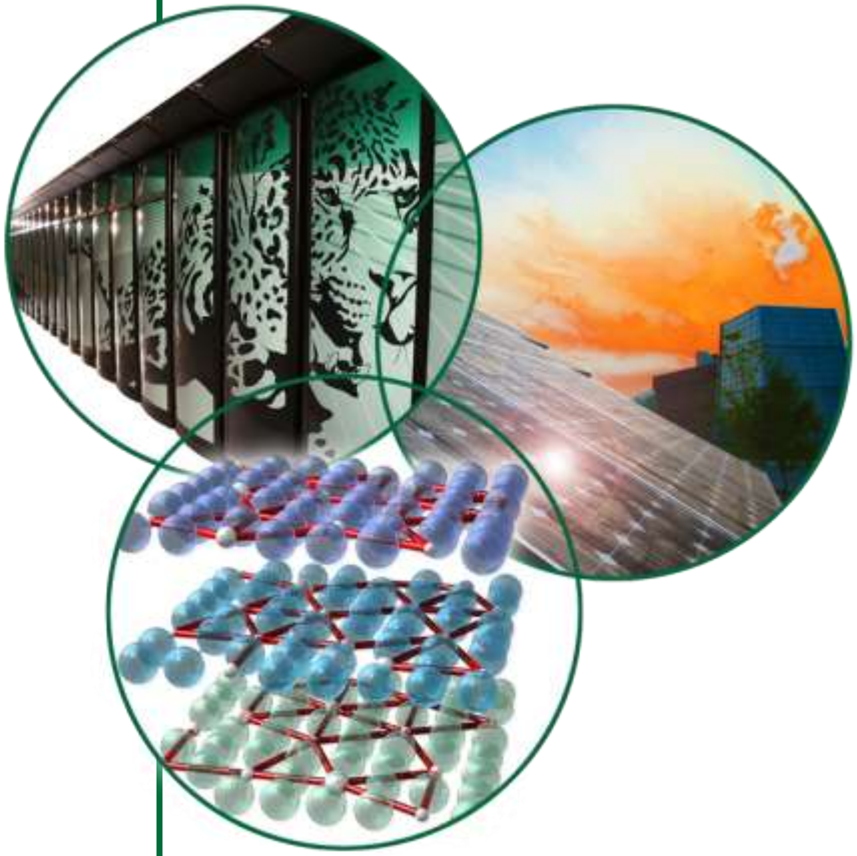
Accelerator Systems Overview and Plans

Kevin Jones, Director
Research Accelerator Division

January 10, 2012



U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Outline

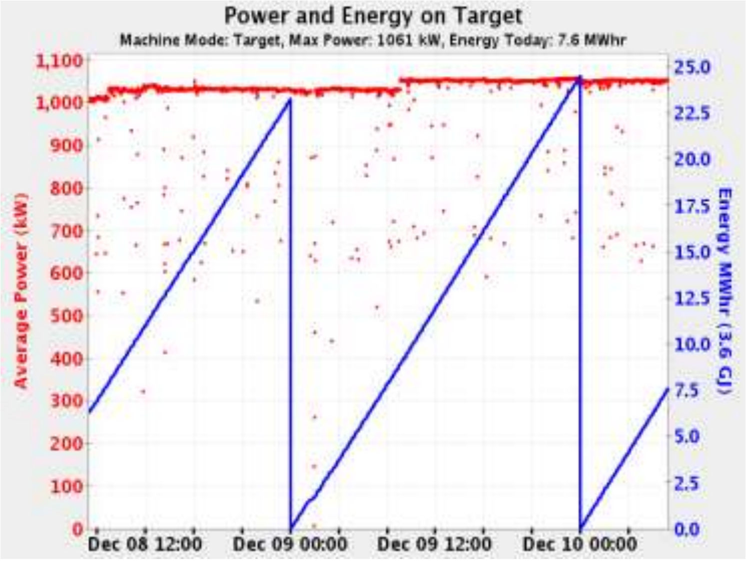
- Progress since the last AAC meeting
- Research Accelerator Division organizational structure and leadership
- Overview and design parameters
- Performance expectations and history
- System performance highlights and limitations
- The path to 1.4 MW
- Long-term objectives

Since the last AAC meeting (Feb 2010)

- Continued operation at a peak beam power of up to 1.08 MW and peak integrated beam power up to 25MW-hrs in a day
- We have increased the beam availability from ~82% (early FY10) to ~94%
- We have made impressive improvements in High Voltage Converter Modulator performance
- We have developed a robust approach that leverages foil lifetime performance and minimize losses
- We have rebuilt the Ring Injection Dump Line to reduce losses and improve performance
- We have made impressive progress in the implementation of laser-based beam diagnostics
- We have implemented a reliable imaging system for beam on target
- We have made substantial progress in building a spare high-beta cryomodule
- We have made significant investments in development of SRF test and processing facilities
- We have made a quantitative leap forward in understanding SCL losses
- We have successfully changed the first target to reach end-of-life during scheduled operation and also did the first core vessel insert replacement
- We have successfully demonstrated fixed frequency operation for better neutron chopper performance
- We have established a robust maintenance management system

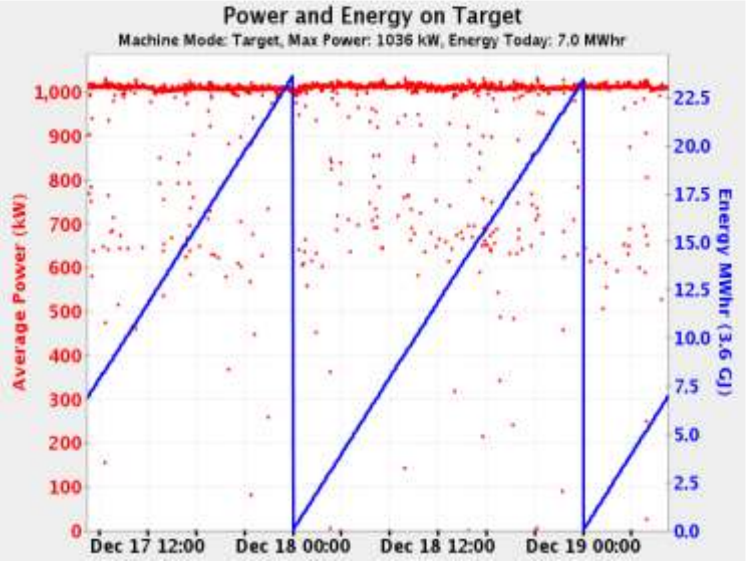
We can reproducibly and reliably deliver 1MW beam power on target

- From the Plan-of-the-Day Meeting on December 10, 2010:
  - Beam to target at ~1.07 MW
  - NP for the last 24 hrs.: Availability – 100%; 25.1 MWhr delivered (0800-0800)
  - New 24 hr. NP delivery record (!) – 25.1 MWhr
  - No recordable downtime for the last 24 hrs



- From the Plan-of-the-Day Meeting on December 19, 2011:
  - Beam to target, ~1.02 MW

NP availability for:	Last 24 hrs.	Last 7 days	Current Run	FY12-1
	97.5%	98.5%	97.4%	94.3%
MWhr:	23.4	157.5	551.3	1356.0
Avg MWhr/day:	23.4	23.8	22.2	19.1



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Neutron Sciences Directorate

Associate Laboratory Director
Kelly Beierschmitt
Robert McGreevy, Deputy Associate Laboratory Director
Herb Mook, Sr. Corporate Fellow
Lori Lane, Executive Secretary

