Accelerator Systems Overview and Plans

Stuart Henderson

Director

Research Accelerator Division

Research Accelerator Division

Mission: Enable world-class neutron science by operating and maintaining the SNS accelerator complex and the site at the highest level of

- Safety,
- Quality,
- Efficiency and
- Performance

The Research Accelerator Division contains all groups and technical systems necessary for

- generating neutrons in support of the science program:
  - Accelerator Systems
  - Target Systems
  - Site Utilities

  } The "Accelerator Complex"
- providing infrastructure support and services for the larger Chestnut Ridge complex

Research Accelerator Division

Stuart Henderson, Division Director

Jim Lawson, Deputy Division Director and Facility Complex Manager

Accelerator Physics
J. Galambos
Group Leader

Accelerator Operations
G. Dodson
Group Leader

Control Systems
K. White
Group Leader

Site Services
T. McLaughlin
Group Leader

CM and SRF Engineering
J. Mammosser
Manager

Computing Integration
B. Mase
Group leader

Cryo Systems
F. Casagrande
Group Leader

Electrical Systems
R. Cutler
Group Leader

Beam Instrumentation
S. Assadi
Group Leader

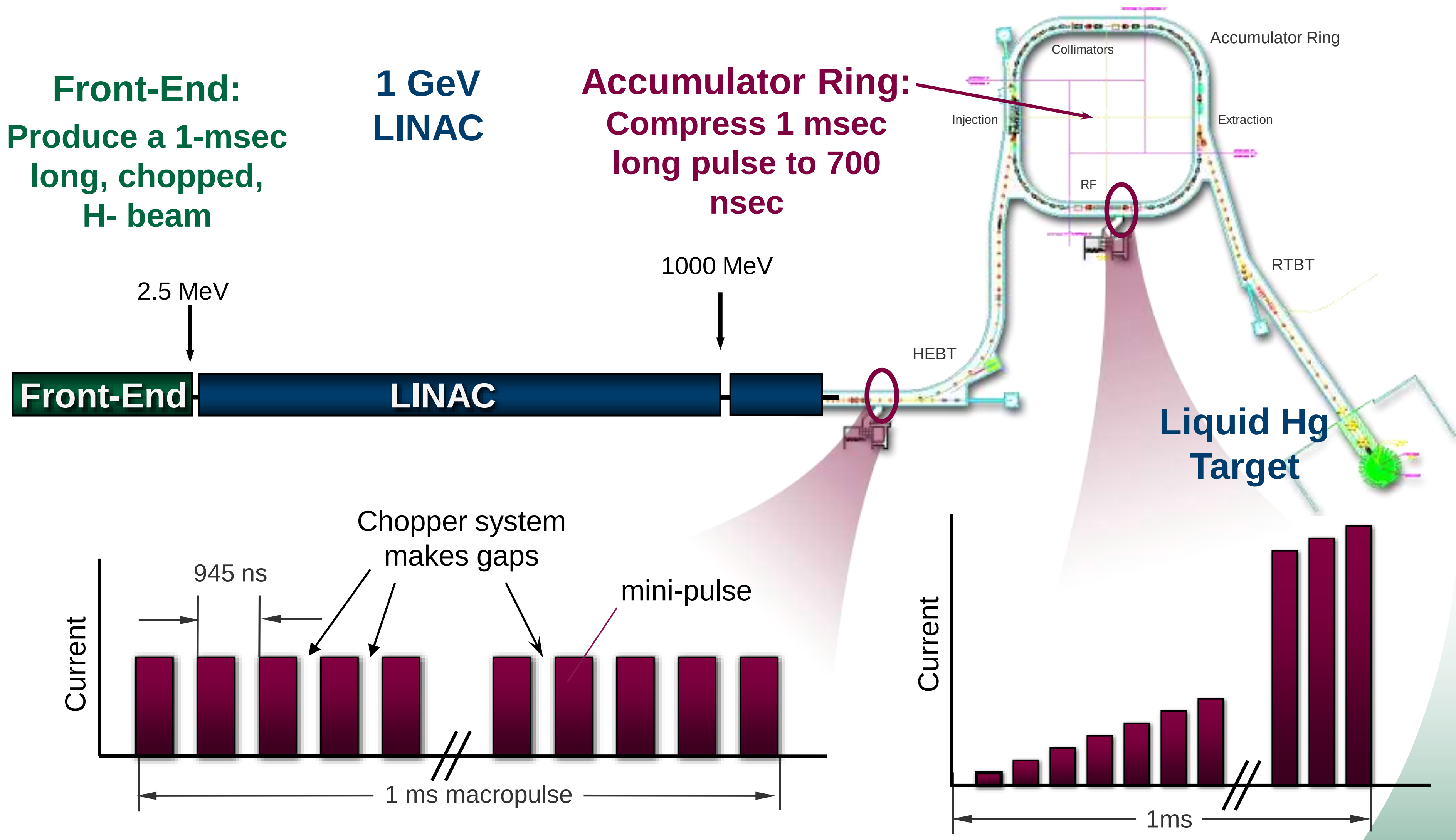
Mechanical Systems and Installation
T. Hunter
Group Leader

