National Synchrotron Light Source II

Accelerator Update

NSLS-II Science Advisory Committee Meeting

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March 28, 2019

U.S. DEPARTMENT OF ENERGY | Office of Science

BROOKHAVEN NATIONAL LABORATORY

Outline

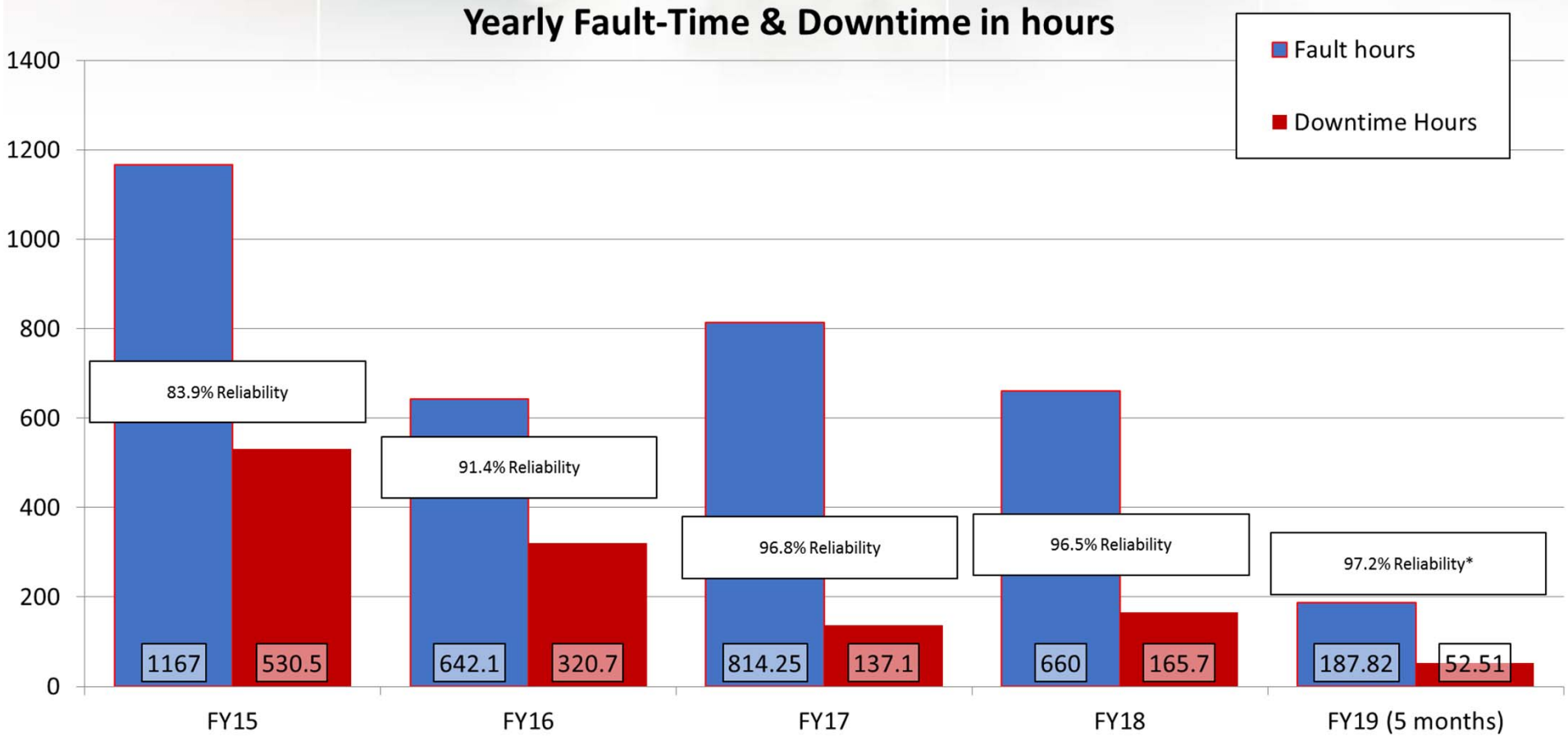
- Status of accelerator operations
  - Reliability and recent events in operations
  - Operations staffing
- Accelerator Division programs
  - Securing high reliability of operations
  - Accelerator R&D and Work For Others
- Conclusions

Related Charge Questions

1) Is the prioritized, resource-loaded schedule for mitigating our vulnerabilities appropriate and achievable?

2) Given funding realities, have we made the right choices in regard to performance vs reliability trade-offs?

