder of tank closing tests, all OK.
- Chain oiler tests (10 second operation)
  - Chain 1 4 second delay and 17 drops
  - Chain 2 3 second delay and 13 drops
  - Chain 3 4.5 second delay and 12 drops
- Closed porthole doors

3 Resistor issues

The main issue observed in this tank opening was multiple damaged resistors up and down the machine. Unit 15 was the worst affected with scorched leads, broken leads and broken stringers and mounts. It is not possible to determine what failed first, but it is certain that operating the machine under sub-optimal conditions lead to damage elsewhere.

Figure 2 through to Figure 4 show some examples of resistor failures found during this tank opening.

Figure 4 shows the aftereffects of a resistor in unit 4 that broke and allowed the spark gap to touch the outer shield. The titanium spark gap appears to have sputtered away, leaving a pool of “slag” on the casting. This was one reason we were reluctant to install solid leads in more units, since it may be that the additional spring the in the solid leads somehow leads to increased stresses on the resistor during dynamic movement.

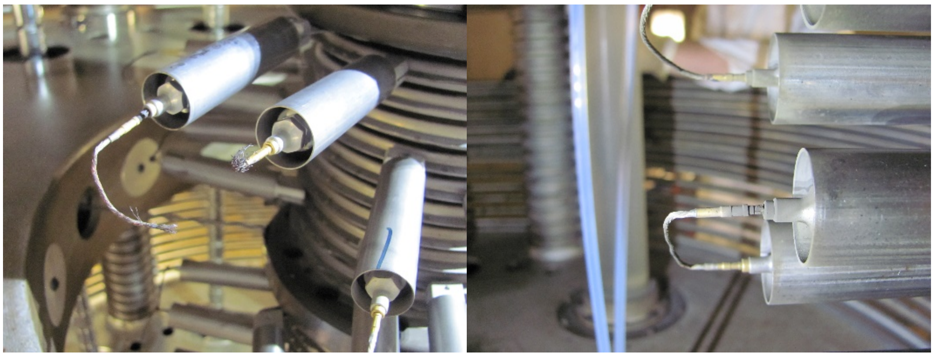