Radio-frequency Systems
T. Hardek,
Group Leader

Target Systems
J. Forester
Group Leader

Ion Source
M. Stockli
Group Leader

SNS Accelerator Complex



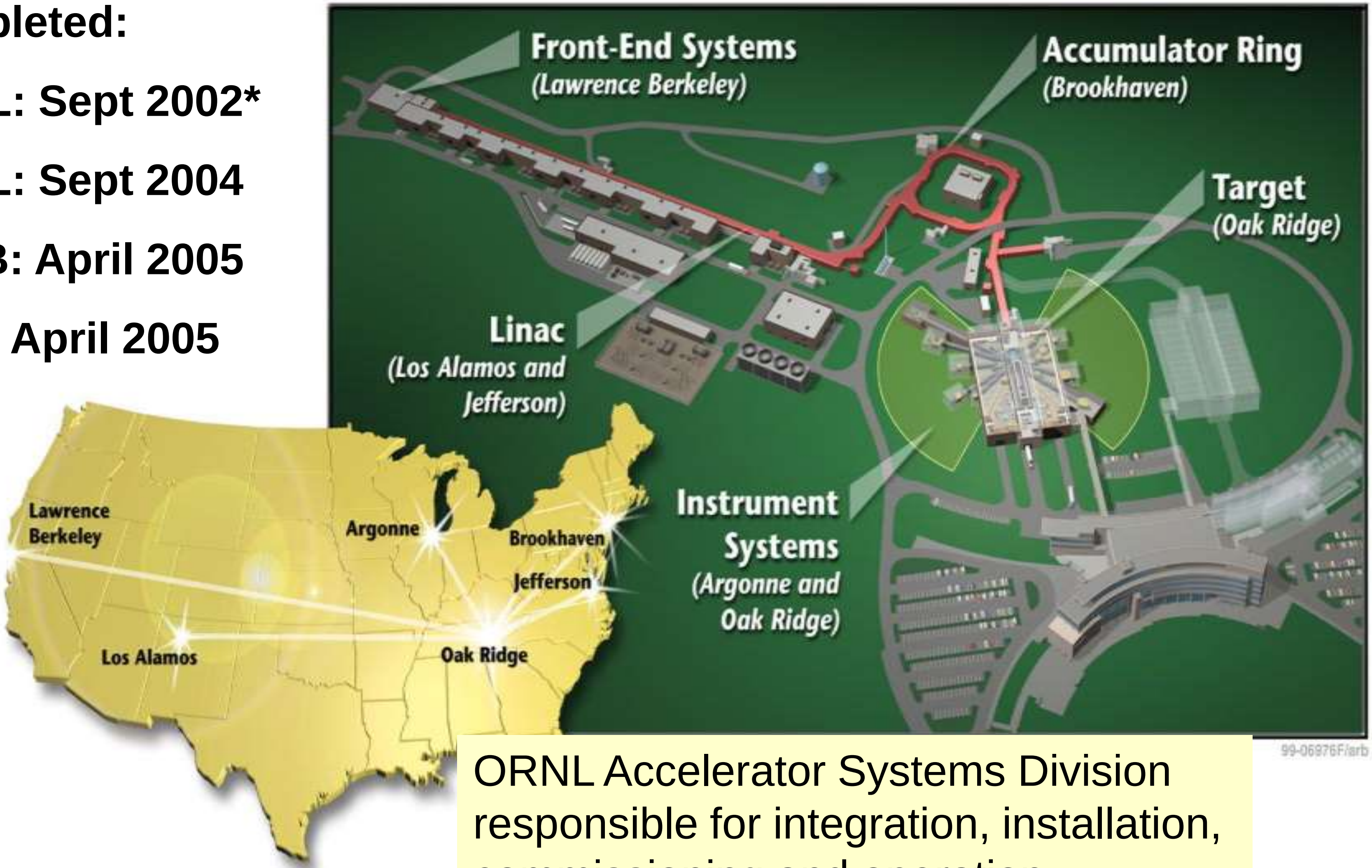
SNS Design Parameters

Kinetic Energy	1.0 GeV
Beam Power	1.4 MW
Linac Beam Duty Factor	6%
Modulator/RF Duty Factor	8%
Peak Linac Current	38 mA
Average Linac Current	1.6 mA
Linac pulse length	1.0 msec
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

The SNS Partnership During Construction

Partner lab obligation completed:

- **LBNL: Sept 2002***
- **LANL: Sept 2004**
- **JLAB: April 2005**
- **BNL: April 2005**



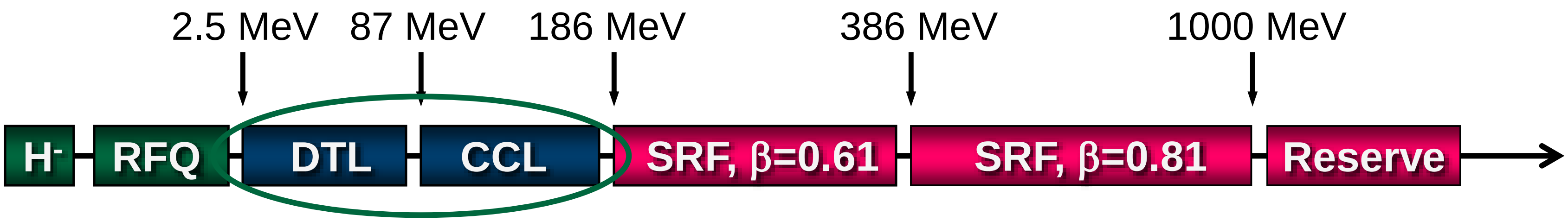
ORNL Accelerator Systems Division responsible for integration, installation, commissioning and operation

SNS Linear Accelerator

Front-end designed and built by Lawrence Berkeley National Laboratory

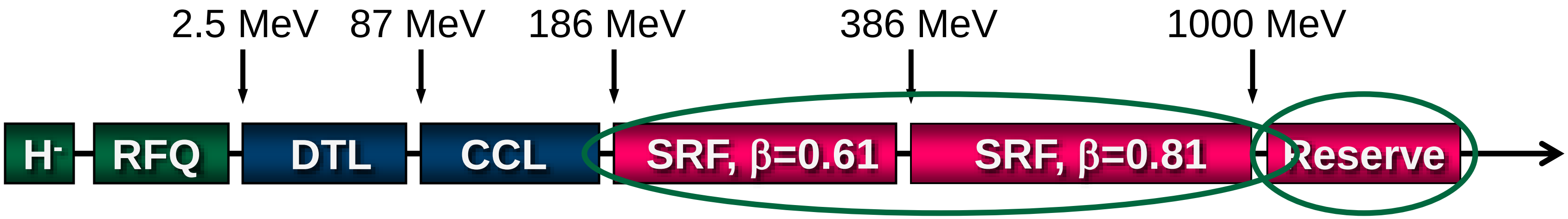
- **Multicusp Cs-enhanced volume production H- ion source**
- **Electrostatic LEBT (Low-energy beam transport)**
- **Chopping of 65 keV beam in LEBT and 2.5 MeV beam in MEBT**
- **402.5 MHz RFQ with 2.5 MeV output energy**
- **Front-end design parameters:**
  - **38 mA peak current**
  - **68% beam-on chopping**
  - **1.0 msec, 60 Hz, 6% duty**
  - **1.6 mA average current**

SNS Linear Accelerator



- **SNS linac is the world's highest energy proton/H- linac**
- **SNS linac architecture consists of**
  - **Conventional normal conducting structures to 186 MeV**
  - **Superconducting structures to 1 GeV**
- **Normal conducting linac was designed and built by Los Alamos National Laboratory**
- **DTL system consists of 6-tanks, each powered by 2.5 MW, 402.5 MHz klystron**
- **CCL system consists of 4 modules, each powered by a 5 MW, 805 MHz klystron; 12 segments form a module**

SNS Linear Accelerator



- **World's first high-energy superconducting linac for protons**
- **Cryomodules designed and built by Jefferson Laboratory**
- **Two cavities geometries, (β_g=0.61, 0.81) are used to cover broad range in particle velocities**
- **SCL consists of 81 independently-powered 805 MHz cavities, each driven by a 550 kW klystron, in 23 cryomodules**
- **Space is reserved for additional cryomodules to give 1.3 GeV**
- **He plant supports operation at 4 or 2 degrees K**