Downtime, Faults and Dumps in FY15…19



*First 5 months of FY19

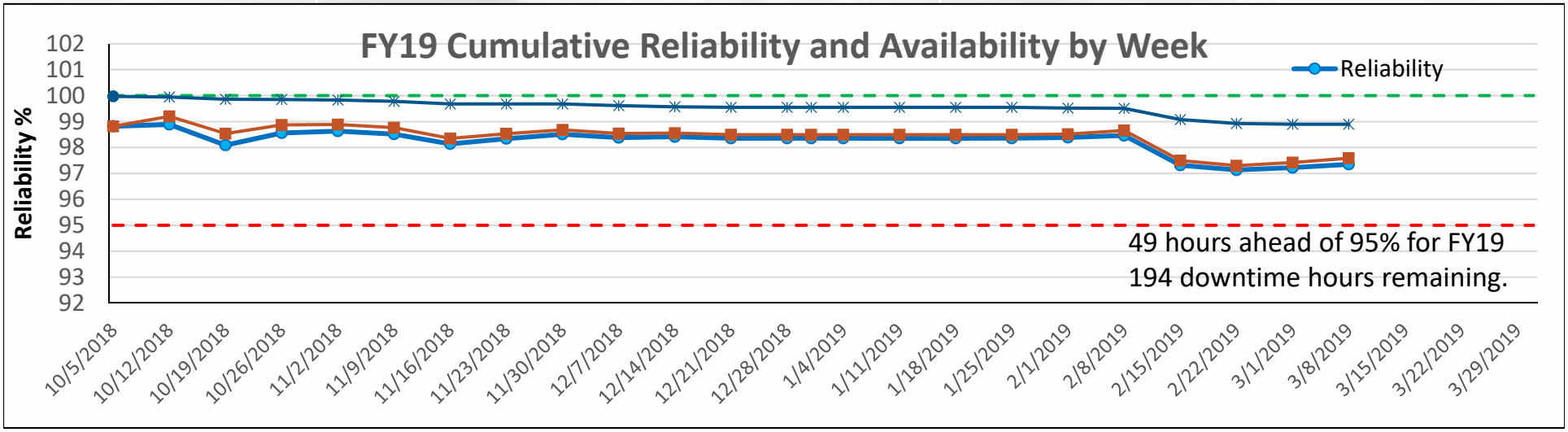
Operations in FY19

- Operating at 400 mA; studies at 475 mA

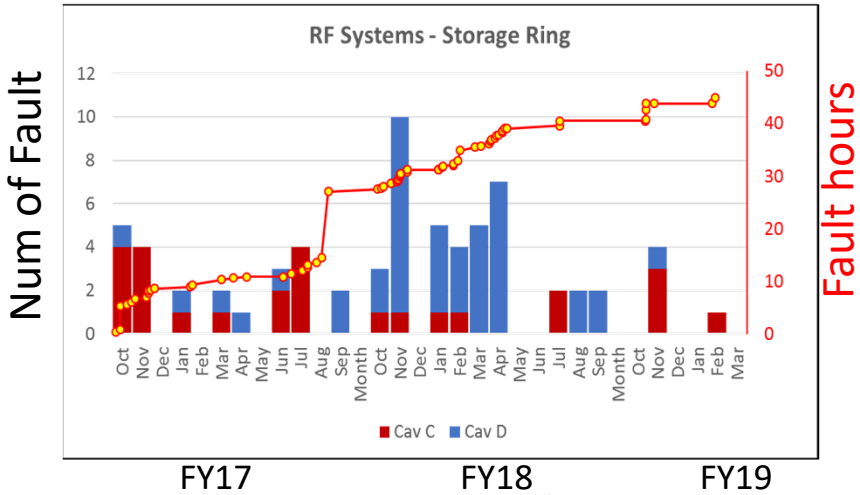
- 3 major operations requirements in FY19
  - Internal reliability goal 97% (DOE goal 95%)
  - ✓ Total operations hours 5000
  - ✓ Internal MTBF goal 40 hours
  - ✓ MTTR goal 1 hr

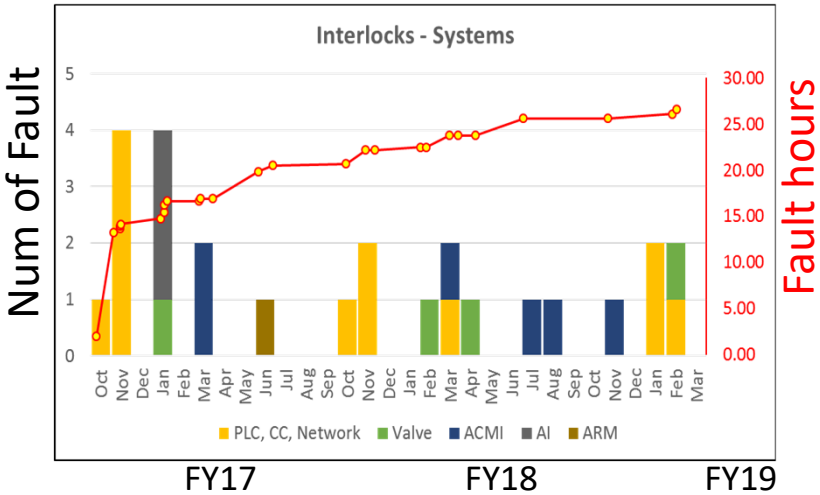
- Main challenges in securing high reliability of operations:
  - Insufficient maturity of machine subsystems
    - Development program targets least reliable systems
  - Insufficient staffing in certain areas
    - Succession planning, programs on increasing efficiency of operations
  - Low component redundancy, Incomplete set of spares
    - Continue procuring spares in FY18 and beyond
    - Developing 3rd RF system
    - New program on Mitigating Vulnerabilities of Accelerator Operations