Joint Institute for Neutron Sciences
Takeshi Egami

Matrix Support
Haifa George, HR Manager
Christy Griffith, Business Manager

Directorate Operations
Crystal Schrof, Acting

User Programs and Outreach
Lynn Kszos, Acting
Laura Morris Edwards, User Office

Quantum Condensed Matter
Stephen Nagler

Biology and Soft Matter
Paul Langan

Chemical and Engineering Materials
Mike Simonson

Neutron Data Analysis and Visualization
Robert McGreevy, Acting

Research Reactors
Ron Crone

Instrument and Source Design
Phil Ferguson

Research Accelerator
Kevin Jones

Research Accelerator Division in 2010

Research Accelerator Director
Stuart Henderson

J. Goodpasture, ES&H Officer
M.Hensley, Administrative Secretary

SNS Accelerator Advisory Committee

G. Dugan, Chair

Matrix Support

K.Smith, HR Manager
L.Hickey, Business Manager
M. Carpenter, QA Manager

Accelerator Physics
J. Galambos
Group Leader

Accelerator Operations
J. Kozak
Group Leader

Control Systems
K. White
Group Leader

Cryogenic Systems
F. Casagrande
Group Leader

Electrical Systems
R. Cutler
Group Leader

Beam Instrumentation
A. Aleksandrov
Acting Group Leader

Vacuum Systems
Vacant
Group Leader

Mechanical Systems and Installation
T. Hunter
Group Leader

Radio-Frequency Systems
T. Hardek
Group Leader

Target Systems
J. Forester
Group Leader

Ion Source
M. Stockli
Group Leader

We defined a set of organizing principles that reflected management and sponsor expectations

- **Provide an efficient, responsive, integrated, cost-effective organization that supports execution of the mission and achievement of the long-term vision for SNS.**
- **Provide key services to the broad SNS enterprise that enhance the success of our partner divisions and users.**
- **Integrate like functions to leverage common disciplines for efficiency, cross training, career development and enhancement, break down barriers to success, and optimize our opportunities to improve and sustain our facilities.**
- **Simplify our communication channels and organizational interfaces to facilitate ease and quality of interaction both internally and externally to the organization.**
- **Strengthen our integrated scientific, technical and operational capabilities.**
- **Foster a strong sense of shared ownership in meeting laboratory and sponsor expectations, performance metrics, and the related challenges that arise.**
- **Establish a reasonable and consistent span of control for each line manager in the organization.**
- **Minimize the overhead costs to the organization.**
- **Ensure clarity of role, responsibility, authority and accountability (R2A2) for each line manager in the organization.**

Research Accelerator Division in 2012

Research Accelerator Division
Kevin Jones, Director
Marit Adjei, Administrator
Jim Goodpasture, ESH
Mario Giannella, Maintenance Integration

- **SNS Accelerator Advisory Committee** — Gerry Dugan, Chair
- **Maintenance Management and Information Systems** — George Dodson
- **Division Support** — Amy Brown, HR; Brian Wilson, Finance; Martha Carpenter, QA
- **Directorate Support** — ESH, Environment, Waste, Safety Basis, QA, Procurement and DCRM

Facility Operations — Sam McKenzie
- **F&O Assignment** — Sam McKenzie
- **Site Services** — Tom McLaughlin
- **NRPD Assignment** — Tim Gillespie

Data Operations — Karen White (Acting)
- **Controls Systems** — Karen White
- **Instrument Data Acquisition and Control** — Steve Hartman (Acting)
- **Computing Integration** — Bridgitte Mase

Accelerator and Target Operations — George Dodson
- **Electrical and RF Systems** — Mark Champion*
- **Mechanical Systems and Operations** — Mike Baumgartner
- **Physics, Ion Source and Instrumentation** — John Galambos
- **Superconducting Linac Systems** — Sang-Ho Kim
- **Accelerator Operations** — Glen Johns

Instrument Operations — Don Abercrombie
- **SNS Instrument Support** — Bobby Cross
- **SNS User Support** — Rob Connatser, Mark Loguillo
- **Sample Environment** — Lisa Debeer-Schmitt
- **Scientific Laboratories** — Chrissi Schnell

*** Mark will start on January 23, 2012**

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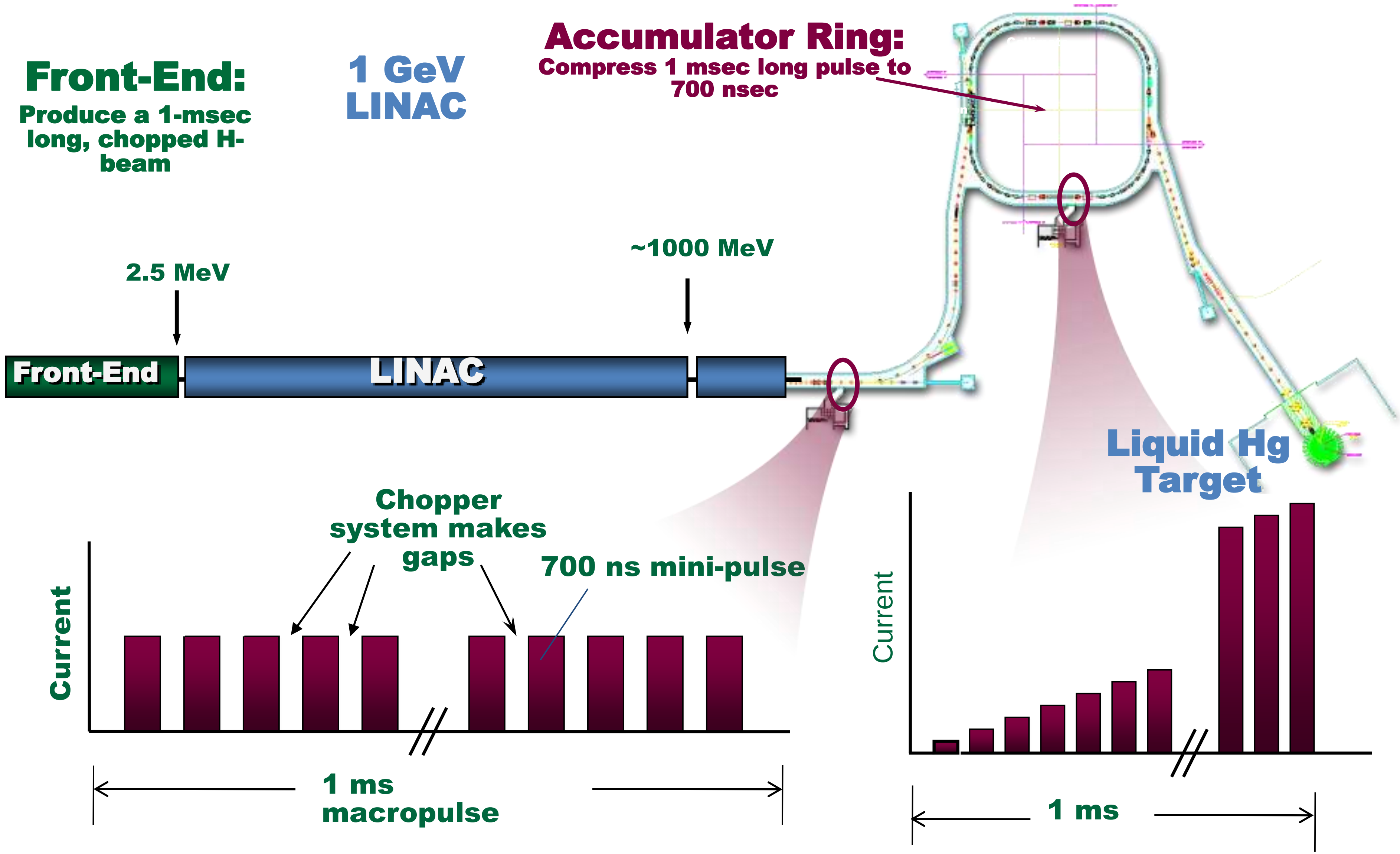
SNS Accelerator Complex



SNS Design Parameters

Kinetic Energy	1.0 GeV
Beam Power	1.4 MW
Linac Beam Duty Factor	6%
Modulator/RF Duty Factor Spec.	8%
Peak Linac Current	38 mA
Average Linac Current	1.6 mA
Linac pulse length	1.0 msec
Repetition Rate	60 Hz
SRF Cavities	81
Ring Accumulation Turns	1060
Peak Ring Current	25 A
Ring Bunch Intensity	1.5×10^{14}
Ring Space Charge Tune Spread	0.15

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SNS Performance Relative to Design