Linac RF Systems

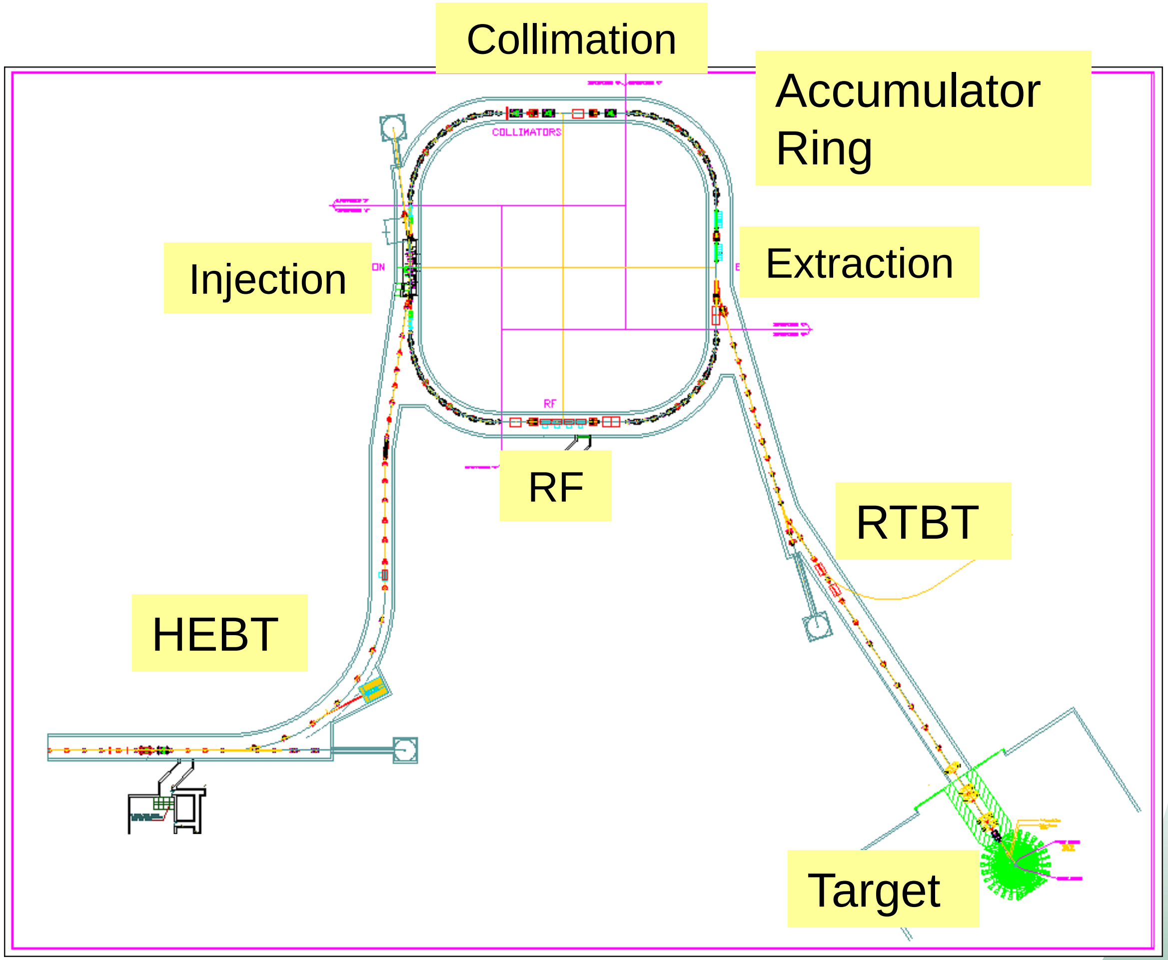
- **Designed by Los Alamos Nat. Lab**
- **All systems 8% duty factor: 1.3 ms, 60 Hz**
- **7 DTL Klystrons: 2.5 MW 402.5 MHz**
- **4 CCL Klystrons: 5 MW 805 MHz**
- **81 SCL Klystrons: 550 kW, 805 MHz**
- **14 IGBT-based modulators each providing 1 MW average power**
- **Digital RF controls with feedback and feedforward**

- **2nd largest klystron and modulator installation in the world!**

Accumulator Ring and Transport Lines

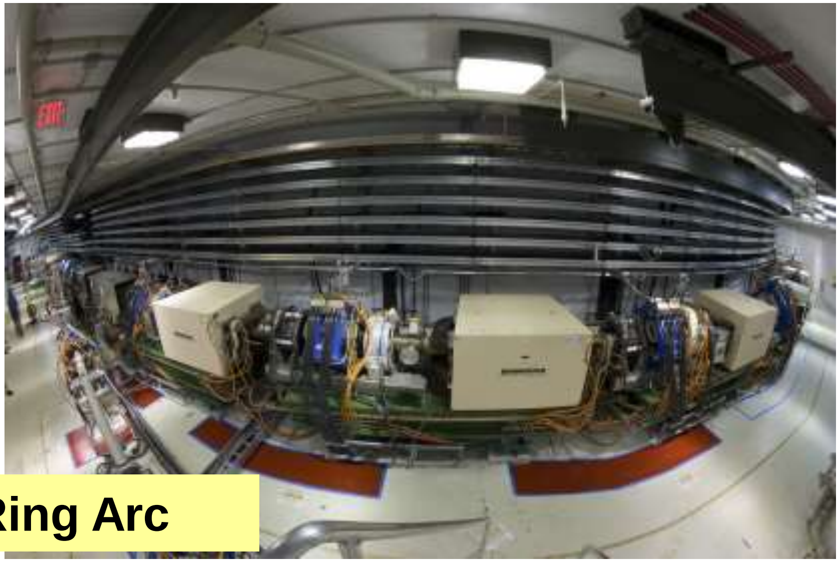
- **Designed and built by Brookhaven National Lab**
- **Accumulates a 1-msec long linac pulse by multi-turn charge exchange injection (H- injection)**

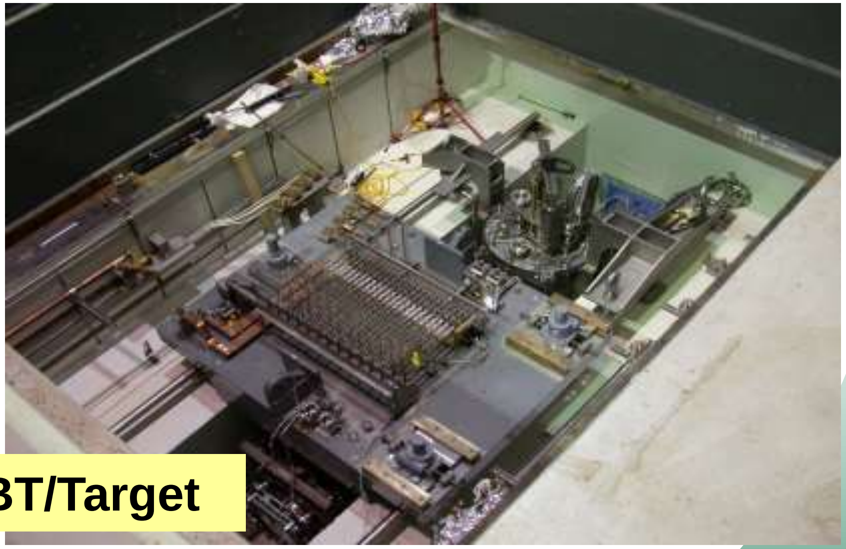
Circum	**248 m**
Energy	**1 GeV**
f_{rev}	**1 MHz**
Q_x, Q_y	**6.23, 6.20**
Accum turns	**1060**
Final Intensity	**$1.5x10^{14}$**
Peak Current	**52 A**



