RF System Performance

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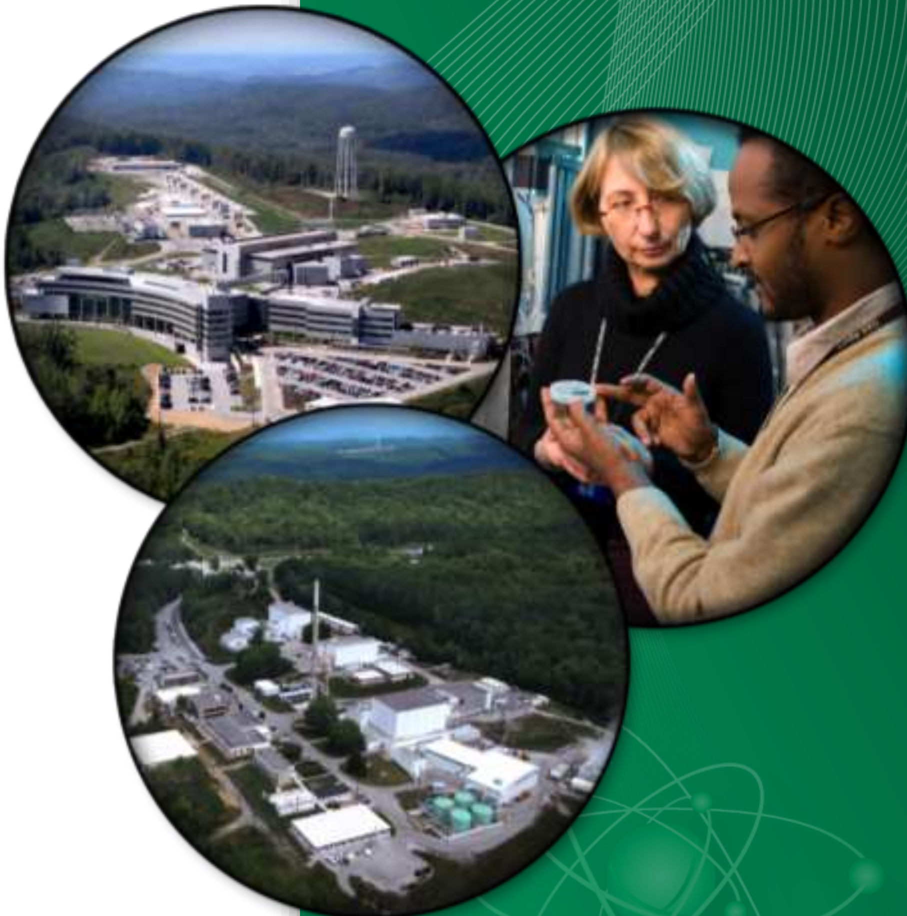
AAC Meeting, 7-9 May, 2013



High Level View: Most of the original equipment is still in use after 7 years of operation

Increased Solid-State Amplifier Utilization

MEBT Rebuncher RF System was upgraded in September 2010 and has performed flawlessly

- 4+1 systems, 25 kW each, 402.5 MHz

Also replaced tube-based drive amplifiers in Ring RF system with solid-state amplifiers (not pictured here, but same vendor)

2 MHz, 120 kW amplifier is presently being tested on the ion source test stand

- Ability to survive ion source sparking has been demonstrated
- Presently working to improve load mismatch capability

High Power Amplifier Inventory

Type	Application	Frequency	Peak Power	Vendor	Installed	Spare
Solid-State	MEBT Rebunchers	402.5 MHz	25 kW	Tomco	4+1*	a few modules
Klystron	RFQ, DTL	402.5 MHz	2.5 MW	E2V & Thales	7+2**	5
Klystron	CCL	805 MHz	5 MW	Thales	4+1**	6
Klystron	SCL	805 MHz	550-700 kW	CPI & Thales	81	51
Tetrode	Accumulator Ring	1 & 2 MHz	500 kW	Thales & CPI	4	4

