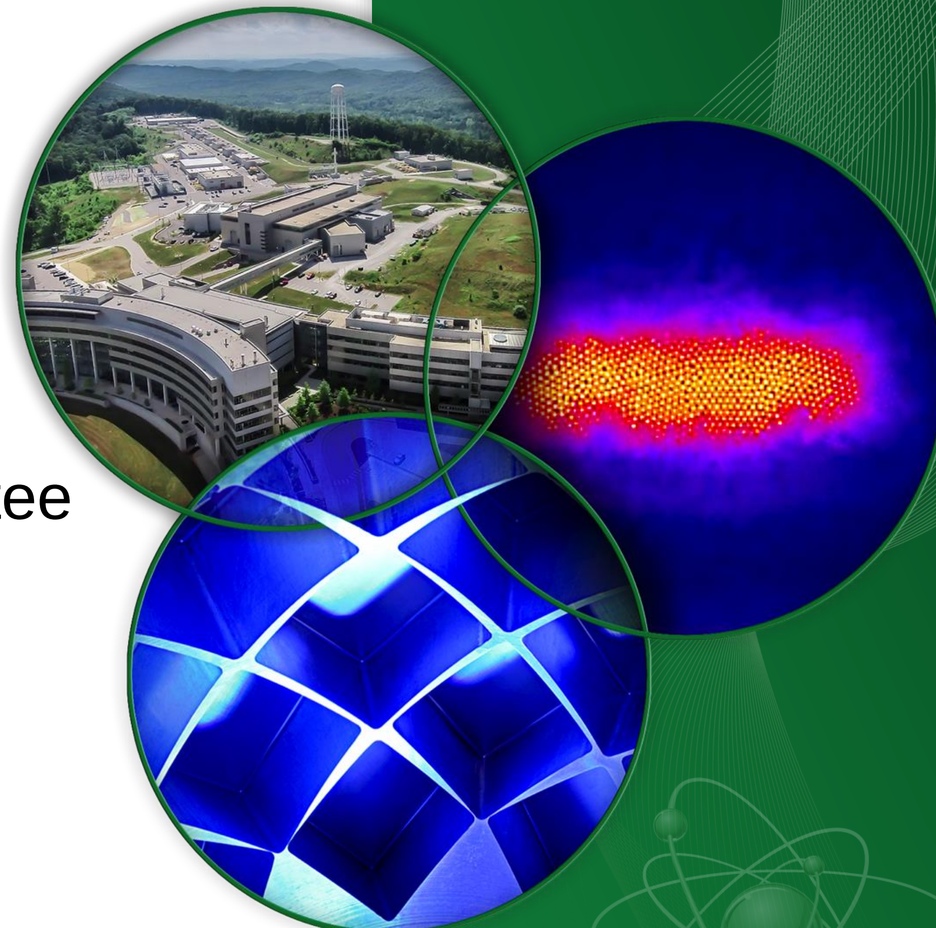
Normal Conducting Linac RF Performance & Challenges



Mark Crofford

Accelerator Advisory Committee

March 24-26, 2015

RF Systems – Outline

- Introduction to the discussion on the normal conducting Linac
- Ion Source RF
- MEBT Rebuncher System
- DTL Circulators
- CCL Klystrons
- Klystron Spares & Vendor Engagement
- Transmitter Issues and Improvements
- LLRF
- DTL & CCL RF Window Status
- Downtime Overview
- Summary

Introduction to the 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)
  - inadequate vacuum pumping capacity
  - beam loss and, perhaps, field emission and/or multipacting
  - glitches in water flow and vacuum interlocks
  - excessive resonance error

Ion Source RF

- The 2 MHz QEI amplifier continues to operate at ground potential outside of the 65 kV enclosure.
  - Only downtime was attributed to a failed connection on the output circuit
- The 2 MHz isolation transformer has required minimal maintenance since installation in July 2010
- The Tektronix generator/control system has been trouble-free
  - Implemented a frequency shift mode to better support plasma ignition
- Use of the Tomco 2 MHz, 120 kW solid-state amplifier has been successful on the test stand
  - The VSWR circuit was modified to improve reflected power operation
  - A second Tomco solid-state amplifier is installed on the ITSF
  - Desire to gain further experience before its use on the production ion source

MEBT Rebuncher System

- MEBT Rebuncher RF amplifiers were upgraded in September 2010 to solid-state devices
- The amplifiers have performed well and cause minimal downtime
  - We have recently experienced two 4.2 kW amplifier module failures
  - One power supply has failed
  - One intermittent cable connection

