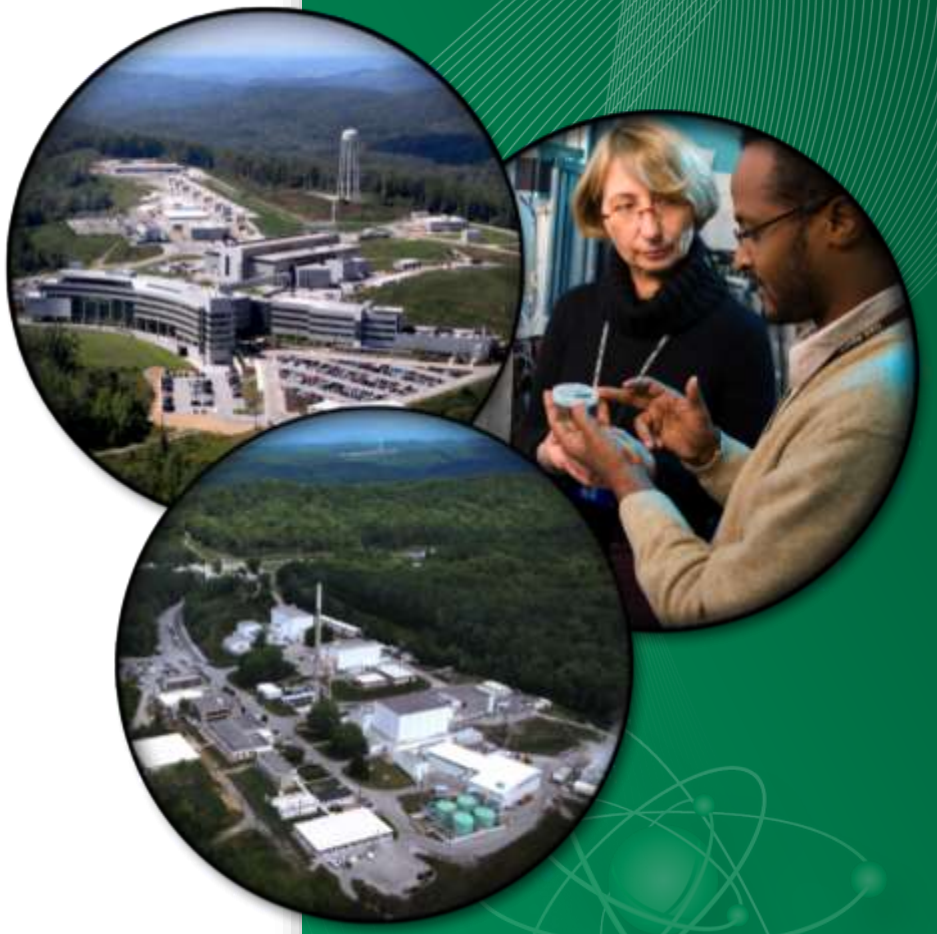
Superconducting RF Activities and Plans



Presented at the

Accelerator Advisory Committee Review

Matthew Howell
SCL Systems Lead Engineer
Research Accelerator Division

May 7-9, 2013

Outline

- **Strategy for stability, reliability, sustainability and achieving 1.4 MW**
  - **Take care in operation**
  - **Cryomodule rework**
  - **Cryomodule development**
  - **Enact an R&D program**
  - **Develop facilities and staff**

Implement strategy for stability, reliability, and sustainability with a cohesive, technically competent team

- Ensure stable and reliable operation:
  - 1) Be cautious with operation
    - Strict operating procedures and instructions followed
    - Subject matter expert is consulted when abnormal conditions arise
  - 2) Enable cryomodule rework capabilities
    - Proactive maintenance and required minor repairs
    - Maximize benefit of existing facilities and spare high beta cryomodule
- Attain long-term sustainability and 1 GeV beam energy for 1.4 MW beam on target
  - 3) Build spare medium beta cryomodule to allow flexibility in conducting repairs
  - 4) Enact a research and development program to address the problems that we will face in advancing the utilization of the SNS
  - 5) Develop facility and staff to perform all required activities: critical offline repair/reworks, cryomodule/cavity development, R&D, implement upgrade

SCL with all related support systems is currently operating with a high reliability of 98%

- **Matured operational experience of pulsed hadron SC Linac as a user facility**
- **Stable operation**
  - **Average trip (downtime): < 1 trip/day (<5 min./day)**
  - **Availability:**
    - Whole SCL system including RF, HVCM, Control, Vacuum, etc.: 98 %
    - SCL cavities/cryomodules/CHL: 99.5 %
- **High Availability**
  - **Understanding and machine setup for SCL systems as a whole**
  - **Proactive maintenance strategy:**
    - Fix annoyances/problems before they limit performance
    - Several cryomodules have been successfully repaired in-house
  - **Operational flexibility of individually powered SCL cavities:**
    - Energy reserve is essential: to circumvent problems that can't be addressed during operation or to minimize a down time
- **Still challenges stand ahead of us . . .**