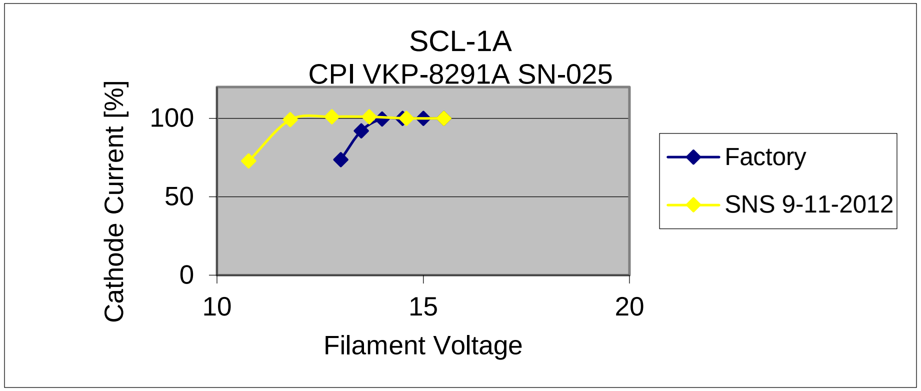
Notes:
- E2V discontinued their production and support of the 2.5 MW klystrons; Thales developed a plug-compatible replacement (3 delivered).
- Thales is presently finishing up production of two 5 MW klystrons.
- CPI has not constructed any SCL klystrons since ~2008.

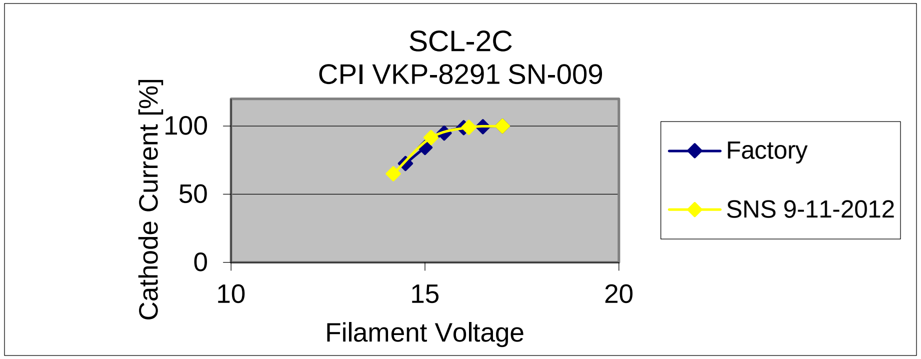
Key:
* hot spare
** test stand

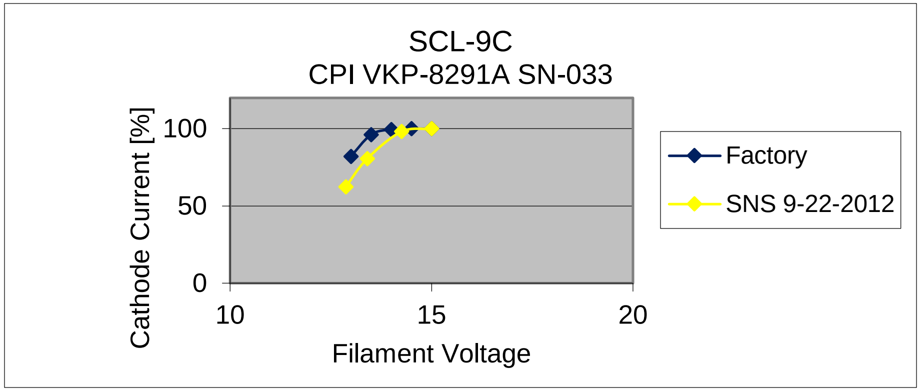
Klystron Lifetime and Vendor Engagement

- The majority of the klystrons presently used in the Linac have about 50,000 hours of run time.
- Cathode loading is relatively low and ranges from 0.5 to 1.25 A / cm^2.
  - lifetimes approaching 100,000 hours are likely, but uncertain
  - zero cathode-based failures to date
- Cathode emission data being collected to assist in monitoring and predicting lifetimes.
- E2V provided original 402.5 MHz klystrons; Thales has produced plug-compatible replacements.
  - Thales has produced every flavor of klystron or tube presently utilized at SNS.
- CPI produced the vast majority of the SC Linac klystrons but has not built any klystrons for us since 2008
  - We would like to procure additional SC Linac spare klystrons to increase spares quantity and maintain vendor engagement, but budgets have been inadequate.