Reliability of Accelerator Operations



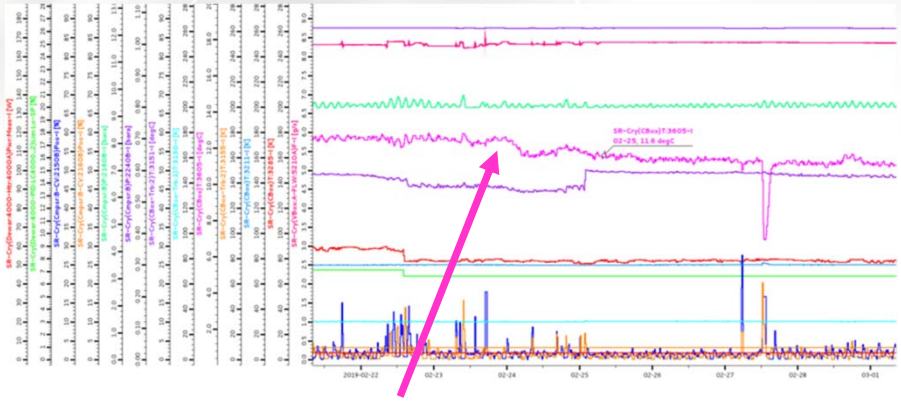
Trends in subsystem performance: a couple of examples





Downtime due to Cryoplant event

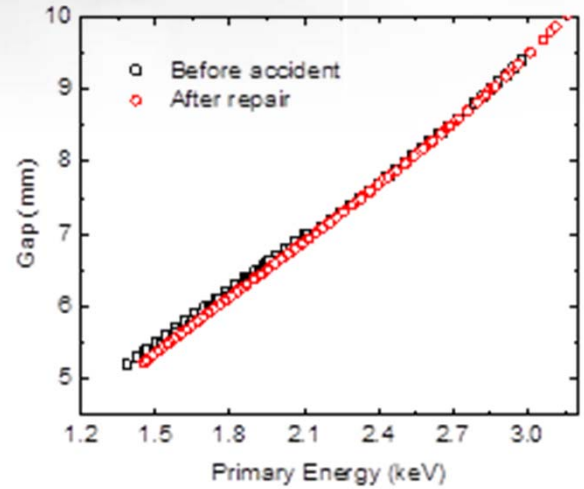
- During cryoplant warm up/cooldown on Feb the cold box tripped while restarting the cryoplant
- Due to long time constants associated with required warm up period restarted the plant on the 2nd attempt
  - ~20 hours of downtime were accrued
- Two weeks later cryoplant showed signs of contamination again
  - likely due to the cavities warming up to above 77K releasing frozen N2 during the above incident
- Second warmup / pump and purge were scheduled for maintenance period of March and was successful
- Plant is in normal operations as of March 7th



N2 exhaust temperature from 80 K heat exchanger trending down, indicative of contamination.

HXN IVU: Repair and Recommissioning Activities

- Complete pre-baking in ID lab by 12/15
- Moved the device to SB2 on 12/18 and to Cell 3 on 12/19 while pulling cables
- Vacuum connection and final baking complete by 1/3/2019
- Cable connection complete by 1/9
- Utility work on 1/7
- Final survey on 1/10
- Function tests complete by 1/22
- Recommissioned FE, AI and ID lookup table on 1/25
- HXN beamline transmitted X-ray to end station on 1/29



- Comparison of calibration tables before and after
- The ion chamber readings (a measure of the flux) before and after the repair. (Hanfei Yan @HXN)