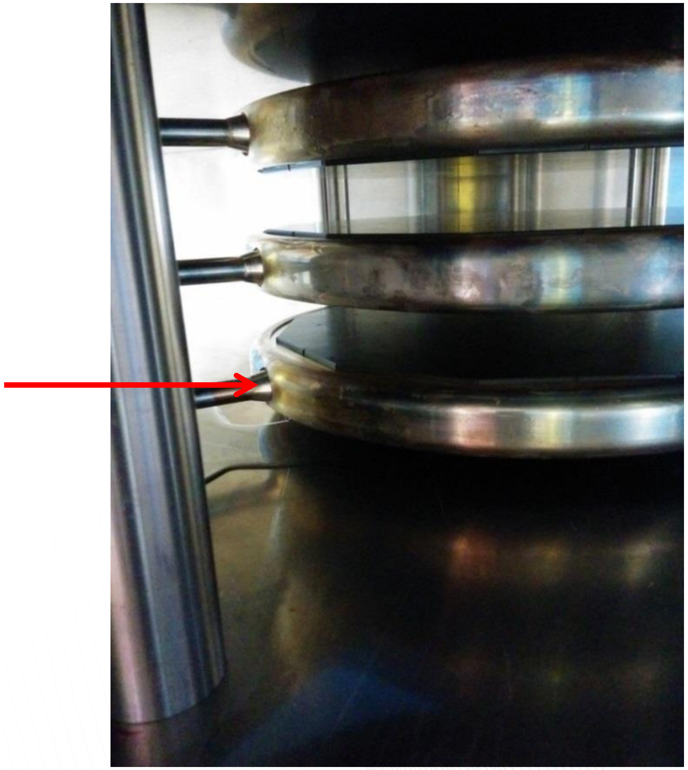
OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

MEBT Rebuncher Cavities

- MEBT chopper target failure resulted in water in the MEBT rebuncher cavities
  - All cavities required RF reconditioning
  - After reassembly the MEBT 3 tuner assembly developed a vacuum leak in the bellows
  - MEBT 1 field probe developed a vacuum leak
- Lack of cavity spare components was noted
  - Fabricated spare field probes
  - Cleaned and conditioned a spare fundamental power coupler
  - Procured C-seals for a cavity rebuild (if required)
  - Working to procure/repair a spare tuner assembly

DTL Circulator Issues

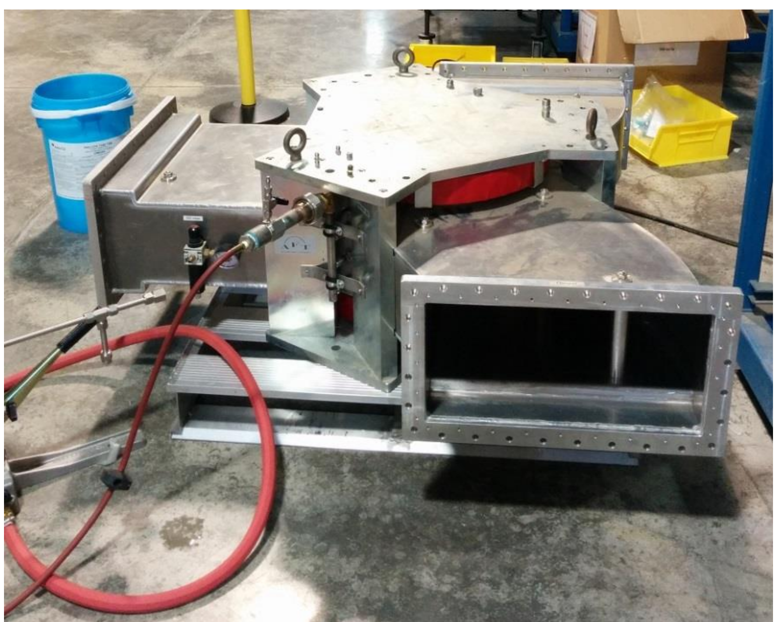
- Arcing was detected in the DTL-6 circulator on June 16th, 2014
- A leak was detected on the bottom pancake of the circulator assembly
- A spare circulator was removed from the RFTF test stand and installed to allow for continued operations
  - No unused spares were available
- Inspections of the remaining 6 circulators revealed similar issues with all installed devices
  - Some show significant corrosion



OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

DTL Circulator Issues (cont.)