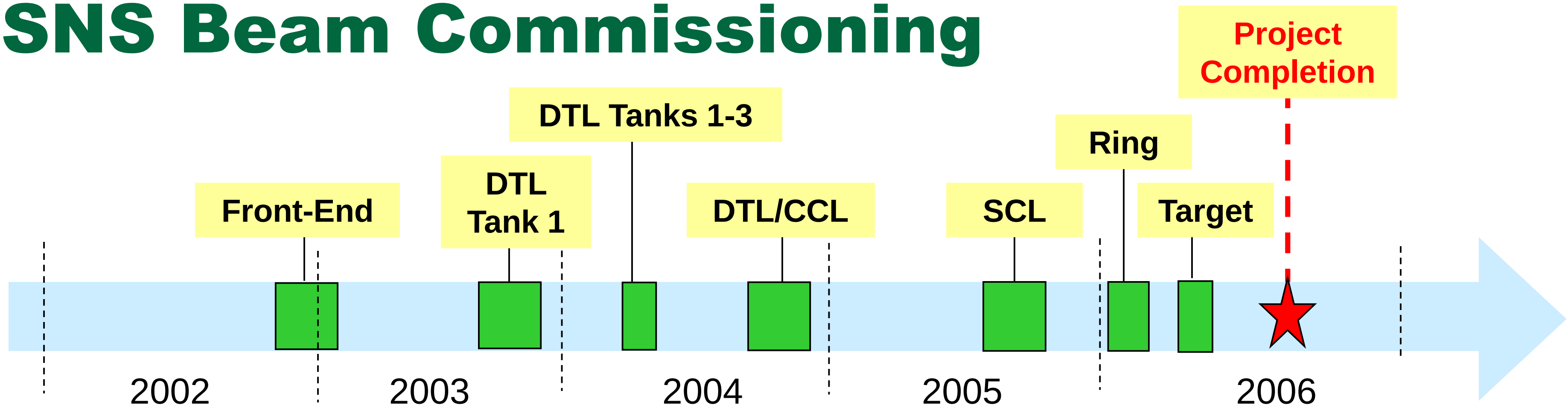
OAK RIDGE
National Laboratory

Ring and Transport Lines

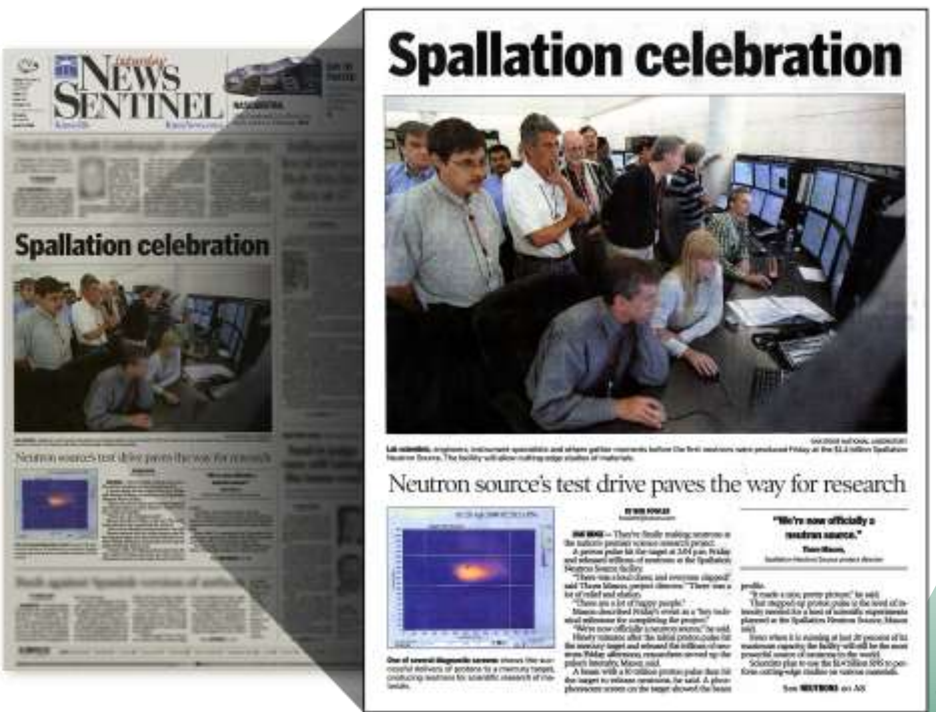




SNS Beam Commissioning



- **First Beam on Target, First Neutrons and Technical Project Completion goals were met April 28, 2006**
  - **10^{13} protons delivered to the target**
  - **Neutron flux goals exceeded**
- **The SNS Construction Project was formally Completed in June 2006**