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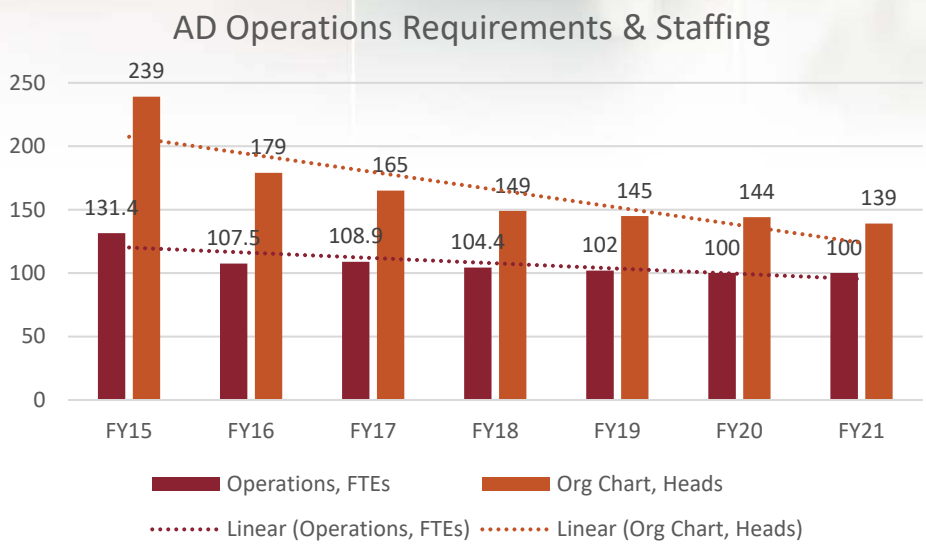
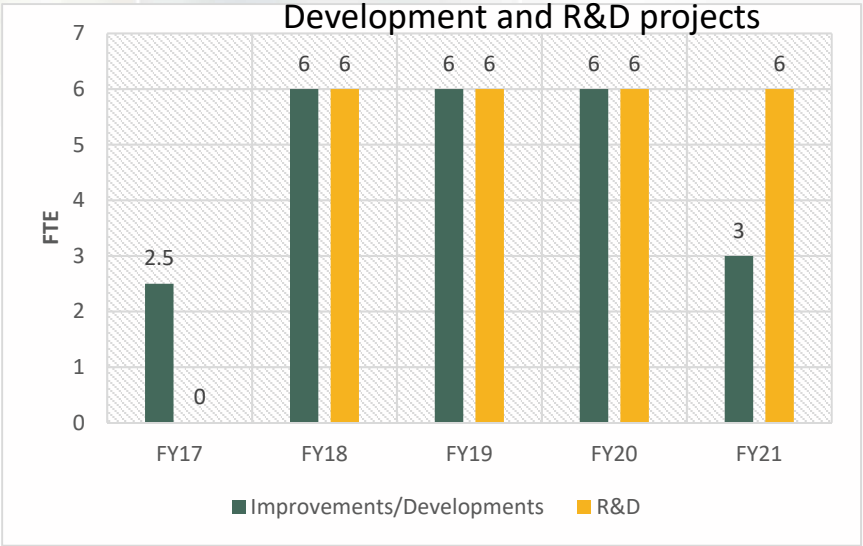
Staffing of Accelerator Division





- Challenge is in increasing reliability of performance of NSLS-II accelerators during transition from construction to operations
  - Diversity of skill sets is reduced
  - Retirements

- Working on increasing efficiency of AD in operations
  - Succession planning and hiring
  - 1st PhD student is on board! Opened positions for a postdoc. 2 more planned.

- Development and R&D projects are funded by AD operations

Programs focused on increasing efficiency of AD operations

- 2 SSVSP and 1 RIF completed since FY17
  - Total reduction of 13 staff members
- Staff attrition through retirements since FY17
  - Total reduction of 7 staff members in FY18-19
- Hiring
  - Hiring for succession planning in FY20-22
  - Head of ME group hired
  - Attracted experienced electronic engineer for RF- and X-BPM operations and development
- Split Mechanical Utilities group between ME and RF groups
- Actively looking for WFO

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Development Projects

- **Development / Improvement projects** significantly improve reliability of operations, increase beam stability and availability, and decrease downtime. These projects are used to fix known issues, optimize performance or enhance protection of subsystems

  - Small (<$30K and <1 year)
    - FY19: 13 approved projects, 4.3FTE
    - Examples: additional memory storage for accelerator archiver, magnet klixon relocation, sand filter upgrade in Cooling Tower.

  - Large (>=$30K or >=1 year)
    - FY19: 16 approved projects, 7.7FTE
    - Examples: booster Hot Cathode Thyrotron pulser upgrade, Magnet temperature monitoring system, refurbishment of linac modulators.

Facility Improvement and R&D Projects

- **Development and R&D projects** are aimed at novel techniques needed for upgrades in the longer-term.
  - FY19: 5 approved projects, 1.7FTE
  - Examples: Testing system for FOFB, PLCs and Motion Control, DI Water test stand, RF Bellow Finger development

- **Facility Improvement Projects** are funded outside of AD operations for improvements and R&D
  - FY19: 4 approved projects, 1.3FTE
  - Examples: Helium purifier for cryoplant, Modeling of Complex Bend element, optimized cooling for ceramic chambers, on-line optimization of storage ring parameters