Figure 2 Multiple resistor issues in unit 15

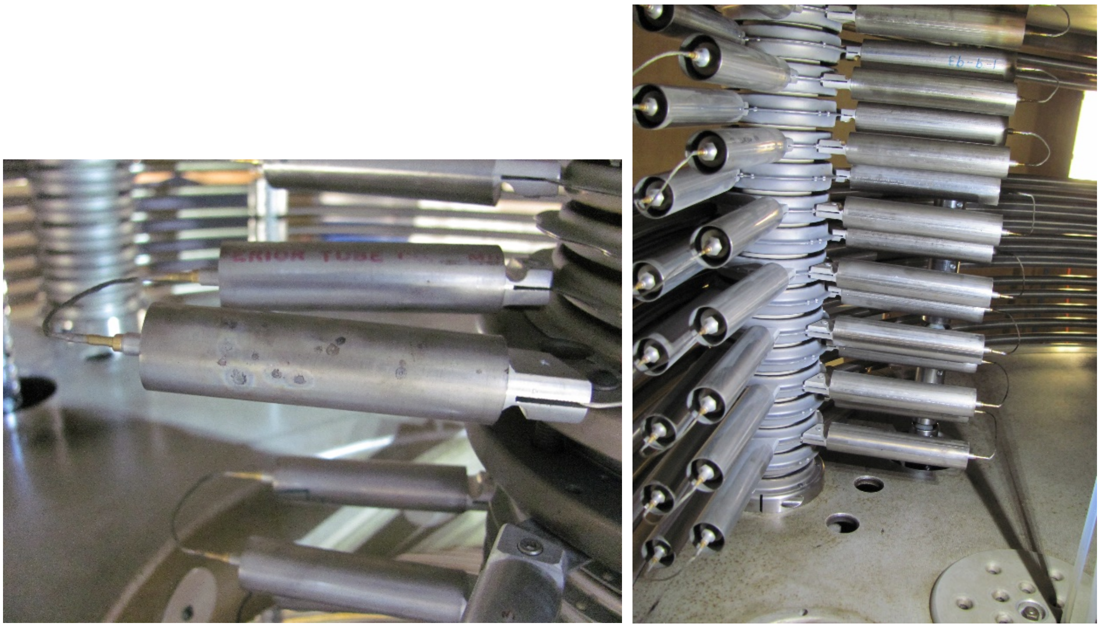

Figure 3 More multiple resistor issues in unit 15

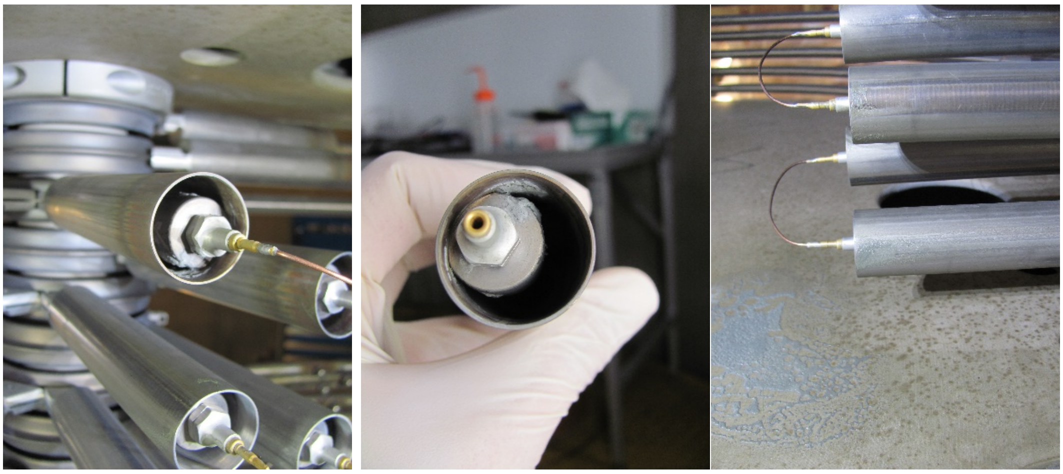

Figure 4 Broken resistor in unit 4 causing arcing between speak gap and shield (left and middle) with the resulting “slag” shown on the casting below (right)

4 SF_6 measurements

Various RGA measurements throughout the tank opening indicated that there was a low level of SF_6 present even at the end of the tank opening. This led us to consider that perhaps the source of low-level SF_6 is not the acceleration tubes, but the ion pumps. These ion pumps are switched off during RGA measurements and may release some previous pumped SF_6. The 300l/s ion pump at the top of the accelerator (inside the tank) was baked and RGA measurements following this did show a reduction in the amount of SF_6. Nevertheless, we need further investigation so that we better understand what we are measuring and which SF_6 levels we can ignore, if any.

Figure 5 shows the measured SF_6 levels in the acceleration tube vacuum space during pump out of the 14UD pressure vessel.