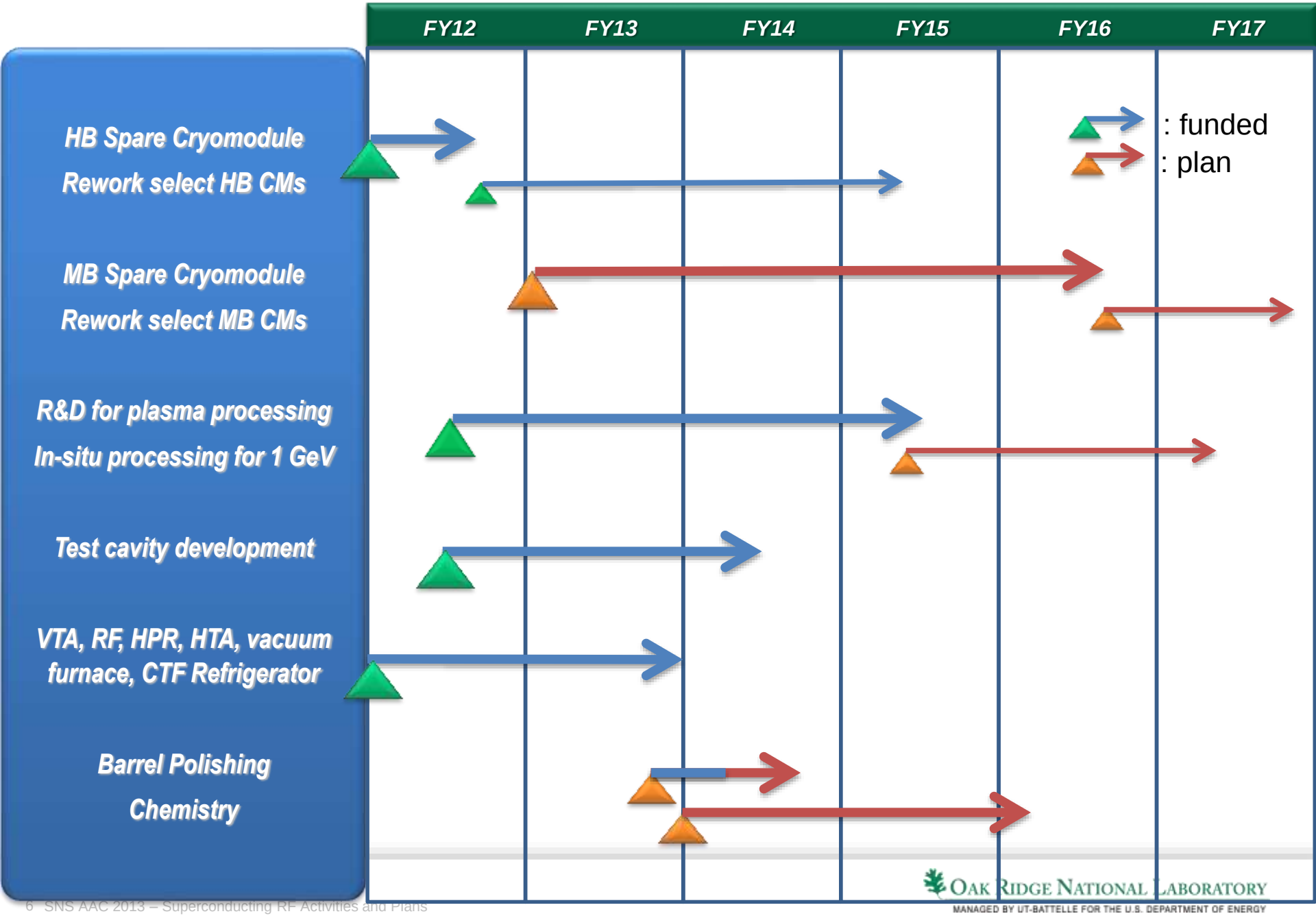
Key issues that require action include lower gradients in high beta cavities, cryomodules requiring repair, degradation of several cavities, and variability of gradients