News Sentinel

Spallation celebration

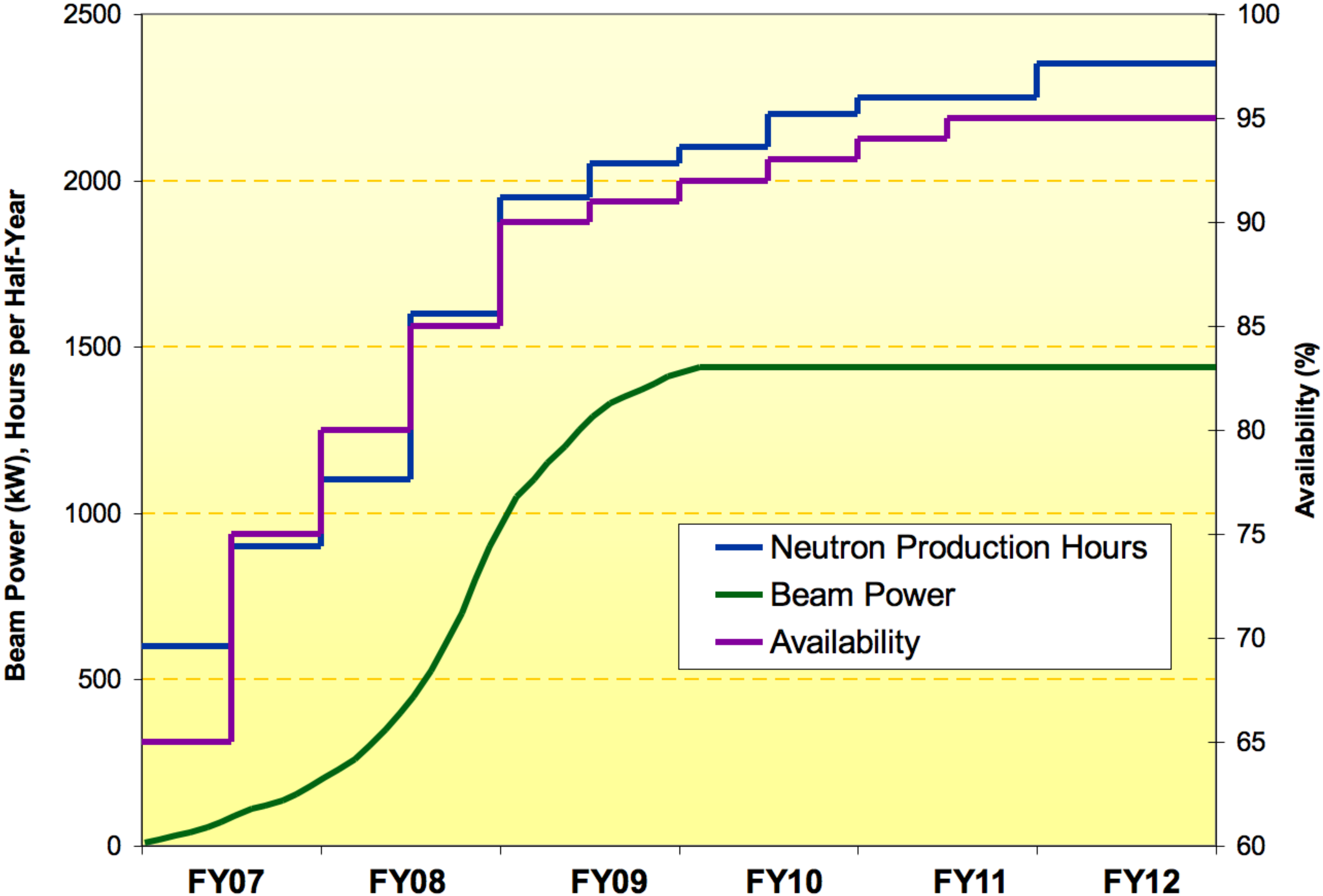
Neutron source's test drive paves the way for research

"We're now officially a neutron source."

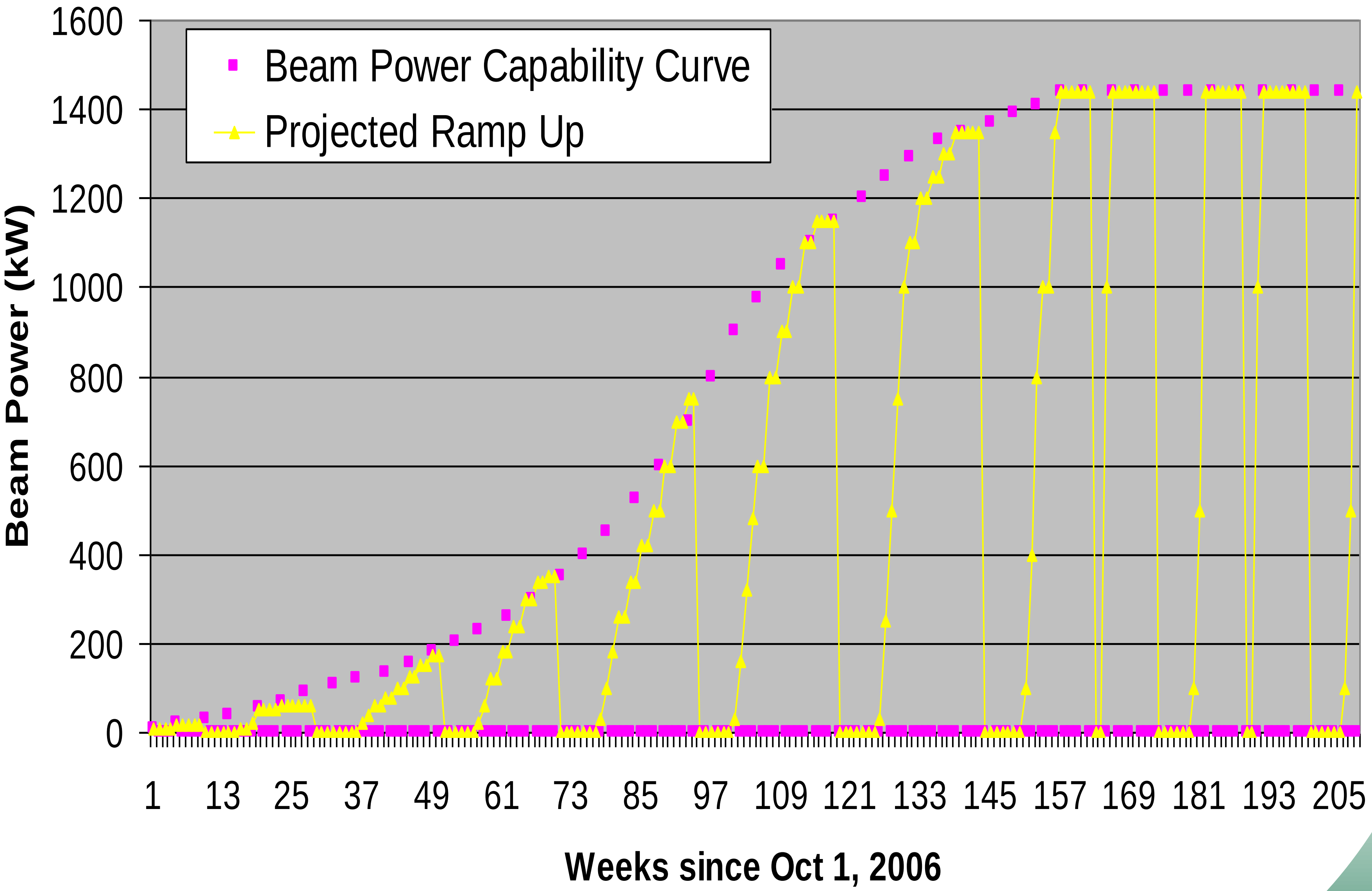
SNS Ramp Up Plan Goals

- Following the successful completion of the construction project and commissioning of the accelerator complex, we immediately turned our attention to ramping-up the performance to the design capability
- The goal is to reach the design capability at the end of a three-year ramp-up period, which started October 1, 2006
  - 1.4 MW beam power
  - 5000 hours of operation per year
  - >90% availability (hours of neutron production delivered/hours scheduled)