Procurement of Spare parts

- Current challenges
  - Each Group maintains spreadsheets on spares in addition to the main list owned by the Coordination Group.
  - Upgrading and replacement due to wear out and obsolescence takes a significant amount of time and system expertise.
  - Many Groups have expressed concern of insufficient labor resources to adequately manage spare parts.
    - Review parts relative to obsolescence, confirming requirements
    - Periodic inventory counts
    - Confirming part numbers and vendors for spares not in hand and placing orders
  - Limited space for spare parts storage is problematic for many groups
- Future plans
  - Introduce a real time integrated inventory control that is web based instead of Excel based
  - Identify specific labor requirements for managing spares and include them in labor budget
  - Evaluate additional space options for spares

Front End

Power Supplies

Vacuum

Diagnostics

Major Accelerator Faults and Events at NSLS-II

1. Events that had large impact on reliability at NSLS-II (2014-2018):

Events	lost reliability, %
SRF cavity leaks, multipactor, contamination	2% in FY16 <1% other years
BD1 faults in 2015 and 2018	13% in FY15 2% in FY18
Cryoplant, burst disk events	Failure in FY17 - 0.6% if entirely during ops.
SR DPS faults	0.2% /year
HXN Vacuum event	0.7% in FY18

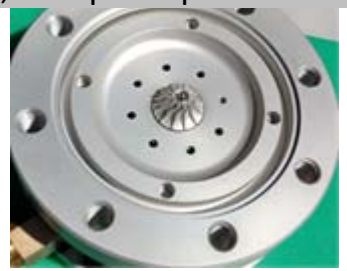
HXN IVU event (2018): 200 gallons of water, 80k$ in repairs

Burst Disk (2017) resulted in contamination of Helium system; 6 months of cleaning cryoplant

2. Overheating events observed to date, NSLS-II:

- Bellows, ceramic chambers, striplines, RF springs
- Multiple leaks opened in flanges due to overheating
- Potential damage to reliability (7 days=3.4% annual reliability):
  - 14 days if RF cavity fails (vacuum or SC issue)
  - 4 days if ceramic chamber fails
  - 5 days if HP PS fails

340,000 rpm expansion turbine



Liquid Helium turbine failure (2016): replaced with spare. If spare failed, 3+ months downtime

Impact from Major Accelerator Faults in LSs

Recent history of major faults among light sources worldwide

facility	year	lost time, days	subsystem	cause
SLAC	2013	14	transformer	no spares in hand
CLS	2013	7	SRF	He-UHV leak at probe seal, 27 month repair
PLS	2017	90	cryoplant	LHe turbines failure
DLS	2014	14	SRF	Indium seal failure, > 2 year repair
ALS	2016	3	BDPS	difficult recovery
APS	2018	3	bellow	vacuum leak due to damage by SR
CLS	2018	180	injector gun	no spares in hand
DLS	2009	14	SRF	Vacuum trips when powered, bad Cu plating
DLS	2015	14	SRF	Window failure

From: 'An unprecedented outage': Canadian Light Source synchrotron breakdown cancels research until November, CBC News, 2018

From: ALS Engineers Resolve Power Supply Failure, Bring ALS Back Online, ALS news, 2016

"…Cavity failure has very serious implications for DLS operation. Up to two weeks are needed to replace a failed cavity with a spare one."
From: http://accelconf.web.cern.ch/AccelConf/srf2017/papers/mopb016.pdf

Figure 6: Cavity D damaged RF window.

Accelerator Vulnerabilities Strategic Plan

Improvement / Development projects required for reliable operations at 500mA/8pm rad

Project	Priority	Cost, M$
Spare RF Cryo Module	1	3.18
Spares not in hand (critical)	2	2.74
RF Cryo Plant	3	1.28
Third Harmonic RF Cavities (THC)	4	7.77
4th RF System	5	11.75
Injector Thermionic Gun	6	1.06
Spares not in hand (priority 2)	7	2.99
Booster Dipole PS converter	8	1.29
Storage Ring Dipole PS converter	9	1.15