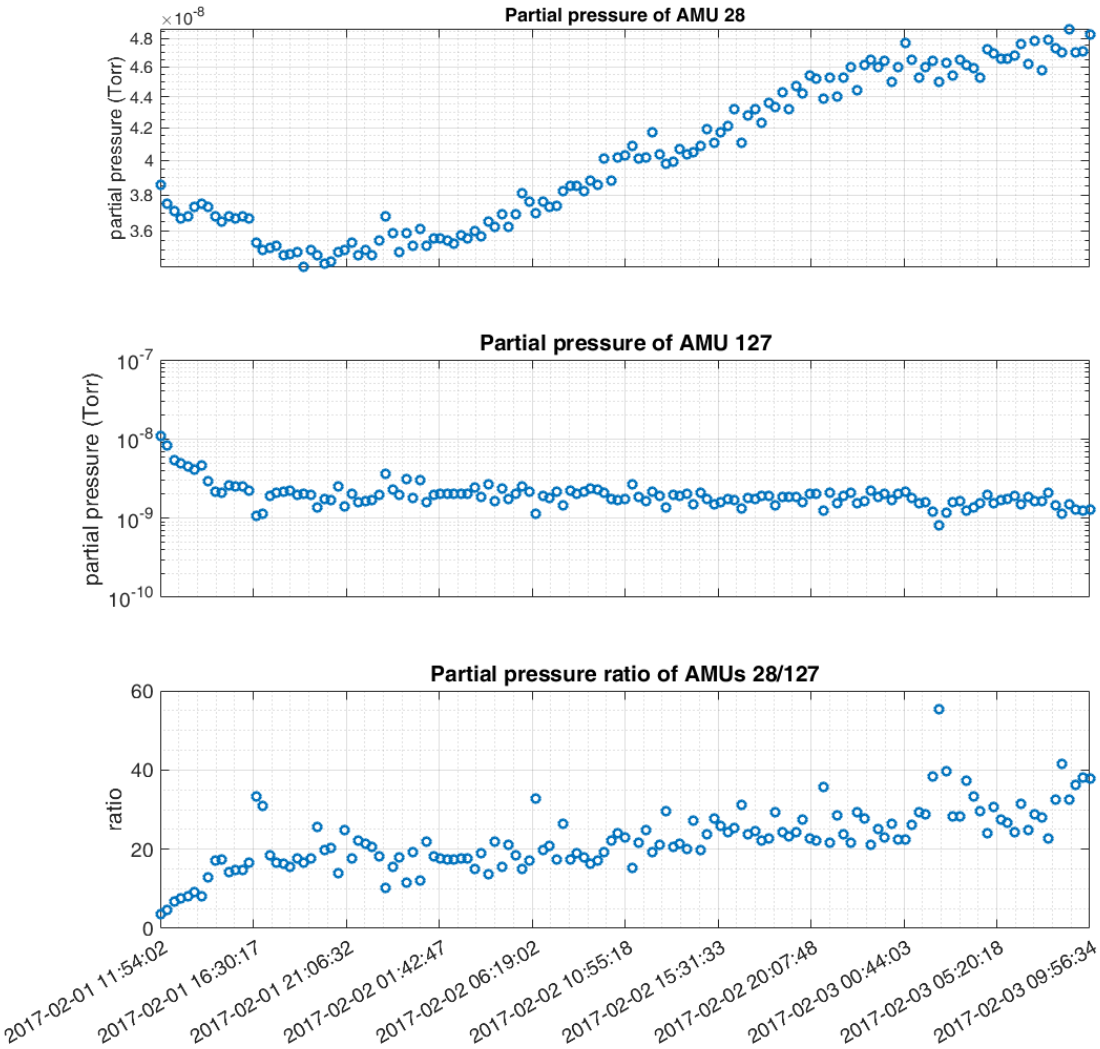

Figure 5 Partial pressures of N2 (AMU=28) and SF5 (AMU=127) starting from gas out of the 14UD.

5 Watch list

Table 1 Watch list of suspect items for review next tank opening

Unit	Component	Description	Condition/ Resolution	Retain watch
6	Post C, gap 10	May have small subtle cracks in ceramic	Increased discoloration, no current leak at 6 kV	Yes
22	Post C, gaps 7 and 10	May be a small subtle crack, but also what may be two, small, surface divots at a “nine o’clock” position	No deterioration	Yes
28	Post B, gap 12	Marks including metallic deposits	No deterioration	Yes
6	Post gap 9	New unused resistors installed on both top and bottom, showing 18µA @ 20kV (lower than 19µA nominal).	Keep track of current as resistors age	Yes

6 Tube ceramic insulator current leakage

The current state of shorted tube ceramic gaps is shown in Table 2

Table 2 Summary of tube ceramic current leakage in the 14UD

Unit	Tube	Gap	Leakage though insulator @5kV (TO #123)	Discovery	Comment	Repair
3	2	2	8 µA	TO #121		Dummy resistors top and bottom, dummy on post gap ????
6	1	2	1.1 µA	TO #123		Dummy resistors top and bottom, dummy on post gap 5, top
7	3	10	12 µA	TO #120		Dummy resistors top and bottom, dummy on post gap 10, top
12	1	2	0.25 µA	TO #123		Dummy resistors top and bottom, dummy on post gap 5, top
13	1	10	0 µA	TO #120	Suspicious arc mark across gap	Dummy resistors top and bottom, dummy on post gap 3, top
13	2	1	0.05 µA	TO #120		Dummy resistors top and bottom, dummy on post gap 8, top
25	3	10	7 µA	TO #120		Dummy resistors top and bottom, dummy on post gap 16, top
26	3	5	0.15 µA	TO # 123		Dummy resistors top and bottom, dummy on post gap 12, bottom
26	3	10	0.01 µA	TO # 123		None, deemed too small. Monitor.
26	3	11	2.5 µA	TO # 123		Dummy resistors top and bottom, dummy on post gap 14, bottom
28	3	1	0.01 µA	TO # 123		None, deemed too small. Monitor
28	3	5	0.47 µA	TO # 123		Dummy resistors top and bottom, dummy on post gap 12, top
28	3	7	0.1 µA	TO # 123		Dummy resistors top and bottom, dummy on post gap 13, top
28	3	9	0.02 µA	TO # 123		None, deemed too small. Monitor
28	3	10	0.05 µA	TO # 123		None, deemed too small. Monitor
28	3	11	0.28 µA	TO # 123		Dummy resistors top and bottom, dummy on post gap 14, top