- **Beam energy below the design value**
  - Operation at high duty factor results in lower achievable gradients mainly due to heating by electron activity
  - Cavity accelerating gradients have been set for the reliable/stable operation (linac output energy last 3 years: 895-938 MeV): present run at 938 MeV + 10 MeV energy reserve
  - Revisited 1 GeV operation at 10 Hz to support physics study (Dec, 2012): Achieved 1.07 GeV
- **Multiple cryom**
  - Coupler win
- **Cavity degrad**
  - Errant beam
    window leak
  - In the curren
  - Historically most degradation has been recovered by thermal cycling of cryomodules
  - One cavity (6c) has not recovered
- **Variability of cavity gradients is not conducive to present upgrade plan**

Fri Dec 21 13:24:42 EST 2012

BPM pair	E (MeV)	Mean (MeV)
SCL_Diag:BPM23, SCL_Diag:BPM24	1,071.002	1,070.972
SCL_Diag:BPM25, SCL_Diag:BPM26	1,064.168	1,064.653
SCL_Diag:BPM27, SCL_Diag:BPM28	0	0
SCL_Diag:BPM29, SCL_Diag:BPM30	1,069.861	1,069.238
SCL_Diag:BPM31, SCL_Diag:BPM32	1,071.897	1,071.163

Overall Plan



Existing facilities are already being utilized to support reliability and sustainability of the SNS

- Repairs have been possible utilizing existing facilities and infrastructure
  - High beta spare cryomodule
  - Assembly and repair tooling
  - Portable clean rooms, vacuum carts, leak detectors for in-situ repairs and cryomodule removal
  - Clean room operations for beam line repairs
  - RF test cave to qualify and RF process cryomodule cavities prior to re-installation into LINAC tunnel
    - Ability to test all cryomodule cavities simultaneously provided by four-way wave guide system developed at SNS

Enabling staff to complete cryomodule rework is essential to the reliability and sustainability of the SNS

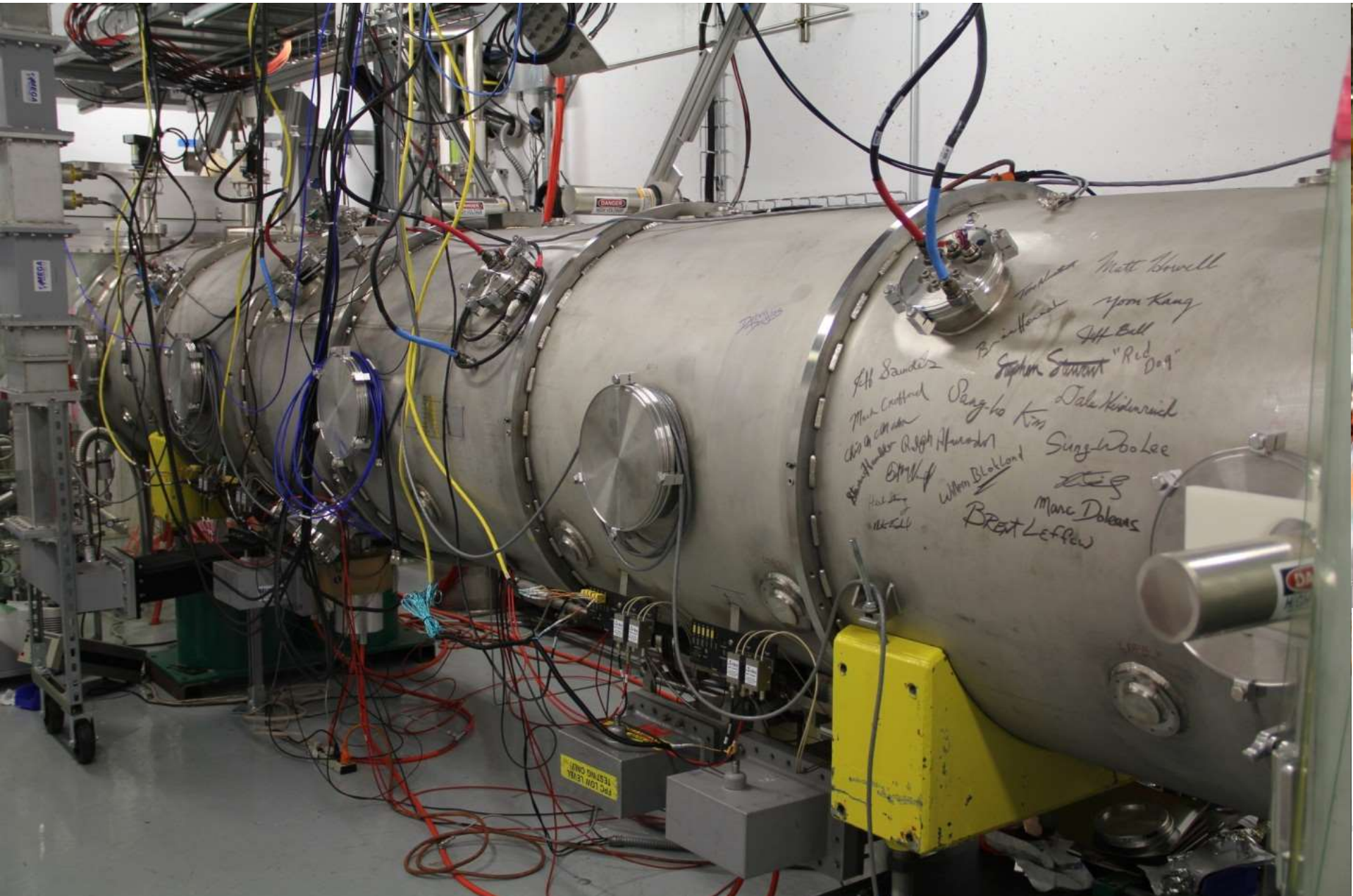
- Multiple cryomodules have been successfully repaired in-situ and offline
  - Two couplers replaced due to window leaks
    - Both repairs were made since the last review
  - Multiple in-process diode feedthroughs removed and surface mount diodes installed
  - Multiple HOM filters detuned and feedthroughs removed
  - Multiple tuner repairs have been completed
  - Repairs have been successfully completed without causing cavity performance degradation