Klystron Lifetime - Emission Data







- Emission data offers a sensitive way to determine condition of klystrons
- Have taken emission data on half of the installed klystrons
- A few klystrons are operating too far into the current limited emission region – Similar to SCL-1A
  - Lowering the filament voltage on these klystrons will increase their lifetime
- Most klystrons show good agreement with factory data – Similar to SCL-2C
  - No sign of degraded performance
- A few klystrons show some cathode degradation – SCL-9C

New Problem: Failure of DTL klystron de-Q-ing load caused output instability

Drift Space

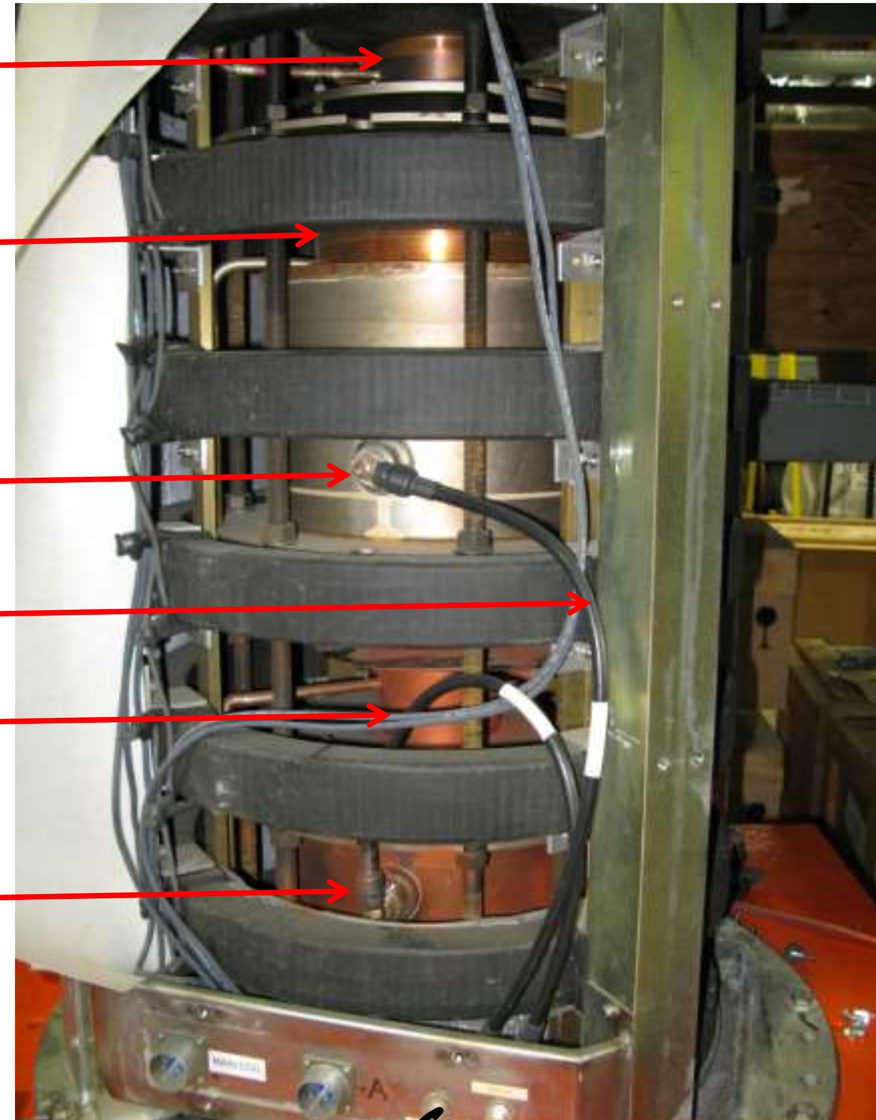
2^{nd} Harmonic Cavity

2^{nd} Cavity

Cable to External Load

Drift Space

Input Cavity



Introduction to Discussion on Normal Conducting Linac

- RF systems reliability is sufficient to achieve neutron production availability >90%.
- Recovery from RF faults in the NC Linac is significantly longer than in the SC Linac due to the long thermal time constants of the copper structures and cooling systems
  - 20-30 minutes compared to a few minutes
- RF faults in the NC Linac are correlated with (or caused by):
  - voltage breakdown (arcing) at RF windows and/or within the cavity
  - vacuum degradation (bursts of outgassing)
  - beam loss and, perhaps, field emission and/or multipacting
  - glitches in water flow and vacuum interlocks
  - inadequate vacuum pumping capacity
  - excessive resonance error