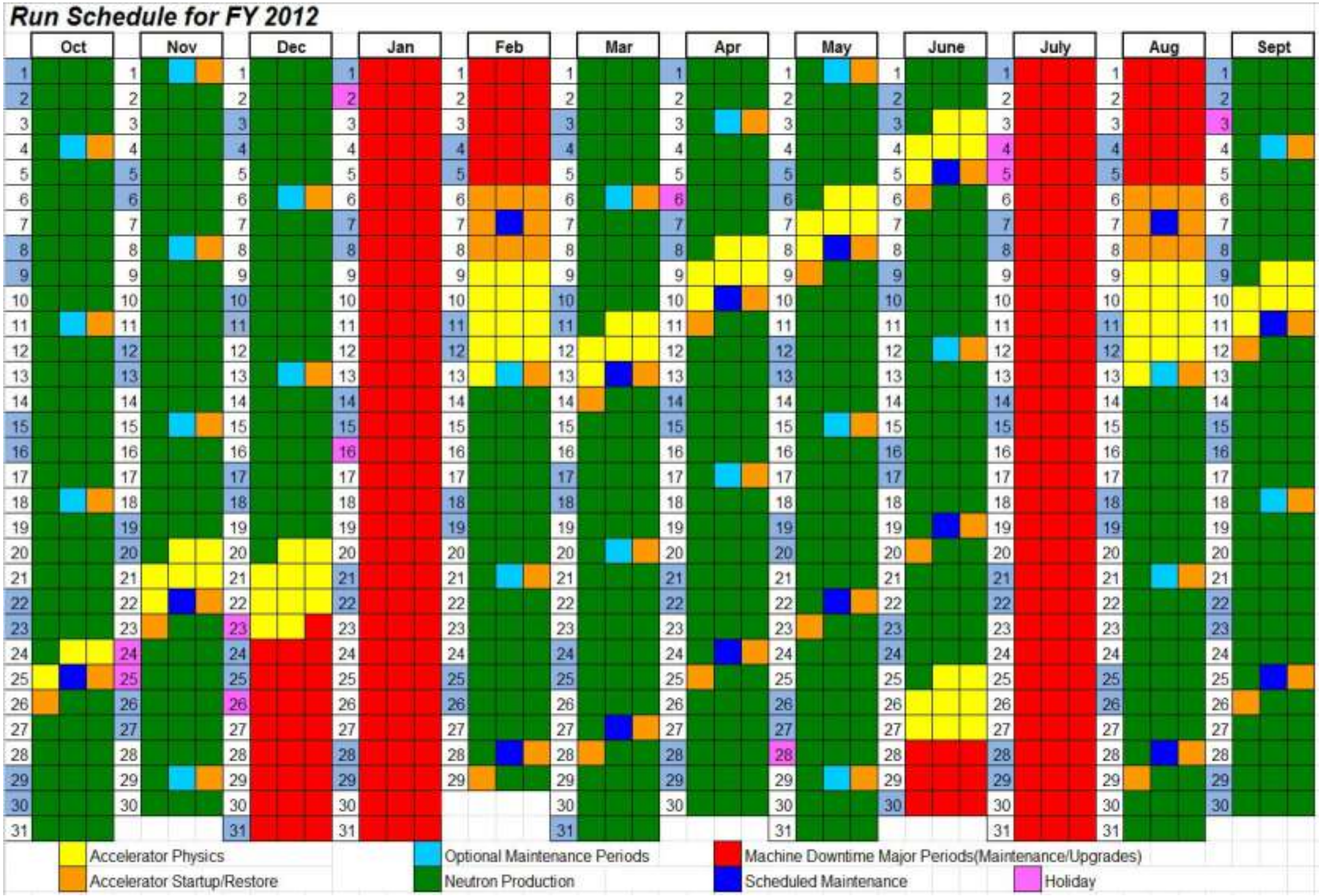
	Design	Best Ever	Routine Operation
Kinetic Energy [GeV]	1.0	1.01	0.925
Beam Power [MW]	1.4	1.089	0.8-1.05
Linac Beam Duty Factor [%]	6	5	5
Modulator/RF Duty Factor [%]	8	7	7
Peak Linac Current [mA]	38	42	38
Average Linac Current [mA]	1.6	1.1	1.1
Linac pulse length [msec]	1.0	1.0	0.80
Repetition Rate [Hz]	60	60	60
SRF Cavities	81	80	79-80
Ring Accumulation Turns	1060	1020	825
Peak Ring Current [A]	25	26	18
Ring Bunch Intensity	1.5×10^{14}	1.55×10^{14}	1.1×10^{14}
Ring Space Charge Tune Spread	0.15	0.18	0.12

Since FY2009 SNS has met or exceeded all sponsor commitments

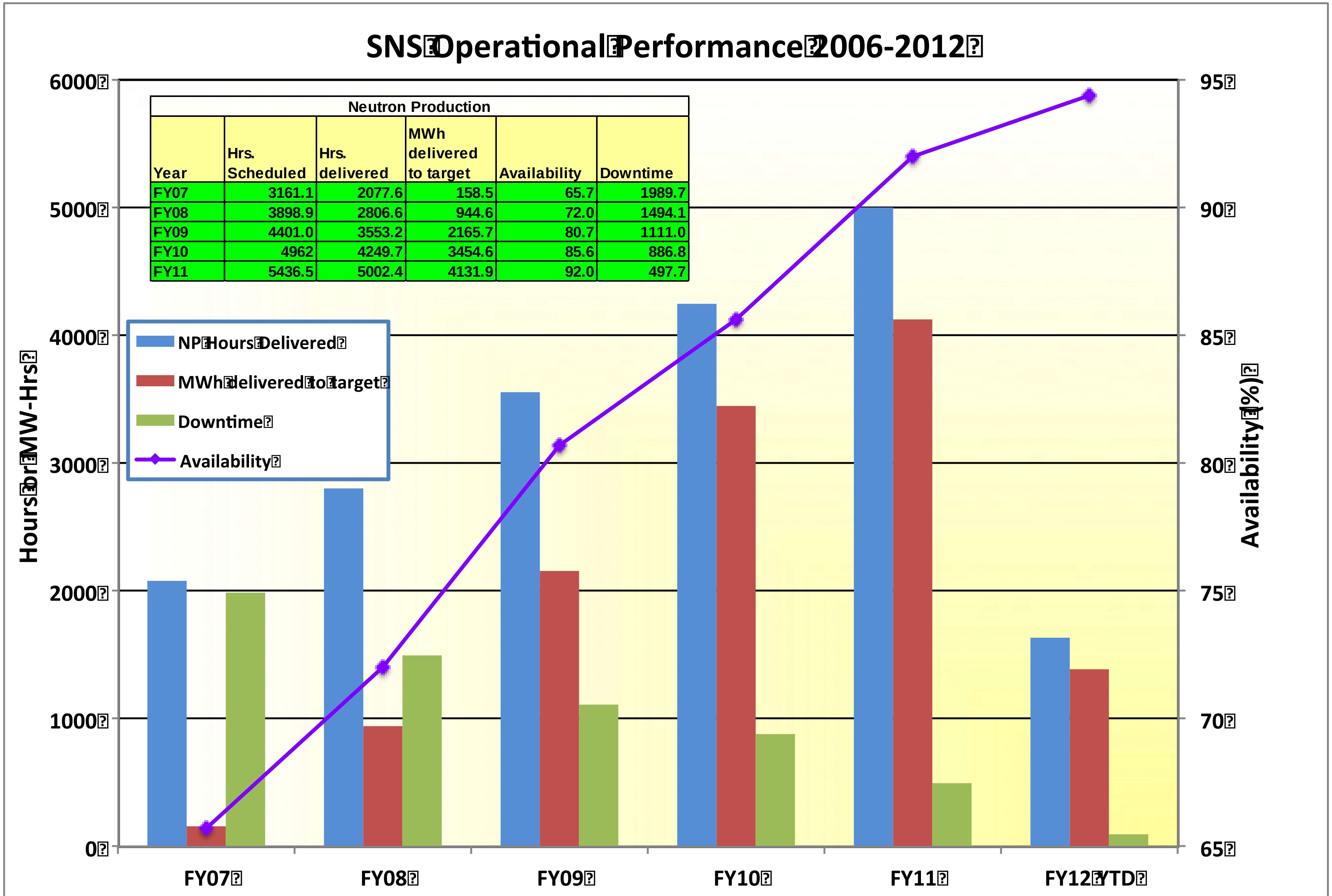
Year	Neutron Production Availability		Integrated Beam Power (MW-hrs)	
	Commitment	Actual	Commitment	Actual
FY2007	68.0%	65.7%	117	159
FY2008	74.0%	72.0%	877	945
FY2009	80.0%	80.7%	2031	2166
FY2010	85.0%	85.6%	3253	3455
FY2011	88.0%	92.0%	NA	4132
FY2012	90.0%	94.4% YTD	NA	1382.4 YTD