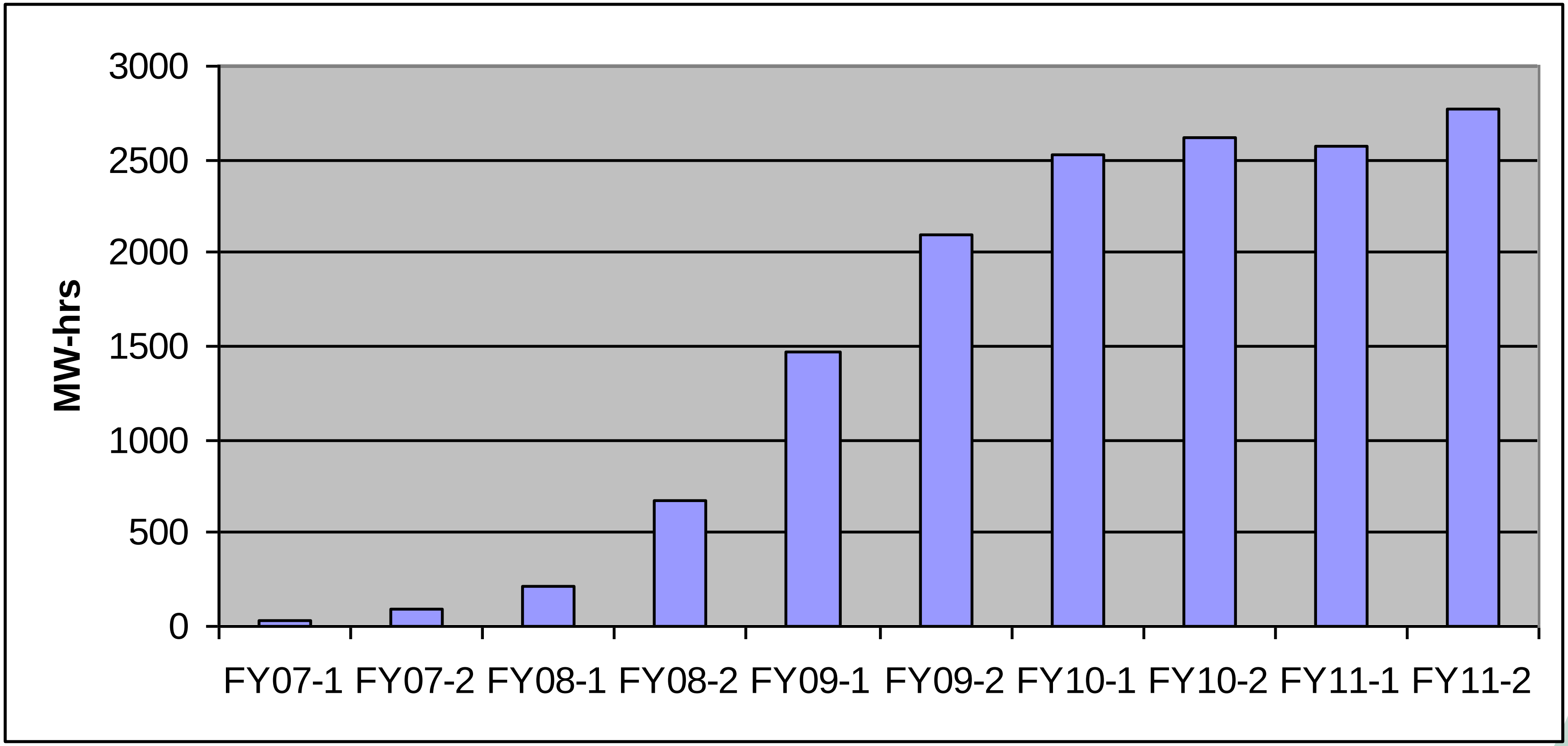
Ramp Up to SNS Design Capability



Beam Power Ramp Up Plan



Integrated Beam on Target Commitment by Half Year

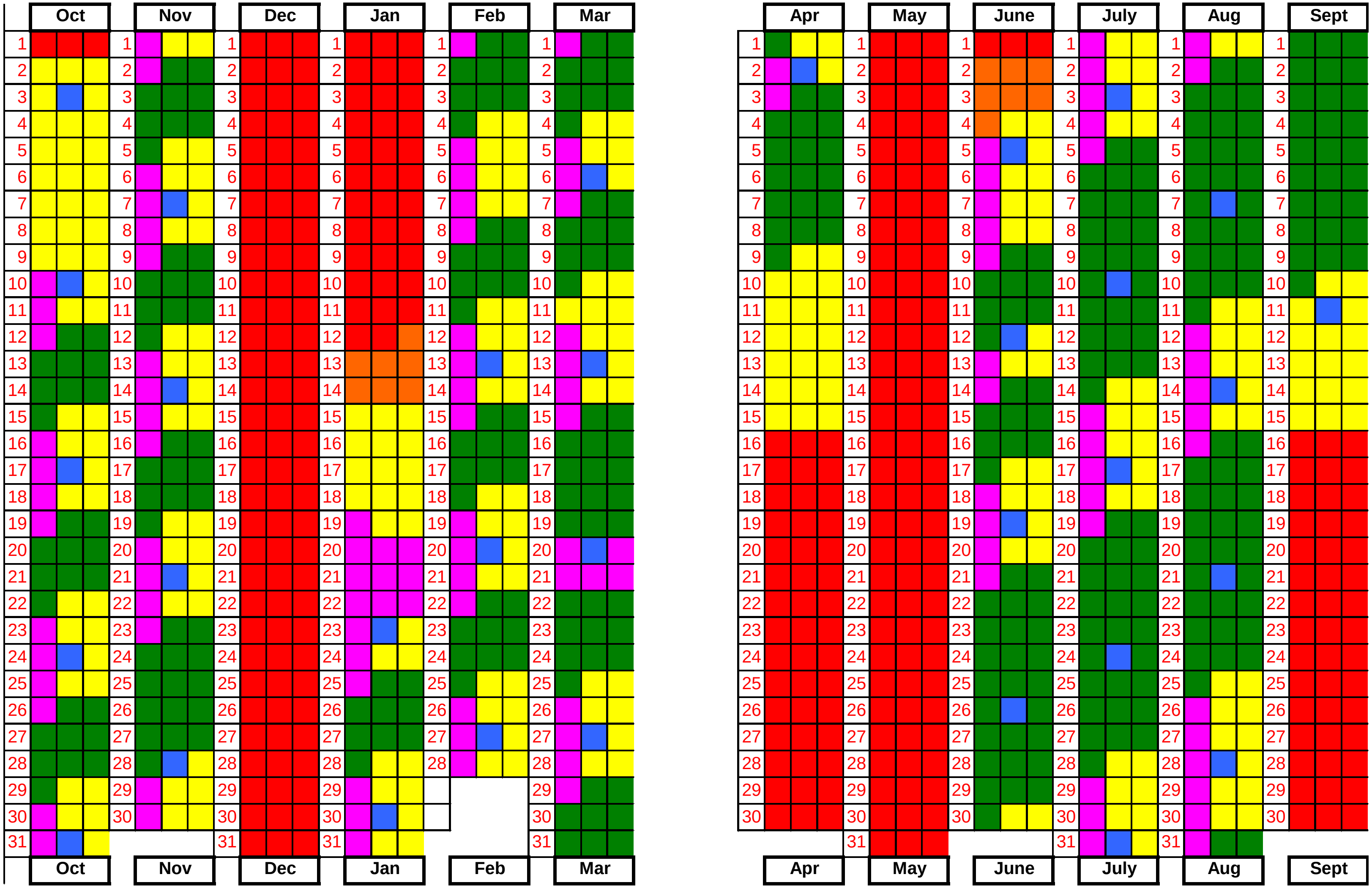


Summary of Performance Goals

	Availability (%)	Neutron Production Hours	Total Operating Hours	Integrated Beam Power Commitment [MW-hrs]
FY07	75	1500	3500	117
FY08	82.5	2700	4000	887
FY09	90.5	4000	5000	3575
FY10	92.5	4300	5000	5133
FY11	94.5	4500	5000	5350