33.2M$

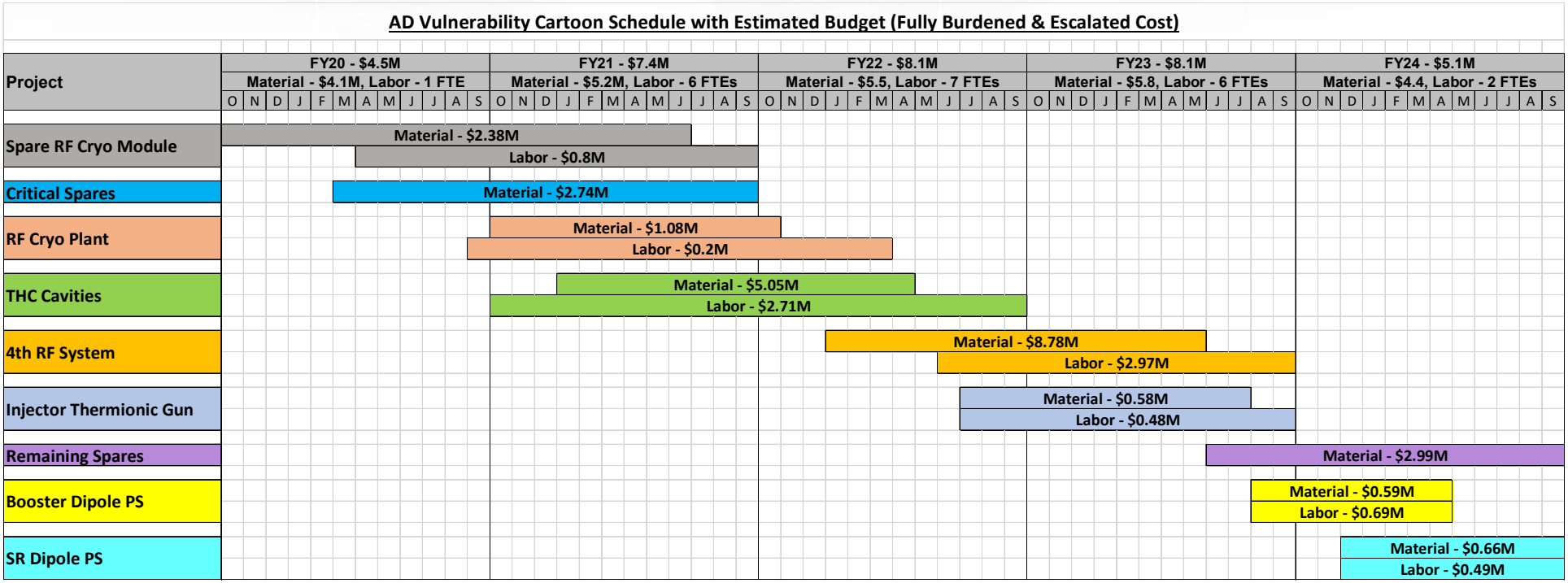
Third Harmonic Cavities

Electron Gun

Cryomodule

- We prioritized these Improvement / Development projects based on multi-parametric analysis of:
  - Impact of operations,
  - emittance and lifetime,
  - heating of chambers.
- All costs (labor + materials) are in fully burdened dollars with 3% escalation each year

Technically Limited Schedule of Accelerator Vulnerability Mitigation Program



- All costs are in fully burdened dollars with 3% escalation each year

Considerations for Planning Parameters of Future Operations in Near Term

Beam Current, Emittance, Peak Current and Lifetime

today's compliment of IDs	I	# of RF	ε_y	I limit, mA	total P	I peak I ave	Lifetime	TO interval	Q/shot
	mA		pm rad	if 1RFC failed	kW	A^2	hrs	min	nC
400 mA, 2RF, no THC, 30 pm rad	400	2	30	281	230	12.0	9	2.7	7.5
400 mA, 2RF, no THC, 8 pm rad	400	2	8	281	230	12.0	5.2	1.5	7.5
400 mA, 2RF, yes THC, 8 pm rad	400	2	8	281	230	4.8	11	3.3	7.5
500 mA, 3RF, no THC, 30 pm rad	500	3	30	500	460	19.8	9	2.7	9.4
500 mA, 3RF, yes THC, 8 pm rad	500	3	8	500	460	7.8	11	3.3	9.4

TODAY

- 500 mA operation without THC creates heating issue in ring components
- 400 mA 8 pm rad operation without THC requires frequent top-off injections due to short lifetime, stressing injector and possibly impacting user scans
- 400 mA, 8 pm rad operations delivers higher brightness than 500 mA, 30 pm rad operations

Intermediate conclusion on Strategic Plan

- Funding of the Vulnerability Mitigation Plan is not practical under the NSLS-II operating budget
- We have chosen to limit our future operations to 400 mA and 30 pm rad until budget for Strategic Plan is available
- Ongoing study program focused on high current will inform us of what other issues are in increasing current / reducing y-emittance in operations

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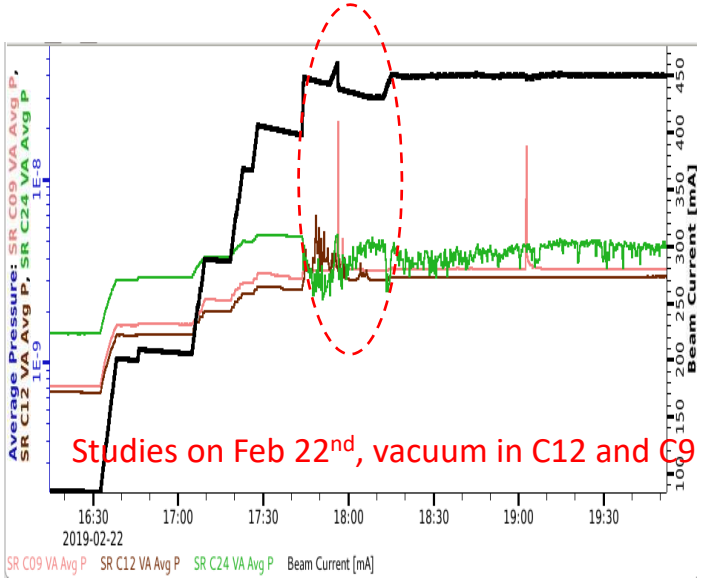
13.7M$