- Issue was isolated to the O-ring seals between the water inlet & outlet connections on the pancakes
- AFT was consulted and performed an on-site repair of the failed circulator and provided training on the repair techniques
- Three spare 402.5 MHz circulators are on order



OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

CCL Klystron Failures

- Three of the four original Thales 5 MW klystrons have failed within 1 year
  - Two klystrons failed on filament open failures (CCL 2&3)
  - One klystron is unable to generate RF power above 3.5 MW (CCL4)
  - Operating hours for the failed klystrons range from 51000 – 57000 hours
  - The remaining original klystron is still in service and the emission curve has not shown degradation
  - The average time to replace a CCL klystron is 14 hours
  - A Thales 5 MW klystron is staged in the klystron gallery ready for installation

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~~ 4 (2***)
Klystron	CCL	805 MHz	5 MW	Thales	4+1**	~~6~~ 3 (2***)
Klystron	SCL	805 MHz	550-700 kW	CPI & Thales	81	~~51~~ 57
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 assisting with oscillation of one 5 MW klystron.
- Of the 57 spare 550-700 kW klystron, 12 are Thales

Key:
* hot spare
** test stand
*** ready

Klystron Lifetime and Vendor Engagement

- The majority of the klystrons presently used in the Linac have about 60,000 hours of run time.
  - lifetimes approaching 100,000 hours are likely, but uncertain
  - one cathode-based failure & 3 filament-based failures to date
  - More attention to cycling of the filaments to maximize lifetime
- Cathode emission data being collected to assist in monitoring and predicting lifetimes.
  - Data utilized to adjust filament settings to maximize cathode life
- 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.

Vendor Engagement (cont.)

- CPI produced the vast majority of the SC Linac klystrons
  - We have recently received 6 new 700 kW klystrons
  - Completed the 1st rebuild of a failed 550 kW, 805 MHz klystron
  - CPI has expressed interest in producing 5 MW 805 MHz & 2.5 MW 402.5 MHz klystrons
- Thales quality has been less than ideal
  - Final two 5 MW klystrons delivered have required vendor involvement
    - One klystron experienced oscillations above 3.8 MW
    - One klystron required extensive conditioning
  - Reluctant to support rebuild of failed klystrons. The quoted price to rebuild was 97% of the price of e new tube.
  - Vacuum issues experienced with the recently delivered spare production RF windows

Transmitter Issues & Improvements

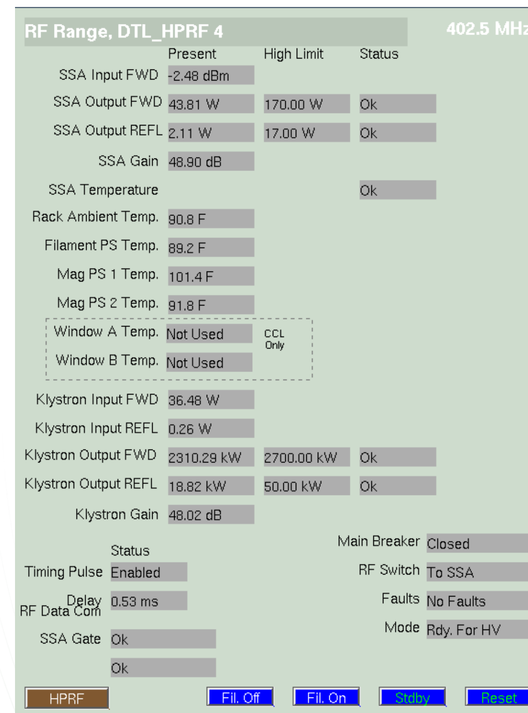
- The magnet power supplies in the warm linac transmitters have been updated
  - Use of COTS supplies – reduced costs
  - Lowered the temperature in the hottest rack by ~18º F
- Replaced low-flow flowmeters with ultrasonic meters
  - Minimize nuisance trips
- Significant increase of solid-state amplifier failures
  - Majority of the failures are traced to the power supply
  - Implemented on-site repair and testing program

Filament Power Supply Issues

- Fourteen filament power supplies have failed since last AAC review
  - 53 filament power supplies are installed
- Vendor involvement discovered a series of defective parts with the same date-code
  - Waiting for detailed failure analysis from vendor
  - Repaired and returned to the SNS
- Development of a stand-alone test stand is underway for improved bench testing
  - Allows for a realistic test without cycling of actual klystron filaments

Transmitter Temperature Measurement System

- Installed temperature measurement system to monitor critical chassis temperatures
- Currently installed in Warm Linac & four SCL racks
  - Rack temperatures were unavailable
  - Supports troubleshooting



OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

LLRF Performance & Issues

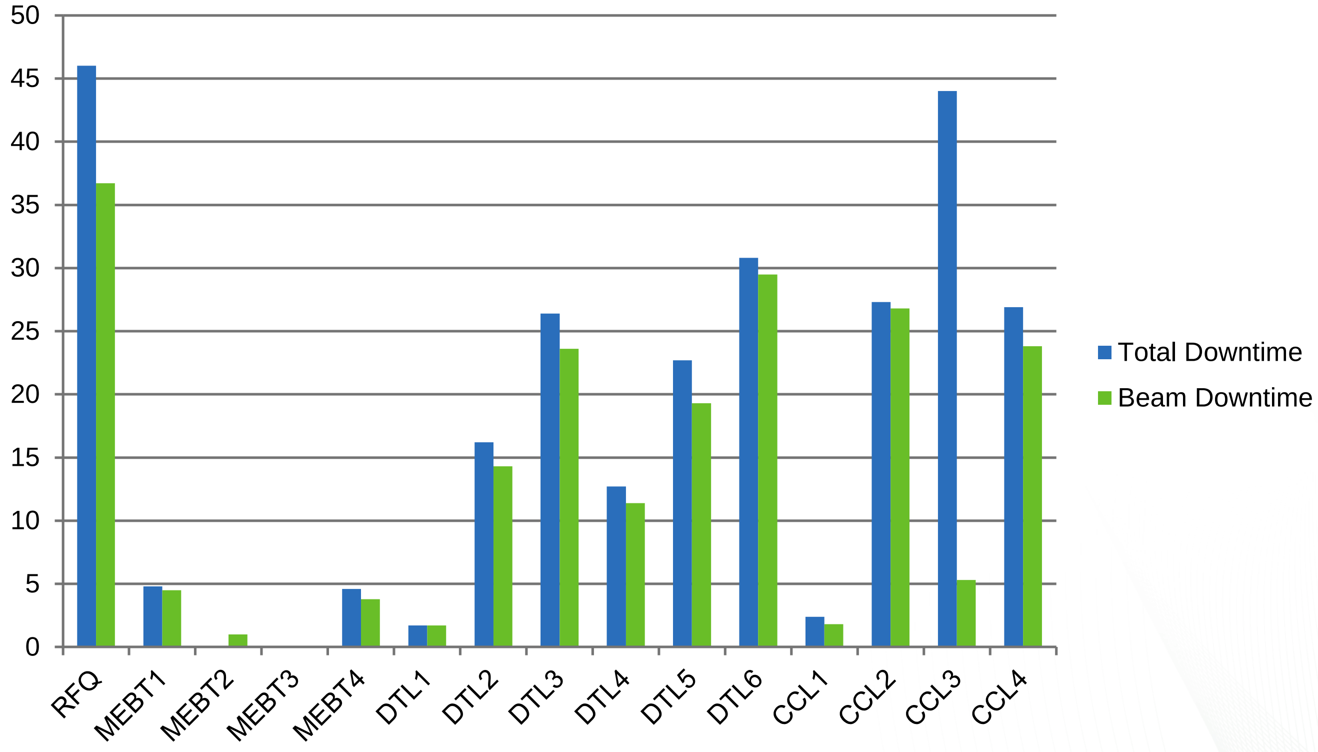
- The LLRF system continues to operate within specification
- The adaptive feed-forward is sufficient but the learning time of the algorithm could be improved
- The output amplifier IC for the RF output circuit has shown issues with the bond wires
  - multiple failures in the past year
  - All amplifier ICs are being replaced during the calibration cycle of the system
- System has several obsolete components to include the FPGAs
  - Adequate spares are available
  - Resources will be needed to redesign in the future

DTL & CCL RF Vacuum Windows

- No DTL or CCL window failures since July 2012
  - Improved RF conditioning techniques
  - Increased attention to detail
- – DTL Window Status
  - Six DTL windows are in use
  - Two windows are processed and stored under vacuum
  - Two new windows have been purchased (TH20616)
    - The windows arrived with vacuum issues and were returned for repair
  - One new prototype window has been tested and fully conditioned
- – CCL Window Status
  - Eight CCL windows are in use
  - Two windows are processed and stored under vacuum
  - Six new windows have been received and are scheduled for testing and RF processing
    - One window was returned to the manufacturer for repair
  - One new prototype window is currently under test

RF Downtime – May2013 to Present

- Total Downtime 265 hours out of 10303 scheduled Accelerator Physics/Neutron Production hours (2.57%)



RF Downtime (cont.)

- Occasional major event quickly adds to the system downtime but this is only ~20% of the total RF downtime
  - DTL 6 circulator failure – 17 hours (June 2014)
  - CCL2 klystron failure – 14 hours (May 2014)
  - CCL3 klystron failure – 16 hours (Oct 2014)
- Majority of trips are ~ 20 – 30 minutes in duration
  - Cavity and window arcing
  - Vacuum excursions/bursts
- Overall reliability of the RF systems is very good
  - Continue to seek ways to improve the systems

Summary

- RF systems reliability is sufficient to achieve neutron production availability >90%
- Starting to see an increase in system failures, we need to continue to seek alternative COTS solutions
- Reasonable supply of klystrons but we would like to engage with CPI for the high power klystrons
- Implementation of better RF conditioning practices have paid off with no new broken RF windows