Year	Neutron Production Hours		Total Operating Hours	
	Commitment	Actual	Commitment	Actual
FY2007	1500	2078	3500	3779
FY2008	2700	2807	4000	4032
FY2009	3500	3553	4500	4916
FY2010	3900	4250	4800	5310
FY2011	4300	5002	5000	5941
FY2012	4500	1633 YTD	5000	1843 YTD

SNS has established a standard 2-shutdown schedule that supports present target longevity

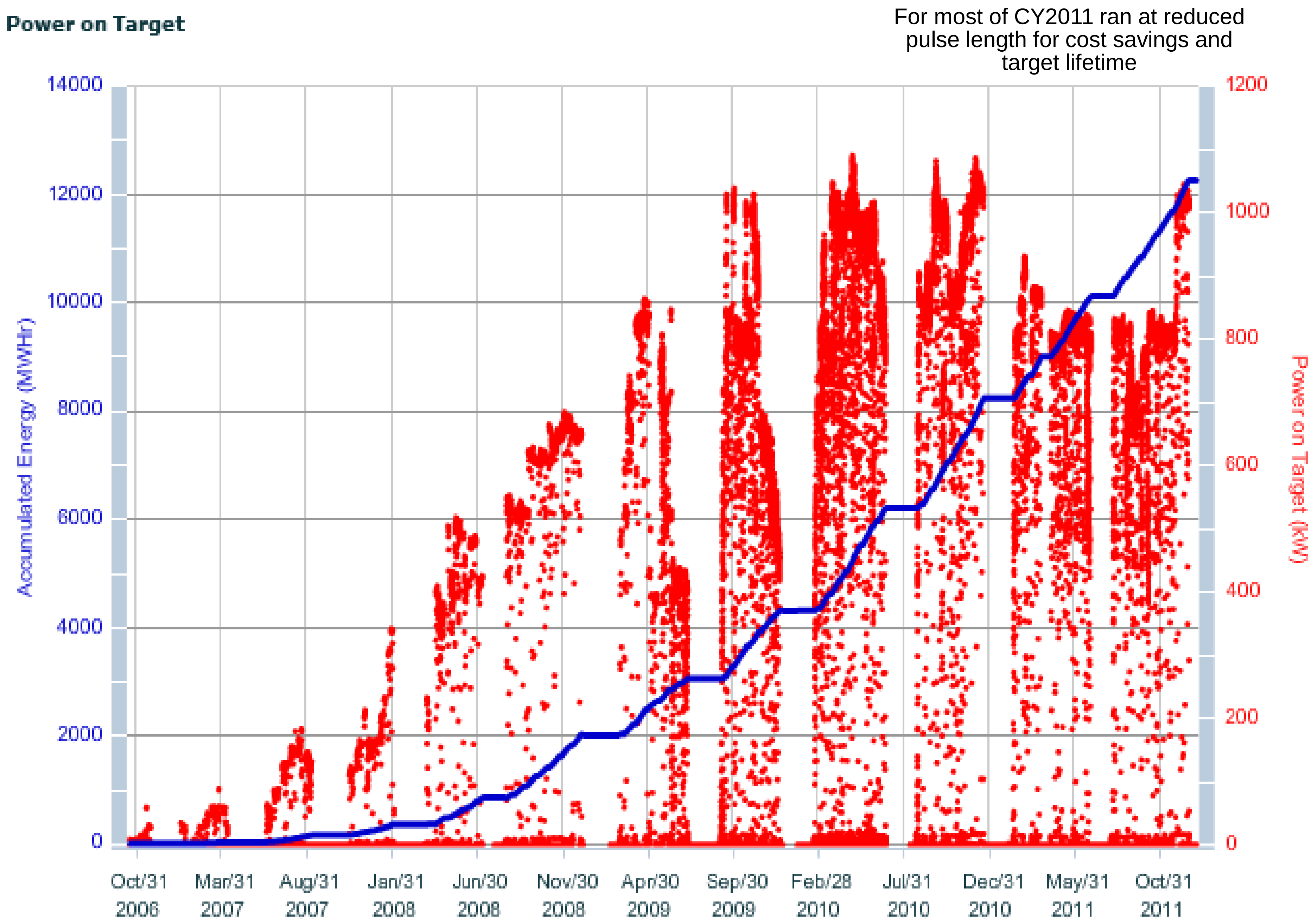


SNS accelerator system performance has become outstanding

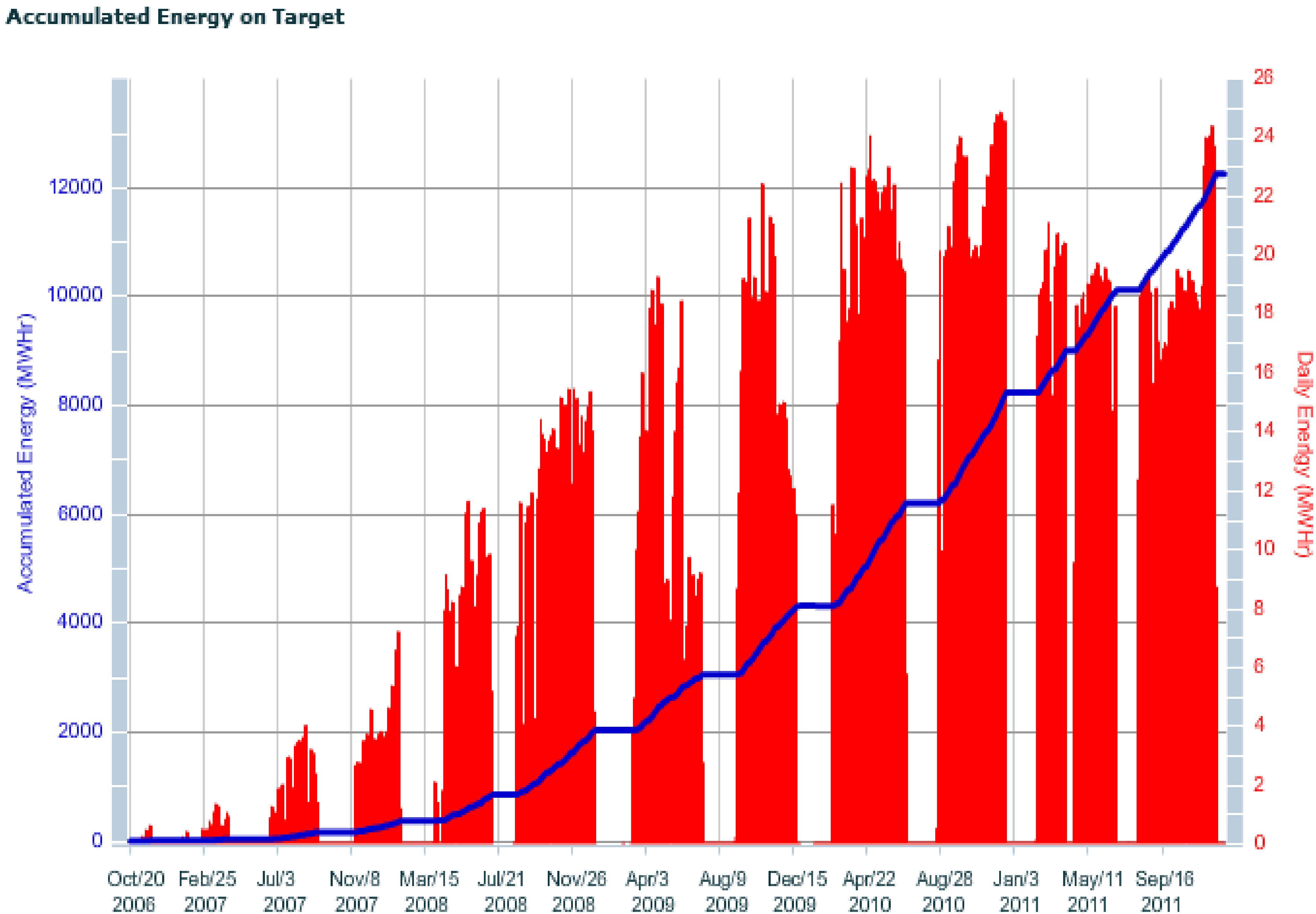


Neutron Production					
Year	Hrs. Scheduled	Hrs. delivered	MWh delivered to target	Availability	Downtime
FY07	3161.1	2077.6	158.5	65.7	1989.7
FY08	3898.9	2806.6	944.6	72.0	1494.1
FY09	4401.0	3553.2	2165.7	80.7	1111.0
FY10	4962	4249.7	3454.6	85.6	886.8
FY11	5436.5	5002.4	4131.9	92.0	497.7