High beta spare cryomodule was developed by in-house SNS resources and is the first to be ASME pressure-vessel code compliant in the world

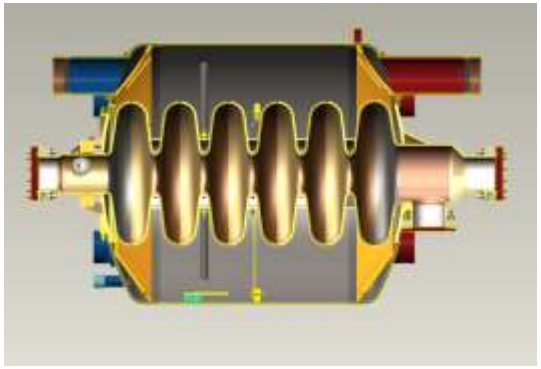
- **Allows removal of operating high beta cryomodule for repair**
  - Rework is the only option for the unrecoverable damages of cavity surface/parts
  - Maintain same beam energy while conducting complex repairs
- **High beta spare cryomodule serves as prototype for upgrades**
  - Fabrication techniques were developed (the first ASME Boiler and Pressure Vessel code stamped cryomodule addressing10CFR851 requirement)
  - Commissioning was successfully performed at the SNS test facility
- **Set the baseline design for a medium beta spare cryomodule**

High beta spare has been in service since the summer of 2012 and all four cavities are operating at 16 MV/m (HB spec – 15.8 MV/m)

The spare is the first high beta cryomodule that meets design gradient specification



A medium beta spare cryomodule is critical to the reliability, sustainability and upgrades of the machine

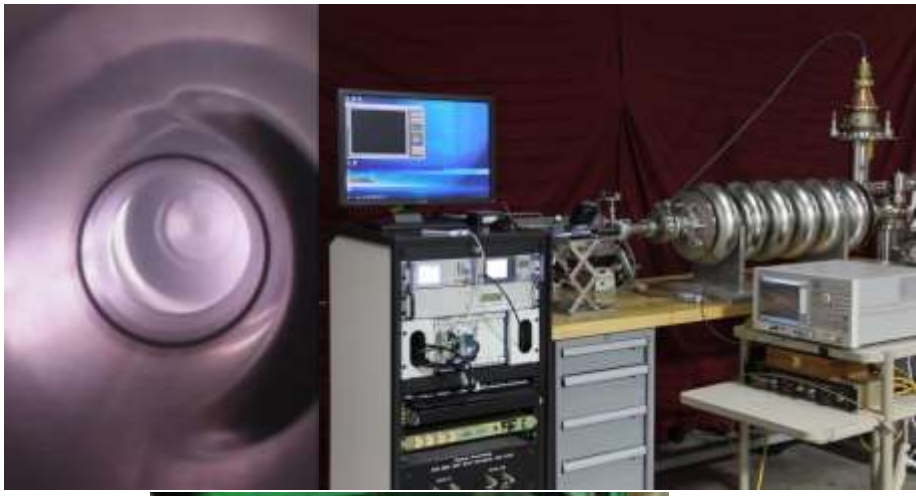


- **Multiple medium beta cryomodules need repair**
  - Cryomodule 9 has a large air to insulating vacuum leak
  - Cryomodule 11 (11b) has a cavity that has never been operated
  - Cryomodule 5 has a coupler issue
  - Recently replaced a coupler on Cryomodule 6
  - Degradation of cavity performance (permanent in only one cavity)
  - More will arise