Integrated Beam Power Commitment is 80% of the Internal Goal

FY07 Operations Schedule



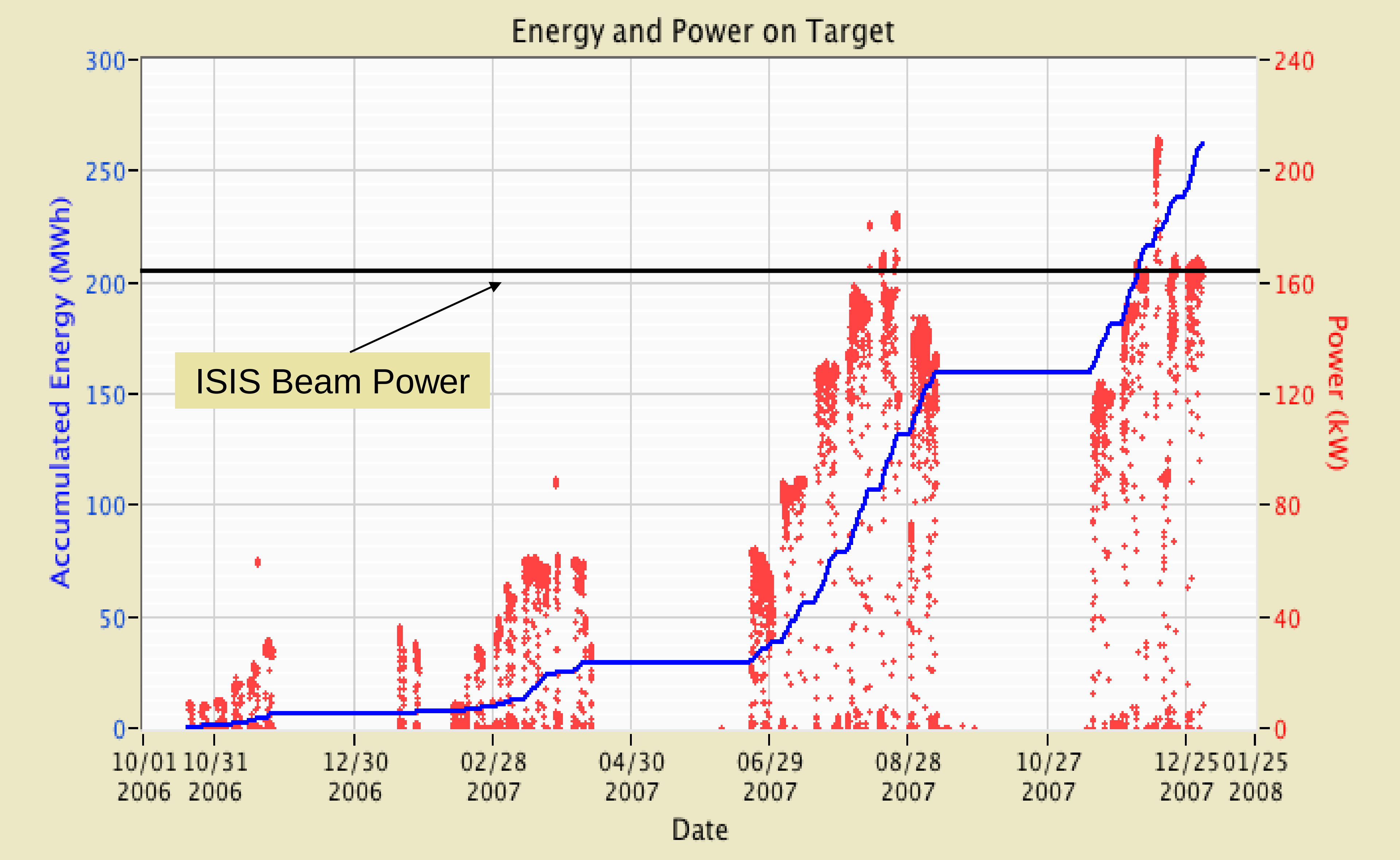
Run 2007-1

Run 2007-2

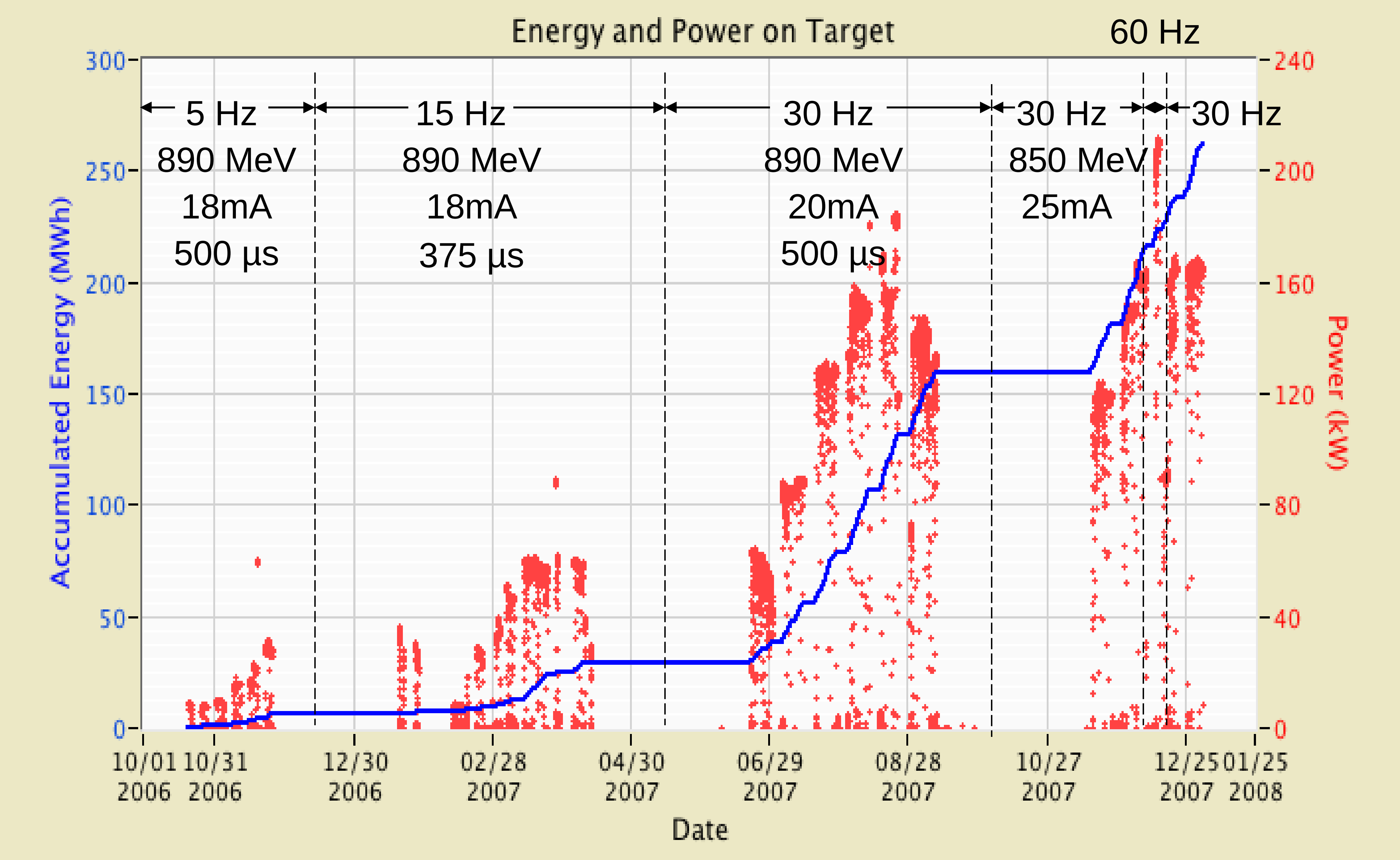
Run 2007-3

- Accelerator Physics
- Accelerator Physics Option