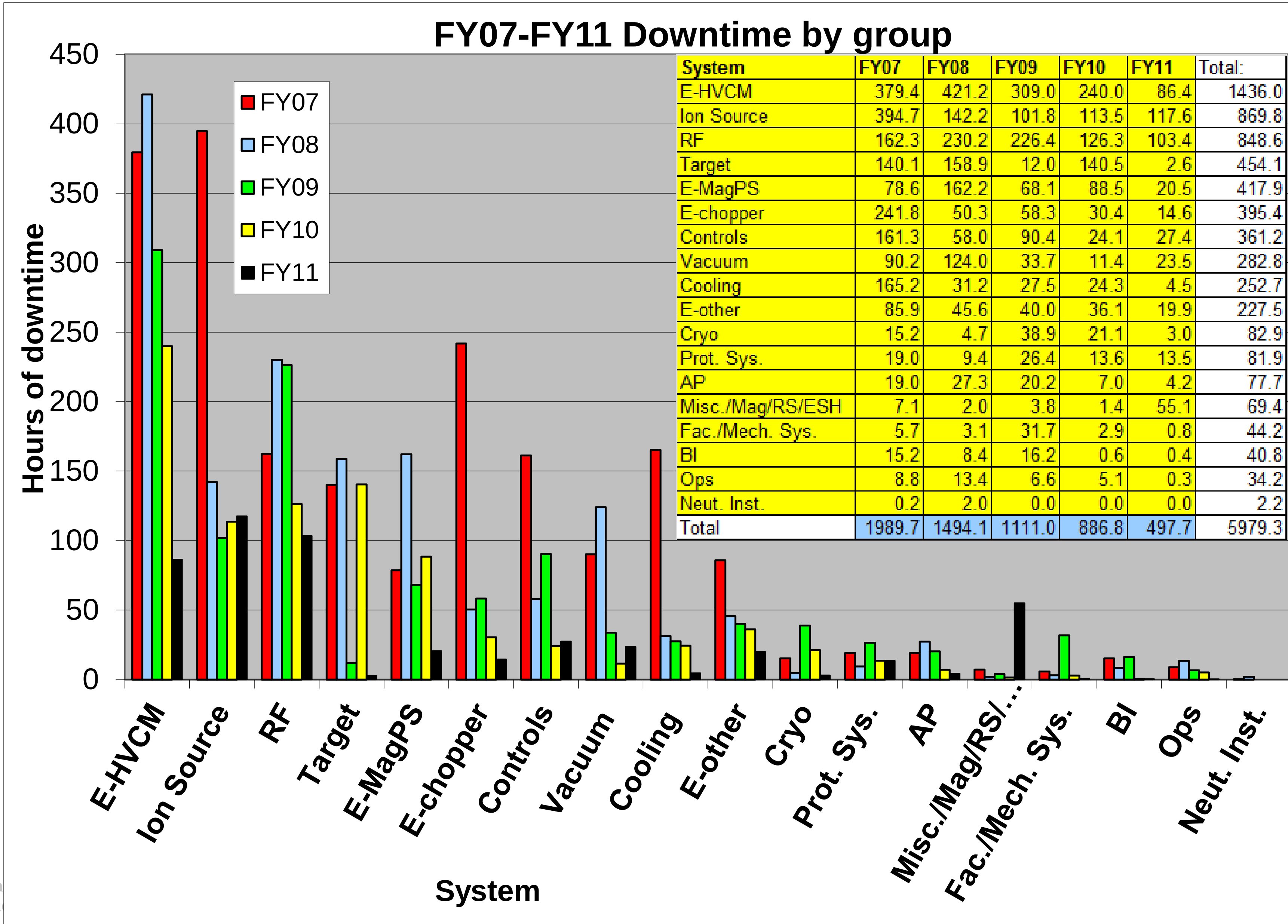
Energy and power on target from October 2006



Accumulated energy on target from October 2006



There have been dramatic improvements in down time for critical systems



System	FY07	FY08	FY09	FY10	FY11	Total:
E-HVCM	379.4	421.2	309.0	240.0	86.4	1436.0
Ion Source	394.7	142.2	101.8	113.5	117.6	869.8
RF	162.3	230.2	226.4	126.3	103.4	848.6
Target	140.1	158.9	12.0	140.5	2.6	454.1
E-MagPS	78.6	162.2	68.1	88.5	20.5	417.9
E-chopper	241.8	50.3	58.3	30.4	14.6	395.4
Controls	161.3	58.0	90.4	24.1	27.4	361.2
Vacuum	90.2	124.0	33.7	11.4	23.5	282.8
Cooling	165.2	31.2	27.5	24.3	4.5	252.7
E-other	85.9	45.6	40.0	36.1	19.9	227.5
Cryo	15.2	4.7	38.9	21.1	3.0	82.9
Prot. Sys.	19.0	9.4	26.4	13.6	13.5	81.9
AP	19.0	27.3	20.2	7.0	4.2	77.7
Misc./Mag/RS/ESH	7.1	2.0	3.8	1.4	55.1	69.4
Fac./Mech. Sys.	5.7	3.1	31.7	2.9	0.8	44.2
BI	15.2	8.4	16.2	0.6	0.4	40.8
Ops	8.8	13.4	6.6	5.1	0.3	34.2
Neut. Inst.	0.2	2.0	0.0	0.0	0.0	2.2
Total	1989.7	1494.1	1111.0	886.8	497.7	5979.3

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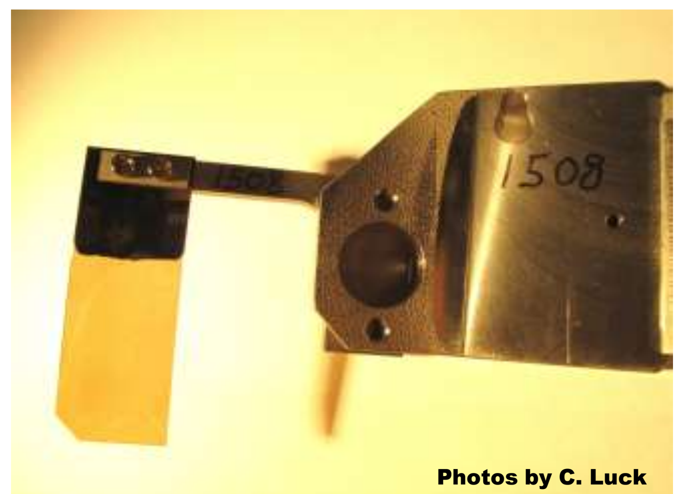
There have been a diverse set of performance issues over the past two years

- Charge-Exchange Injection
  - Stripper foil mechanism motion is unpredictable and can require manual intervention
  - Significant issues with new primary stripper foil mechanism and vacuum chamber – project is being re-evaluated
- Target Systems
  - Contamination and performance problems with the cryogenic moderator system limited beam on target power for a period of time
- RF Systems
  - Managing DTL tank and coupler/window performance through adjustments to RF fill ramp
- Ion Source
  - RF Antenna infant mortality problems (typically in first week of operation)
  - Sources 2 and 4 contaminated by a failed vacuum pump resulting in rapid loss of beam
- Superconducting Linac
  - Forced to lowered gradients on several cavities and take two cavities out of service
- Controls
  - Beginning to experience obsolescence issues with PPS/IPPS PLCs and timing system electronics, among others
- Electrical Systems
  - Beginning to experience end-of-life and obsolescence issues with power supplies (DC and pulsed)