High Current Studies towards 500 mA

- Operation mode: 400 mA with 80% filling pattern, 3 MV voltage
  - During prior shutdowns we replaced ~60 RF springs around the ring
  - Peak T is now at 63 ^{o}C (vs 76 ^{o}C before)

- High current beam studies:
  - We studied 450 mA with 80% filling pattern on Feb 2nd
  - We attempted to study 475 mA on Feb 22nd
    - Observed sudden beam loss from 460 mA to 438 mA
    - High vacuum activity in C12 and C9 cells

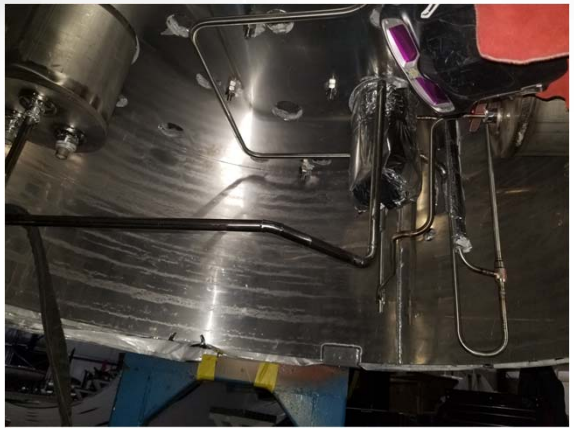


- Reached 475 mA on March 15th
  - Vacuum activity in several cells
  - Steadily growing temperature in one of the bellows

- Study results are under investigation. We will proceed with studies once the observed effects are understood.

Status of 3rd RF System project

- Cryomodule
  - Ready for cold test in April shutdown
- Valve box
  - 4 WEKA valves installed with piping spools, 12 to go
- SSA Transmitter
  - FDR complete, long lead procurements pending
- Cryo Transfer lines
  - Ability Engineering Inc. selected vendor, contract in place
- In-house electronic module production started
  - Production of RF modules ~50% complete
- SOW being prepared for warm piping and installation contract.
  - This is the last major procurement in the 3rd RF system project.



Valve Box WEKA valve and piping installation at PHPK

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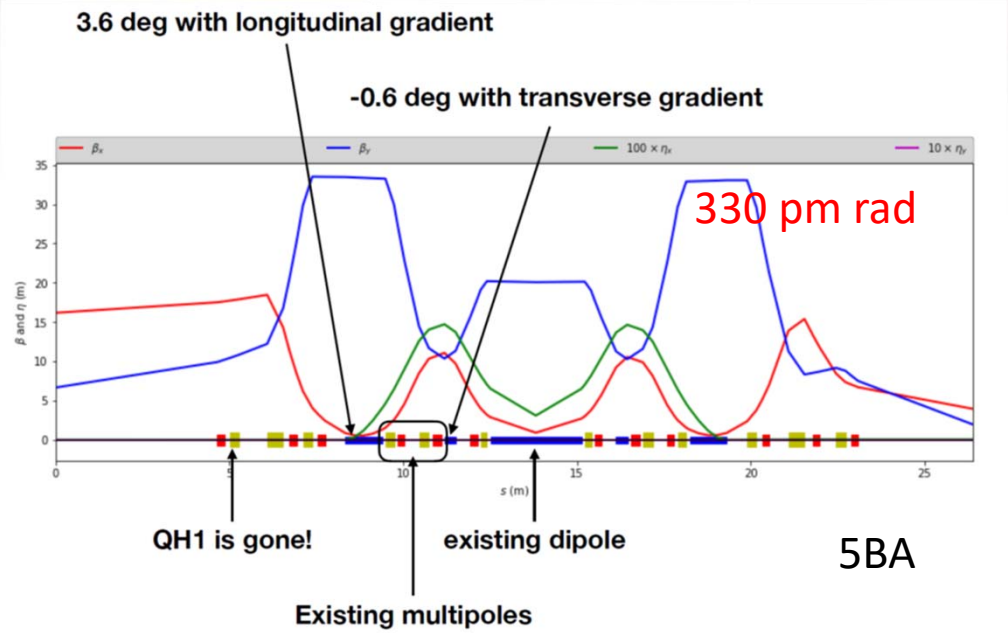
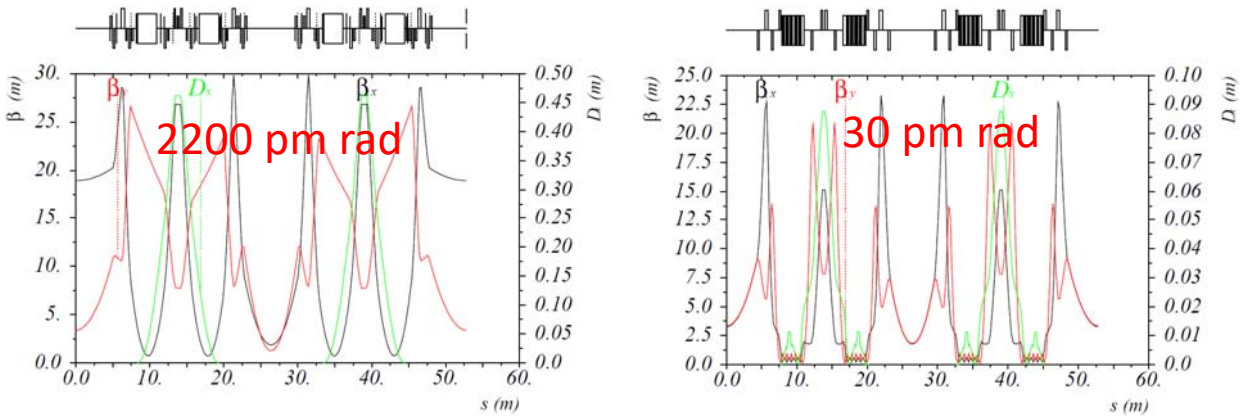
R&D