- **Status of code compliant medium beta spare cryomodule**
  - There are no usable spare medium beta cavities
  - Cavity design is complete (no HOM coupler, new end group design)
  - Cold mass design has started and is ongoing
  - Long term procurements can start in FY 2013 provided funds are available
  - Completed cryomodule is approximately three years away after starting long-term procurements

An R&D program was enacted for 1 GeV beam operation and Second Target Station

- **Plasma Processing**
  - Preliminary testing looks promising
  - R&D underway to identify a method to recover and improve cavity performance
- **Cavity Development**
  - Improve thermal properties of end groups
  - Mechanical design changes to improve surface condition of end groups
  - Test cavities are in fabrication at RI
  - Internal studies using medium beta dies
- **Fundamental Power Coupler**
  - No RF design changes
  - Improve thermal property for higher power (ex. 70kW average for upgrade project)
  - Developed two prototypes that will be tested



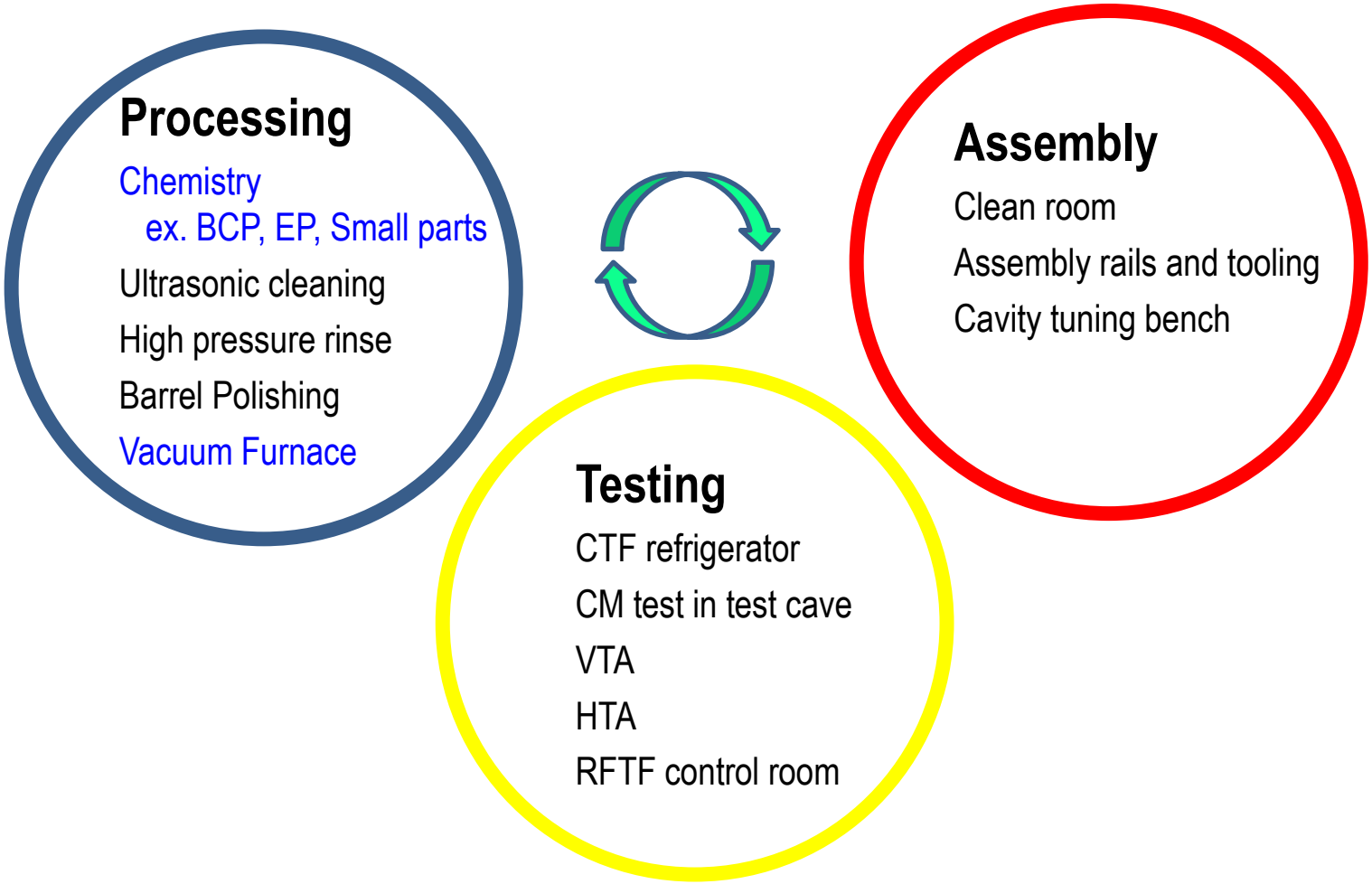
SRF facilities are being developed to meet the immediate reliability goals and to provide for the long term stewardship of the accelerator

- **Mission Statement**

  The SCL Systems Facility will enable laboratory staff to develop and test improvement plans for the SNS SCL, advance material science for SRF, cultivate collaborations with other laboratories, and contribute to future machines and projects.