Stripper foil operation has improved but challenges remain

- Three challenges persist:
  - Foils become wrinkled and twisted, losing the straight edges we need to get the minimum beam loss
  - Foil flutter / shaking. We tend to move beam away from corner to stop it, but this increases the beam loss.
  - Faulty foil changer mechanism & incorrect electron catcher location

This foil lasted the entire Feb. – June 2010 run cycle



Photos by C. Luck

Now standard foil
U-shaped corrugations, corner cut off

An oil contamination event in the Cryogenic Moderator System (CMS) cost ~6 days of FY10 neutron production

- The helium compressor bulk oil separator failed and overloaded the downstream oil removal skid

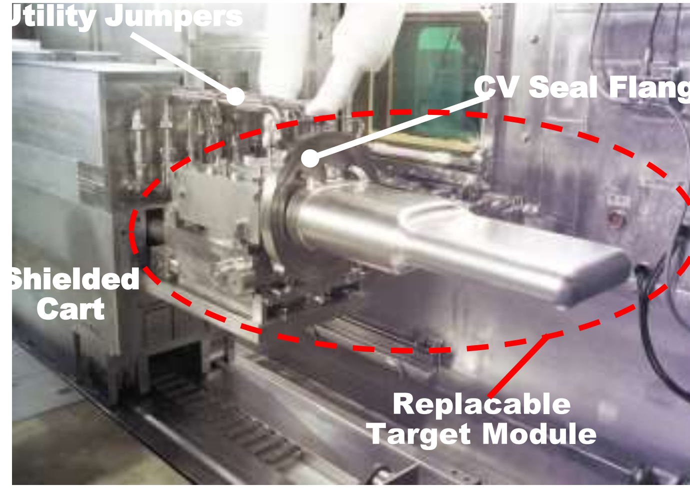
Oil Removal Skid

Bulk Oil Separator

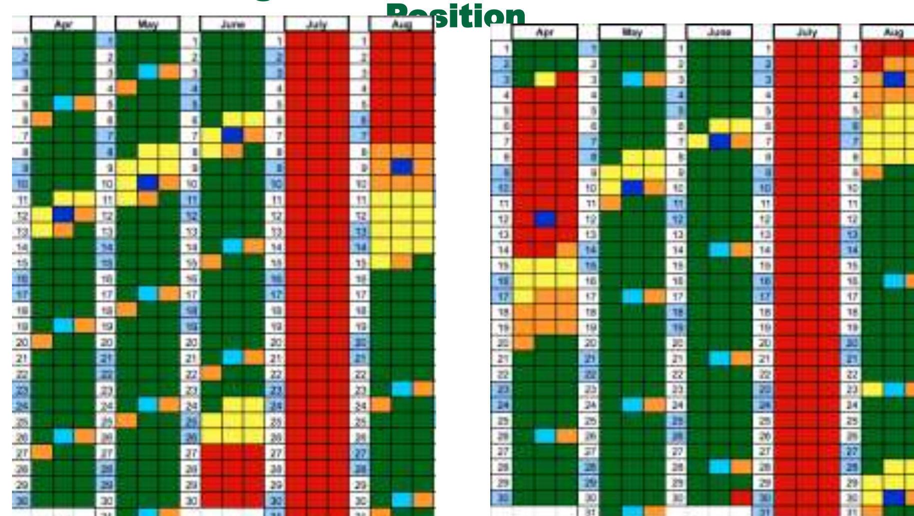
OAK RIDGE National Laboratory

SNS Target Module 3 was replaced at end-of-life

- SNS mercury target module #3 reached end-of-life on April 3, 2011 after 2800 MW-h, including more than 700 hours above 1 MW
  - Running the target to end-of-life was a planned event, but due to uncertainty in predicting lifetime it could not be scheduled
  - Previously spent targets (2) were removed prior to reaching end-of-life conditions to minimize impact on user program
- Target module replaced and system restarted on schedule (2 weeks)
- Shutdown for target replacement used to accomplish work previously planned for summer maintenance shutdown
  - Recovered 2 weeks for user program by reworking SNS operating schedule to shorten summer shutdown
- Post-Irradiation-Examination of this recently spent target module will be discussed elsewhere



SNS Target Module on Cart – Retracted Position



Rev 1 **Rev 2**

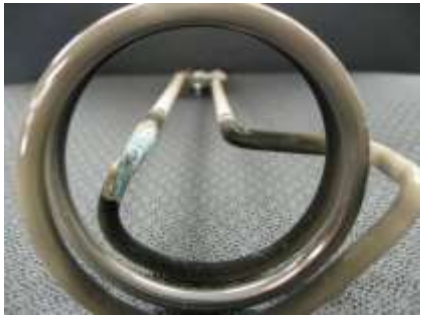
SNS FY11 Schedule Revisions 1 and 2 showing adaptation to add unscheduled target replacement (April/red) while preserving neutron production hours (June-August/green)

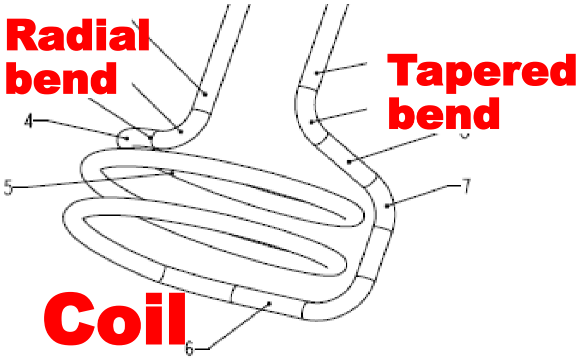
Several thermal/mechanical issues have developed in the warm linac

- Have recently developed a vacuum to water channel leak in DTL-4 Tank
  - We traced the leak to an RF vacuum window and believe it is a braze joint failure.
- Replaced 2 DTL windows due to vacuum leaks at waveguide flange braze joint
- Have arcing in the Iris/Window regions of several DTL tanks
- During the July 2010 shutdown we inspected DTL-3 and DTL-4 coupling Irises
  - Did not see signs of arcing on DTL-4
  - Found DTL-3 missing an RF Shield on the vacuum pumping port
  - Installed Shield during January 2011 shutdown
  - Irises have some high field regions we can improve
  - Intend to redesign irises and fabricate replacement for DTL 3 and a couple of spares (Redesign and prototype is funded. Manufacture of replacement units is not currently funded.)
- During February 2011 startup we broke a CCL window
  - Believe this is a thermal failure from Thales past experience
  - Not satisfied with original water cooling path design
  - Will improve design and manufacture new spares locally (Design is funded. Manufacture of windows is not presently funded.)
- Will want to redesign both DTL and CCL Couplers for operation at 1.4 MW
  - Increased beam loading will require higher power through already troublesome couplers

Increases in the ion source power and pulse length led to higher antenna failure rate

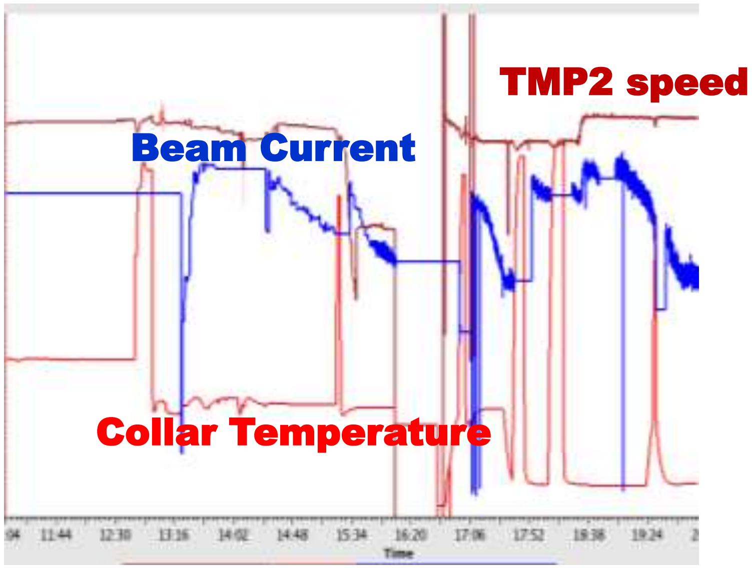
- Since raising the RF power to ~60 kW and the source pulse length to 0.9 ms in 2010, the antenna failure rate increased from ~1 per run to ~4 per run
- Most antennas fail within the first week of operation, long before the end of the typical 4-week service cycle, which suggests infant mortality
- Failure analysis shows that ~77% of antennas fail in the leg bends, which penetrate into the core of the plasma
  - Apparently intense heating combined with high porosity can drive the porcelain surface above the melting point, which destroys the insulation