Fault/Risk Mitigation in the NC Linac

- Spare RFQ is under production.
- Water flow sensors are being upgraded for increased reliability.
- Vacuum system is being upgraded for increased pumping capacity and improved serviceability/redundancy of vacuum gauges.
- Infrared window temperature interlock is being developed.
- Additional spare RF windows are under production.
- A new window design is under development at alternate vendor.
- Transmitter temperature monitoring is being implemented.
  - Addresses failures that may be induced by hot spots in the klystron gallery

Three DTL RF Vacuum Windows Replaced to Date

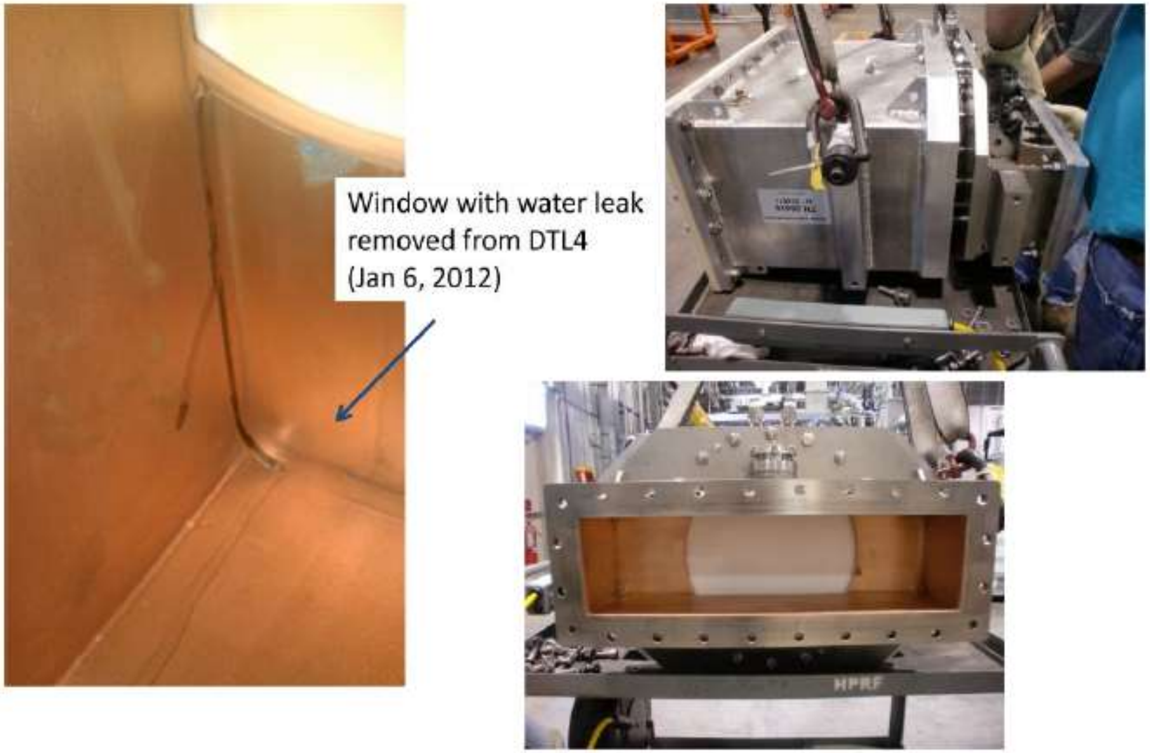


Figure 1 - DTL Window with water leak into vacuum

- **DTL6 window replaced 1/21/10 because of suspected flange or o-ring vacuum leak**
- **DTL4 window replaced 4/26/11 because of arcing**
- **DTL4 window replaced 12/26/11 because of water leak to vacuum**

Five CCL RF Vacuum Windows Replaced to Date

Figure 3 - CCL Window with fracture of ceramic window.