- **With this facility in place, SNS can be responsive to customer needs!**
  - Conduct our own repairs
  - R&D focused on improving our application
  - Support Second Target Station (STS) with increased capability
- **System is not intended to be production scale**
  - Reduces capital investment
  - Ensures priorities of facility are in line with SNS objectives

An effective SRF facility requires a balance among all three functions of processing, assembly, and testing



Processing Facilities

- **Chemistry (plan)**
  - Small parts
  - Bulk chemistry conducted at the cavity vendor
- **Vacuum furnace**
  - R&D furnace procured
  - Full size furnace (future)
- **Barrel Polishing**
  - System under procurement from MFI
- **High Pressure Rinse (HPR)**
  - System operational since Early 2013
- **Ultrasonic Cleaning**
  - System in operation since 2008

Testing – Cryogenic Test Facility (CTF) Refrigeration System

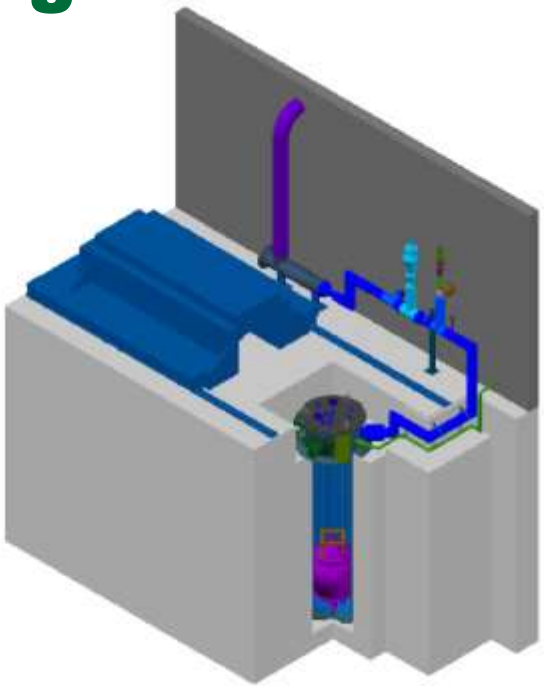
- **CTF Description**
  - Independent 4K cryogenic plant to support SRF activities
    - Refrigeration capacity – 640 W @ 4.5K
    - Liquefaction capacity – 225 liter/hour
  - Scope addition to allow for portable Dewar fill station to support sample environment and science needs
  - System is expandable to allow for 2K operation
    - Kinney pump is being refurbished by Fermi Laboratory
    - Additional utility work is needed to complete this upgrade
- **CTF Status**
  - Compressor, gas management, and oil removal system installed and commissioned
  - Cold box and helium dewar are installed and ready for commissioning (July 2013)
  - Controls effort is ongoing
    - Testing with vendor at end of May
  - PDR of liquid fill station is complete
    - Vendor will deliver early in FY2014
  - Kinney pump refurbishment is ongoing at Fermi Lab – delivery by July 2013

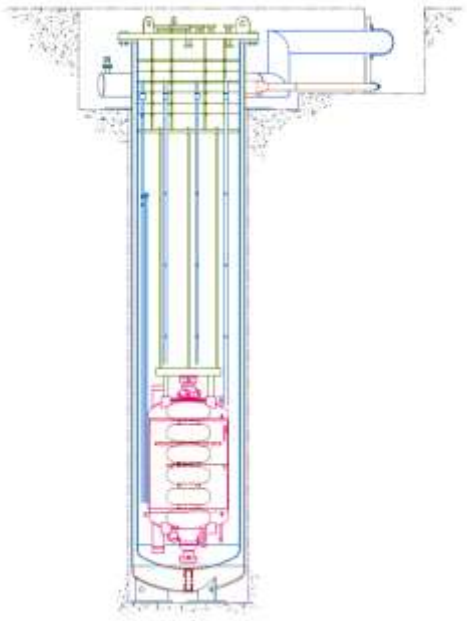
Testing – Cryogenic Test Facility (CTF) Refrigeration System Pictures