- Limited scope of R&D in AD
- Upgrade Lattices
  - 5-BA
  - Complex Bend
  - Magnet designs
  - Work with M. Borland
- White paper on upgrade in 2019
- Studies 3rd Harmonic RF cavity
- Studies of MW instabilities
- ML proposals and collaborations
- 2 active LDRDs: NSLS-II upgrade and UEM
- Contributions to eRHIC design

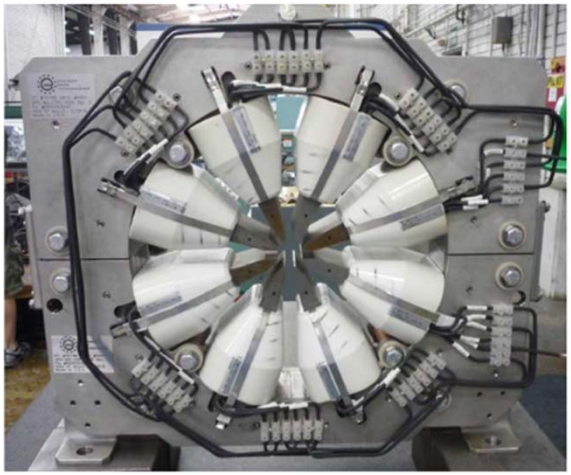


NSLS-II today → Complex Bend



Work For Others

- Actively looking for WFO!
  - Needed for retaining skills and knowledge
  - Exciting projects for AD experts
  - NOT funded by NSLS-II operations budget
  - Allows DOE to level labor effort across partner labs
- APS-U
  - Accelerator and Beamline engineering
  - Component testing
- ALS-U
  - Power supply system design
  - AR vacuum system design
  - Accelerator and Beamline PPS
- eRHIC design and beam physics
  - Machine lattice, Collective effects, Beam-beam effects, effects from ions and optimization of BPMs
- LCLS-II
  - Consulting on ME aspects of CryoModules



Corrector Magnet (laminated)

Designed by Brookhaven National Laboratory measurements agree with simulations.

Recommendations from the Previous SAC Meeting

- Make a decision on pursuing the 3rd harmonic cavity implementation and decide whether to do so before going to 500-mA operations.

Response: We completed accelerator physics studies on beam dynamics with 3rd HRF cavity. The latter is a prerequisite of reaching 500 mA / 8 pm·rad and belongs to the program on Mitigating Vulnerability of operations. THC project is on hold until funds are available.

- Develop a prioritized resource loaded schedule for the reliability program, including the 3rd harmonic cavity

Response: Technically limited schedule has been developed, see slide #19. Actual schedule will depend on availability of funds.

Conclusions

- NSLS-II accelerators have delivered reliability at the 97.2% level in FY19

- We are busy with:
  - Increasing annual operations time
  - Balancing staff in the areas of concern
  - Procuring sufficient inventory of spares
  - Building necessary subsystem redundancy

- We are looking ahead for future upgrades of the NSLS-II facility to keep our facility at the cutting edge
  - Critical for maintaining skillset and keeping up morale of NSLS-II accelerator staff

- Actively looking for Work for Others and collaboration with other facilities

- Doing well due to breath and depth of expertise, talent and diligence of NSLS-II staff.