An operational issue resulted in poisoning of Sources 2 and 4

- Source #2 was installed on September 27, 2011, leak checked satisfactorily and started up normally, with some RGA anomalies at masses 28 and 32
- Cesiation yielded ~33 mA but the beam current decayed by ~18%/hour, while masses 28 and 44 rose
- Re-cesiation increased the beam current, but accelerated the decay and the RGA showed large amounts of CO, CH_4, and C_3H_6
- Numerous re-cesiations restored the beam but did not improve the beam decay, consistent with the Cs not sticking to the collar
- Lowering the Cs collar temperature slowed the decay rate, but it was still substantial
- The conclusion was drawn that the molybdenum collar was severely poisoned



We are beginning to experience end-of-life and obsolescence issues in the control system

- Obsolescence
  - MPS and Timing systems contain components at or near end-of-life; constant effort to address components according to spare levels, failure risk and consequences of failure
- Timing Master – replacement designed, built; testing in RFTF
- Timing Receiver – replacement designed; 60 delivered, running unit tests, then will run with new master in RFTF
- Fiber to Fiber Fan-out – parts not available for repair; < 10% spares; new design in progress
- Fiber to Copper Fan-out – limited ability to repair; 10% spares; new design will follow fiber to fiber fan-out
- MPS Trigger Control Chassis - unique interface chassis with no spare; new chassis (and spares) designed, built, installed in accelerator
- MPS needs redesign to be sustainable for the future – resource limited

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Continued sustainable operation is predicated on robust maintenance, mitigating obsolescence and maintaining adequate spares

- We continue to focus on beam availability during Neutron Production and Accelerator Physics; this is our highest priority
  - If necessary, we sacrifice beam power for availability
- Our limited ability to implement HVCM upgrades during scheduled shutdowns has restricted further increases in beam power
- We emphasize careful maintenance planning and resource allocation during scheduled shutdowns and regular maintenance periods
- We strive to maintain adequate inventories of spare components within budget limitations
- We anticipate obsolescence and strive to develop mitigation plans again within budget limitations
- We continue rigorous management of changes to the accelerator system through a Configuration Control Committee

FY2012 represents the culmination of increases in sponsor commitments

Year	Availability Commitment	Neutron Production Hours	Total Operating Hours
FY 2010	85	3900	4800
FY 2011	88	4300	5000
FY 2012	90	4500	5000
FY 2013	90	4500	5000
FY2014	90	4500	5000

We are developing a new 5-year plan to achieve routine operation at 1.4 MW to Target Station 1

- DOE has cancelled the Power Upgrade Project – John Galambos will report on how the project has been concluded
- Budgets for accelerator operations and maintenance and accelerator improvement projects continue to decline
- Realistic constraints on ability to perform major project work in two one-month long outages dictate that implementation of improvements must be extended
- The plan focuses on all the elements necessary to raise power to target:
  - Beam Energy (925 MeV to 1 GeV)
  - Beam Current (Average macropulse peak current from 23 to 26 mA)
  - Beam Pulse Length (800 µs to 975 µs)
  - Stable ring injection and e-p instability control

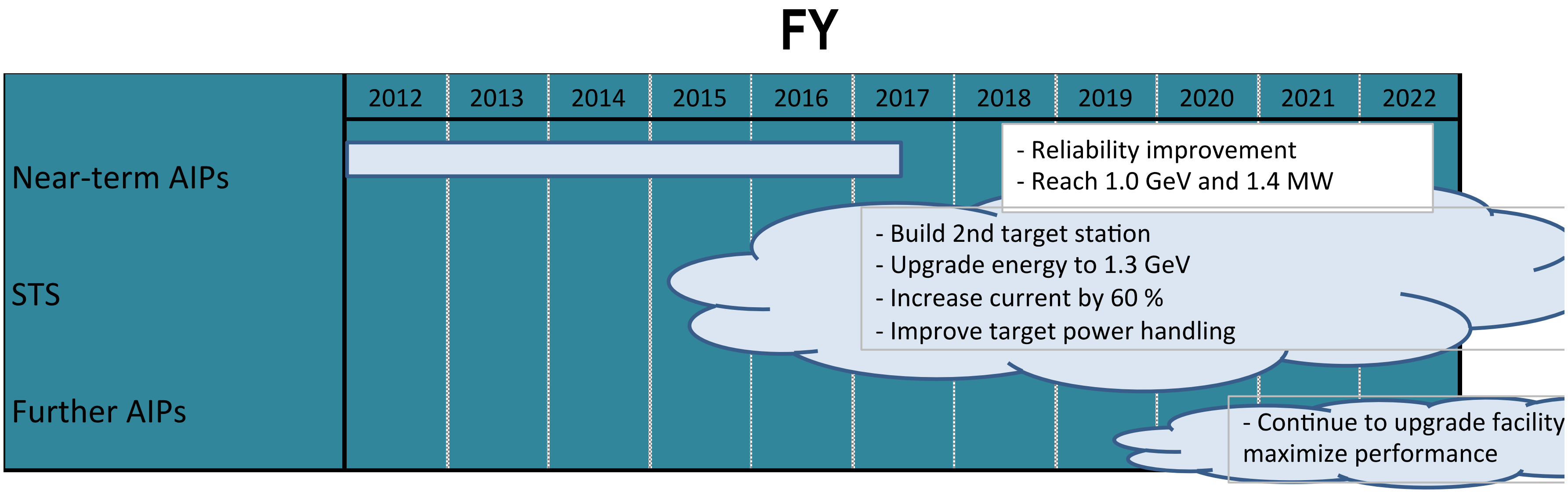
Beam energy increase focuses on addressing field gradient issues in the superconducting linac

- **Improve high beta SRF cavity performance**
  - Focus on plamsa processing for in-situ restoration of performance
  - R&D activities ($1,300k)
  - In-situ implementation ($1,000k)
- **Superconducting RF facilities and capabilities**
  - Spare high beta cryomodule (funded, nearing completion)
  - Vertical test assembly (funded, ongoing)
  - High pressure rinse capability (funded, ongoing)
  - Two high beta test cavities (funded, in procurement)
  - Spare medium beta cryomodule ($3,500k)
  - Cryogenic test facility development ($900k)
  - Kinney pump ($200k)
  - Test cave water system improvements ($100k)
  - Horizontal test facility ($750k)
  - Cavity chemistry capability ($2,500k)
  - RF/controls/testing/commissioning ($250k)
- **Cryomodule re-work**
  - Two high beta and two medium beta cryomodules ($1,000k)

Other parameters are addressed by improvements to HVCMs, Ion Source, RF couplers and so on

- **Extend RF pulse length (HVCM)**
  - Pulse ripple reduction ($375k)
  - Controllers ($900k)
  - IGBT snubbers ($225k)
  - HVCM cooling ($300k)
  - Alternate topology ($750k)
- **Extend RF pulse length (Couplers)**
  - DTL RF couplers ($400k)
  - CCL RF couplers ($400k)
- **Increase peak current**
  - Antenna and ion source development ($250k)
- **Ring injection and stability improvements**
  - e-p instability damping systems development ($1,000k)
  - Laser stripping 10 μs demonstration ($500k)

The path to 1.4MW provides a strong foundation for an extension to ~3MW and a second target station