Testing – VTA

- **Vertical Test Area (VTA) System Description**
  - 1800L underground Dewar
  - Integrated with CTF refrigeration and liquid fill systems
  - Accommodates 4K and 2K testing
  - Shielded by a 100,000 pound moveable lead shield
  - RF power supplied from 2kW amplifier integrated with fully functional control system – pulsed or continuous
  - Bare cavity and cavity in helium vessel qualification
- **VTA Status**
  - Dewar received from Eden and installed
  - Shield lid manufactured and commissioned
  - RF system is complete and ready for commissioning
  - Top insert is procured and ready for assembly
  - Piping is in progress (Batch filling using portable dewars will support commissioning)
  - Integration of system with CTF refrigerator will be part of CTF commissioning

Testing – VTA Pictures





Lakeshore 218
Temperature Monitors

Tektronix 4104B
Oscilloscope

National Instruments
PXIe 8133
PXI 6229

RF Switch Control

SNS Designed Equipment

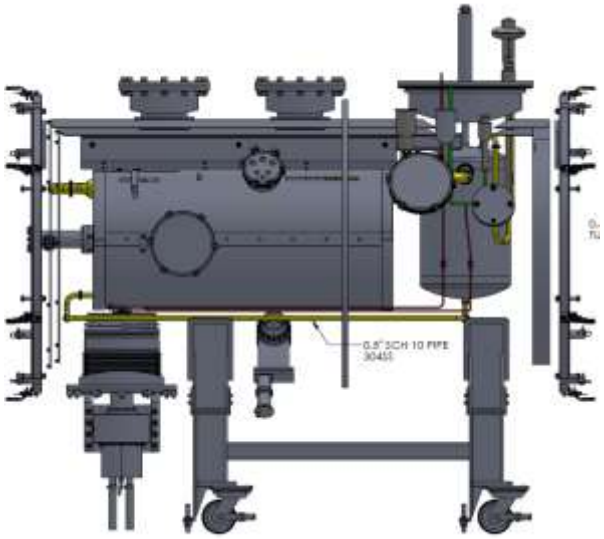
- Calibration Amplifier
- Patch Panel
- Cavity Input PLL
- RF Drive
- Power Monitoring
- Signal Buffer Amp
- Signal Distribution

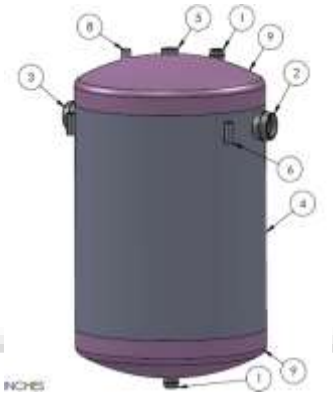
COTS Test Equipment

Agilent Equipment
- 53230A Freq Counter
- E4416A Power Meter (X2)
- E4417A Power Meter (X2)
- N5181A Sig Gen

Testing –HTA

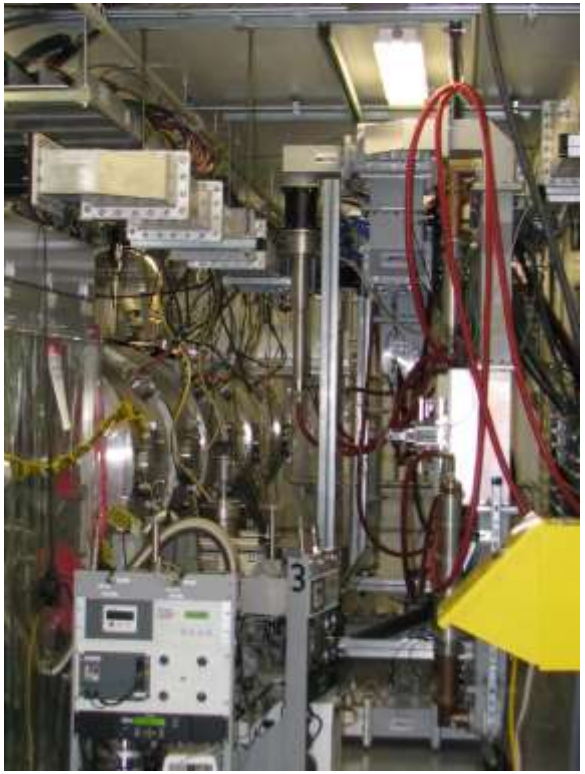
- **Horizontal Test Apparatus (HTA) Description**
  - Provides cavity in helium vessel integrated with coupler testing
  - Same condition in the CM and pulsed RF operation
  - Provides nice platform for plasma processing R&D
- **HTA Status**
  - Under modification at Ability Engineering
    - Delivery scheduled for end of May
    - Hinge assembly - designed and implemented
    - Thermal shields have been repaired and installed
    - Magnetic shielding design is complete
    - Piping design is complete