7 Machine hour meter readings

Table 3 Machine hour meter readings

Date compiled	1/2/2017					
Team member(s)	PL					
Reading	Chain #1 (1O)	Chain #2 (2N)	Chain #3 (3P)	LE shaft	HE shaft	Ch. volts
Notes	New @TO121	New @TO121	New @TO118			
Current reading	34984	34923	35071	55340	55331	34343
Previous reading (TO #126)	30986	30925	31073	50689	50682	30975
Change in hours	3998	3998	3998	4651	4649	3368
Previous total hours	9454	9393	13883			
Current total hours	13452	13391	17881			

Clearly, the problem charging volts meter has partially resolved itself.

8 Terminal voltage distribution for period of service

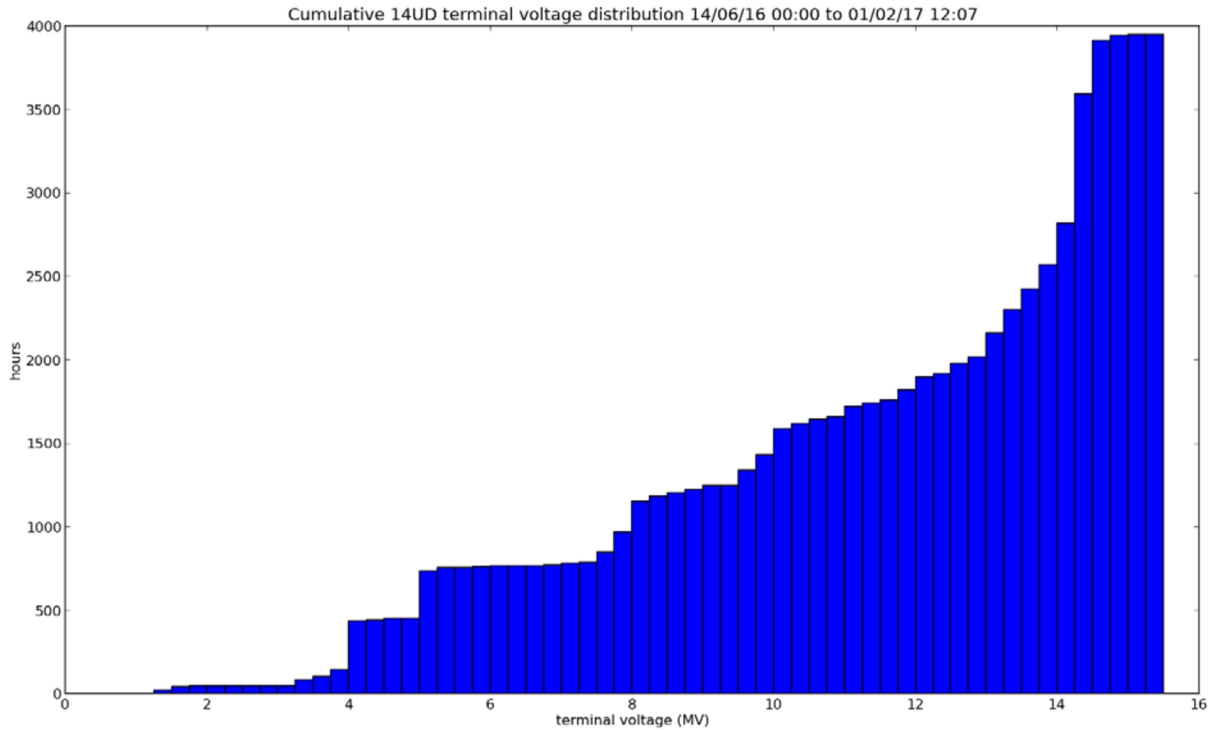

Figure 6 Cumulative terminal voltage distribution for period of operation from the end of tank opening 126 to the start of tank opening 127 (not including the week spent conditioning the machine immediately after tank opening 126)

The total hours with voltage on the terminal was 3948 hrs, which gives a utilization of 71% assuming a twenty-four hour, seven-day maximum. If the Christmas shutdown period is removed from the total available hours, then the utilization is 74%.

9 Initial performance

By 14th March, the 14UD was slowly conditioned with al units live up to 14.2 MV. By slowly means we allow maximum one spark (or less) per hour of conditioning. Since tank closing in the end of February the 14UD reliably operated up to 13.5 MV in February-March 2017. Right now it is still early stage of conditioning. The goal is to condition on a run up to 15 MV to allow reliable operation up to14.7 MV.