STS = Second Target Station

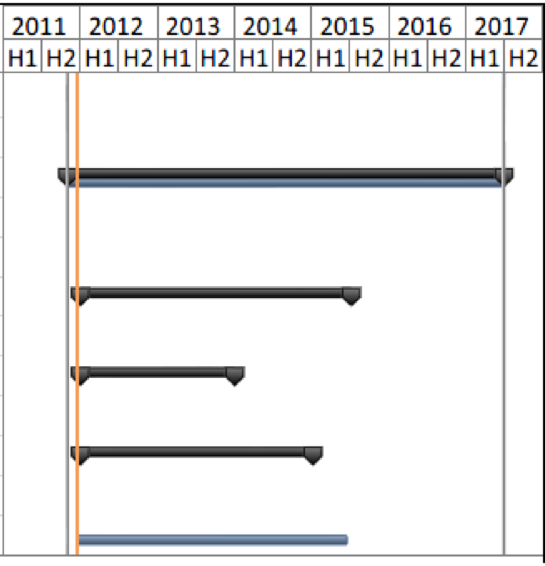
- STS does have CD-0
  - Plan is to move forward with the STS project in ~2017
  - The original PUP scope (energy increase to 1.3 GeV) becomes part of the STS project
  - The STS project includes a current upgrade
  - Investment in target engineering is also required

Conclusion

- It has been a year of successes and challenges
- 1 MW has been achieved in routine operation
- Availability has increased to 85% (YTD)
- Performance was limited in the last year by stripper foil issues and modulator failures that limited duty factor; both issues, we believe, have been mitigated
- Our focus now is on increasing availability and stabilizing operation at 1 MW
- These achievements are thanks to the hard work, dedication and talent of the SNS staff

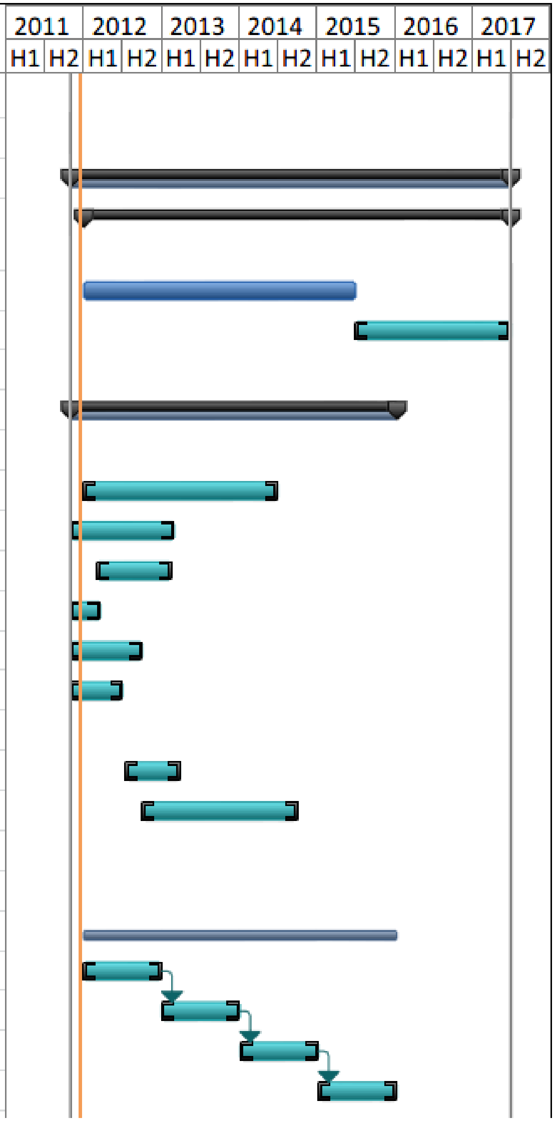
SNS Accelerator Systems 5 Year Plan for Operation at 1.4MW

Task Name	Duration	Start	Finish	Notes
SNS Accelerator Five Year Plan				Plan($16100K)
Beam Energy	1479 days	Tue 11/1/11	Fri 6/30/17	Plan($11000k)
High Voltage Modulators	917 days	Sun 1/1/12	Tue 7/7/15	Plan($2550k)
RF Systems	523 days	Sun 1/1/12	Wed 1/1/14	Plan($800k)
Ion Source	788 days	Sun 1/1/12	Wed 1/7/15	Plan($250k)
Ring Systems				Plan($1500k)



Accelerator 5 year Plan – Beam Energy

Task Name	Duration	Start	Finish	Notes
SNS Accelerator Five Year Plan				**Plan($16100K)**
Beam Energy	**1479 days**	**Tue 11/1/11**	**Fri 6/30/17**	**Plan($11000k)**
Improve High Beta SRF Cavity Performance	**1435 days**	**Mon 1/2/12**	**Fri 6/30/17**	**Plan ($2300k)**
Plasma Processing R&D	913 days	Mon 1/2/12	Wed 7/1/15	Plan ($1300k)
Plasma Process Cavities	523 days	Wed 7/1/15	Fri 6/30/17	Plan($1000k)
Cryomodule Rework	**1096 days**	**Tue 11/1/11**	**Tue 1/12/16**	**Plan ($8700k)**
Spare Hign Beta Cryomodule				Funded
Spare Medium Beta Cryomodule	652 days	Sun 1/1/12	Mon 6/30/14	Plan ($3500k)
CTF development	348 days	Tue 11/1/11	Thu 2/28/13	Plan AIP($900k)
Kinney pump	250 days	Mon 3/5/12	Fri 2/15/13	Plan ($200k)
Test cave water system improvement	100 days	Tue 11/1/11	Mon 3/19/12	Plan ($100k)
VTA	240 days	Tue 11/1/11	Mon 10/1/12	Funded
High Pressure Rinse	175 days	Tue 11/1/11	Sat 6/30/12	Funded
Two High Beta Test Cavities				Plan ($500k)
Horizontal Test Facility	185 days	Mon 7/16/12	Fri 3/29/13	Plan ($750k)
Cavity Chemestry	522 days	Mon 10/1/12	Tue 9/30/14	Plan ($2500k)
RF/Controls/Testing/Commissioning				Plan($250k)
Cryomodule Rework				**Plan($1000k)**
HB1	263 days	Sun 1/1/12	Tue 1/1/13	Plan($250k)
HB2	263 days	Wed 1/2/13	Fri 1/3/14	Plan($250k)
MB1	263 days	Mon 1/6/14	Wed 1/7/15	Plan($250k)
MB2	263 days	Thu 1/8/15	Mon 1/11/16	Plan($250k)



Accelerator 5 year Plan – HVCM, TF, Ion Source and Ring Systems

Task Name	Duration	Start	Finish	Notes
Accelerator 5 Year Plan				**Plan($16100K)**
High Voltage Modulators	**917 days**	**Sun 1/1/12**	**Tue 7/7/15**	**Plan($2550k)**
Pulse Ripple Reduction	263 days	Sun 1/1/12	Tue 1/1/13	Plan($375K)
Controller	392 days	Wed 1/2/13	Thu 7/3/14	Plan($900k)
IGBT Snubbers	263 days	Fri 7/4/14	Tue 7/7/15	Plan($225k)
HVCM Cooling	263 days	Sun 1/1/12	Tue 1/1/13	Plan($300k)
Alternate Topology	718 days	Sun 1/1/12	Tue 9/30/14	Plan($750k)
RF Systems	**523 days**	**Sun 1/1/12**	**Wed 1/1/14**	**Plan($800k)**
DTL RF Couplers	524 days	Sun 1/1/12	Wed 1/1/14	Plan ($400k)
CCL RF Couplers	524 days	Sun 1/1/12	Wed 1/1/14	Plan ($400k)
Ion Source	**788 days**	**Sun 1/1/12**	**Wed 1/7/15**	**Plan($250k)**
Antena Development	789 days	Sun 1/1/12	Wed 1/7/15	Plan($250k)
Ring Systems				**Plan($1500k)**
Laser Stripping				**Plan ($500k)**
HEBT Insert 10uS Demonstra	523 days	Mon 1/2/12	Wed 1/1/14	Plan ($500k)
e-P Instability				**Plan($1000k)**
Continued Development	902 days	Mon 1/2/12	Tue 6/16/15	Plan($1000k)