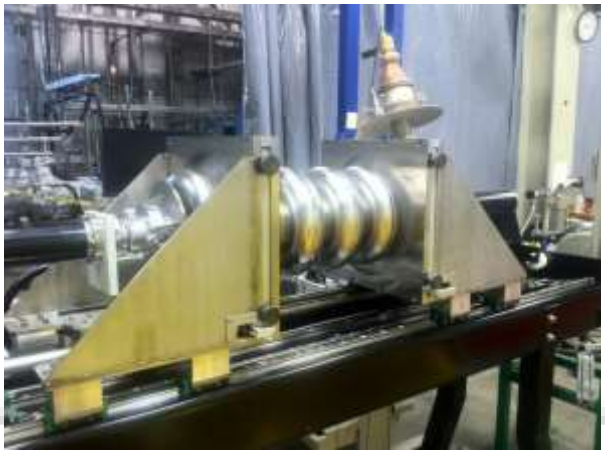


Testing –RFTF Control Room and Test Cave

- **Cryomodule Testing**
  - 5MW, 805 MHz HPRF system
  - Single and multiple cavity testing
- **HTA Testing**
  - Powered by either 5 MW system or 2kW amplifier
- **VTA Testing**
  - 2kW amplifier
  - Continuous or pulsed testing



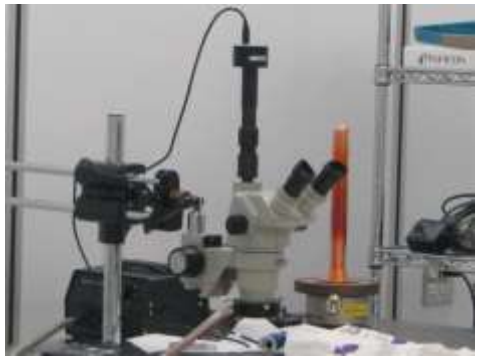
Assembly Systems



- **Clean Room**
  - Ultrasonic cleaning
  - Laminar flow hoods
  - Microscope for imaging
  - Beam line work
- **Assembly Tooling**
  - Cryomodule assembly rails
  - End can assembly carts
  - Transfer carts

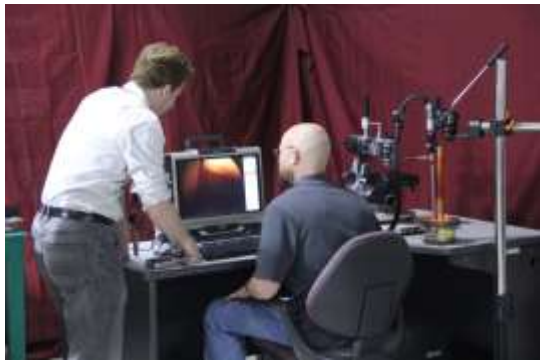
Cavity Tuning Bench

- Mechanically re-shape cells to provide proper frequency and balance stored energy in cells



Staff Development

- **Cryomodule Development**
  - Cross trained multiple technicians and staff members during high beta spare cryomodule development
  - Procedures and travelers developed
- **Cryomodule Rework**
  - Experience gained for variety of repairs
  - Experience gained working with activated parts
- **Cryomodule Testing**
  - Refined/developed techniques and procedures to test cryomodules in test cave
- **Facilities Development/Commissioning**
  - Unique training opportunity for staff having in-depth understanding of system, and making use of vendors and industry experts
- **Research and Development**
  - Gained valuable experiences/knowledge from machine commissioning and operation
  - Developing practical programs for accelerator performance improvement and STS



Summary

- **The current reliability and availability of the SCL is high but there are key issues that must be addressed**
- **Cryomodule rework and development is an active program**
  - High beta spare cryomodule commissioned and operating in LINAC
  - Medium beta spare cryomodule design initiated
  - CM6, CM20 repaired
- **Research and development is ongoing to improve the current performance of the accelerator and prepare for the STS**
  - Plasma R&D focused on achieving 1.4 MW
  - Cavity and coupler development in preparation for STS
- **An investment in facility development is already supporting the operation and has ensured priorities are aligned with SNS goals**
  - Existing facilities: HPR, Clean room, test cave, RF systems, CM assembly
  - Facilities in progress: VTA, HTA, Barrel polishing, CTF refrigerator, R&D vacuum furnace
  - Facilities for future: BCP or EP, Small parts chemistry, Full size vacuum furnace