- **CCL2b window broken 11/2/07**
- **CCL3b window broken 2/3/11**
- **CCL4b window broken 1/28/12**
- **CCL1b & CCL4b windows replaced due to excessive arcing and vacuum activity July 2012**

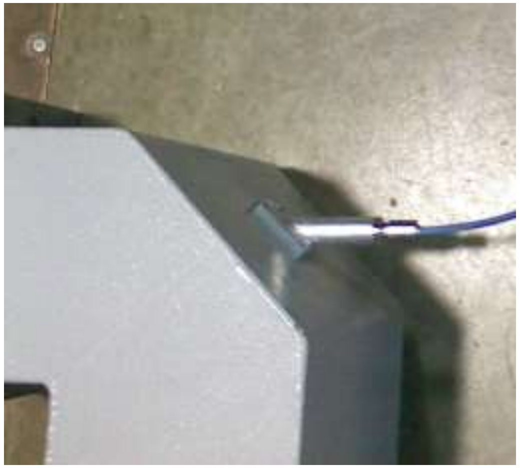
Actions Taken to Prevent Further RF Window Failures

- RF Structures team commissioned to investigate problems and create a Risk Mitigation Plan → Completed June 2012
- Key elements:
  - Order additional spares from Thales (3 each for DTL and CCL)
  - Develop alternative window designs with experienced RF vendor
  - Implemented more conservative procedure for *in situ* RF conditioning
  - Develop interlock based on infrared measurement of window temperature
- Significantly, nearly all of the CCL ion pumps were replaced during the summer 2012 shutdown due to poor performance
- Numerous vacuum system improvements are planned for the DTL

IR Window Temperature Measurement

- Utilizes commercially available system
- Indirect measurement of surface window temperature
  - allows for tracking temperature changes in window
  - plan to implement interlock
- Integrated into EPICS via transmitter PLC
- Prototype system – installed on CCL3 & 4

Raytek Controller
(in transmitter rack)



Sensor in waveguide
(in Linac tunnel)

Transmitter Temperature Measurement

- Temperature measurement of the transmitter racks and individual chassis is currently not available
  - Add 4 temperature sensors to the warm linac transmitters
  - Add 6 temperature sensors to the cold linac transmitters
- Allows tracking of temperatures on key subsystems and overall rack temperatures
  - Solid state amplifier
  - Filament supply
  - Magnet supply
- Use of available PLC inputs to interface with EPICS
- Implementation scheduled for completion August 2013

RF Structures Issues and Concerns

- Spare RFQ nearing completion
- DTL & CCL: no spare structures, but an assortment of spare parts
- Input Couplers:
  - 1 each on DTL tanks
  - 2 each on CCL structures
  - Couplers are removable and therefore replaceable.
  - There is no clear evidence to date indicating upgraded couplers are needed to achieve 1.4 MW beam operation.
- RF windows have been somewhat problematic, but generally perform well if adequately protected via interlocks and procedures
- Water leaks are a concern, especially in the DTL, where the drift tubes are water cooled. Need to monitor and control water chemistry throughout the facility.

RF Structures

- The DTL utilizes many o-rings in its vacuum envelope
  - The DTL tanks exhibit a significant vacuum degradation upon turning off the RF for maintenance periods
  - The reason is uncertain, but seems to be related to RF heating of the tank
  - Is this a precursor of a failure that will require – at minimum – replacement of o-rings?

Technical Risks

- Failure to maintain adequate key spares; obsolescence
  - Obsolescence is specially concerning for Low-Level RF and Transmitter electronics.
- Physical Integrity of NC Linac structures (vacuum, water, RF windows)
- Variability of SC Linac klystron lifetime
  - what is an acceptable number of spares?
- Overall performance of the NC Linac
  - what limitations may arise as we increase beam power?

Summary

- RF systems reliability is sufficient to achieve neutron production availability >90%.
- Good supply of spare klystrons, but we would like to purchase additional units for the SC Linac.
- Solid-state upgrades have proven to be very reliable.
- Numerous risk mitigation activities are in progress.
- Looking forward to increasing the beam power and addressing any related performance limitations.