- Accelerator Startup (RF)
- Machine Downtime Major Periods(Maintenance/Upgrades)
- Machine Downtime Periods Weekly Maintenance Option
- Neutron Production

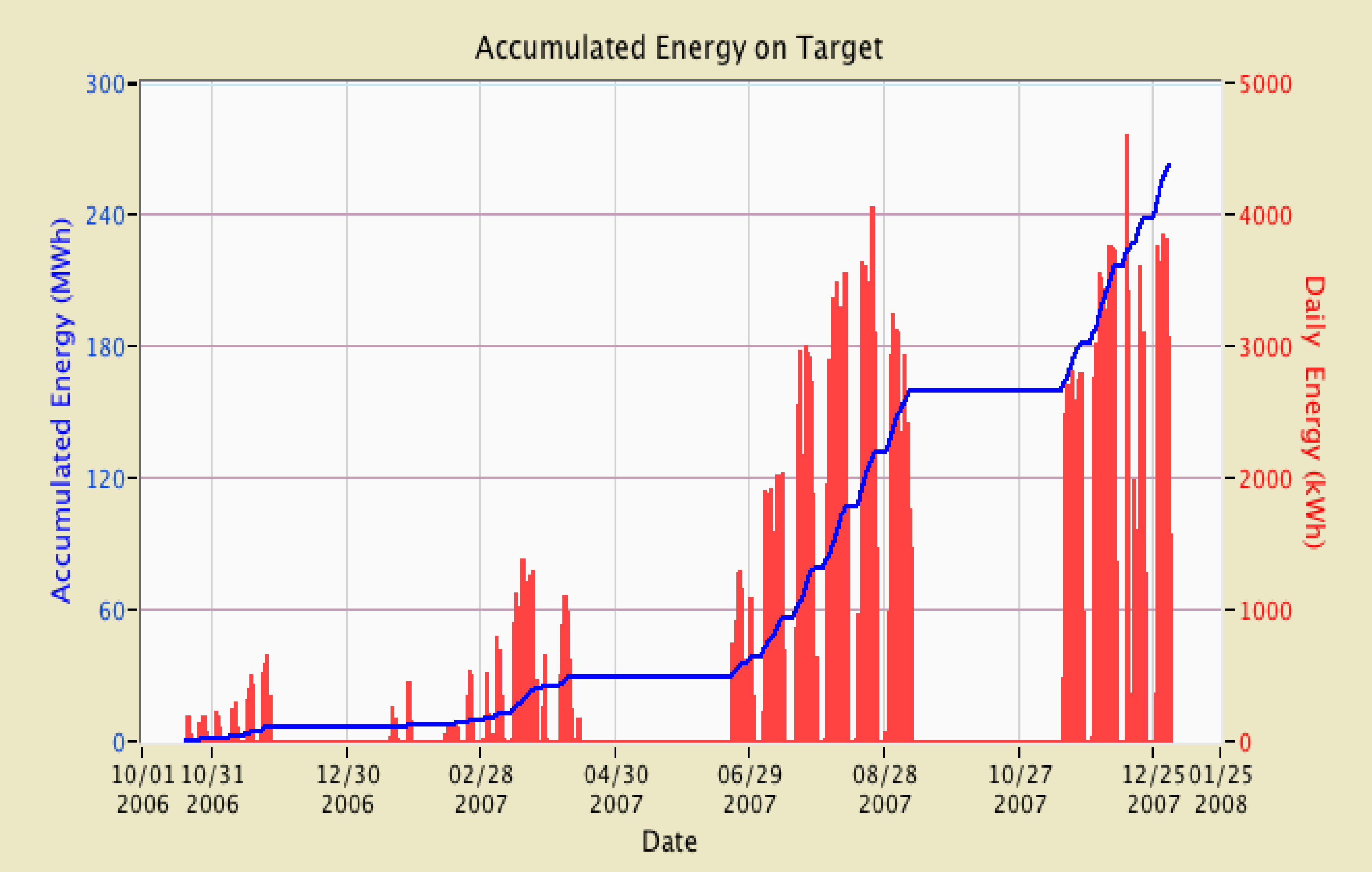
Beam Power History Since October 2006



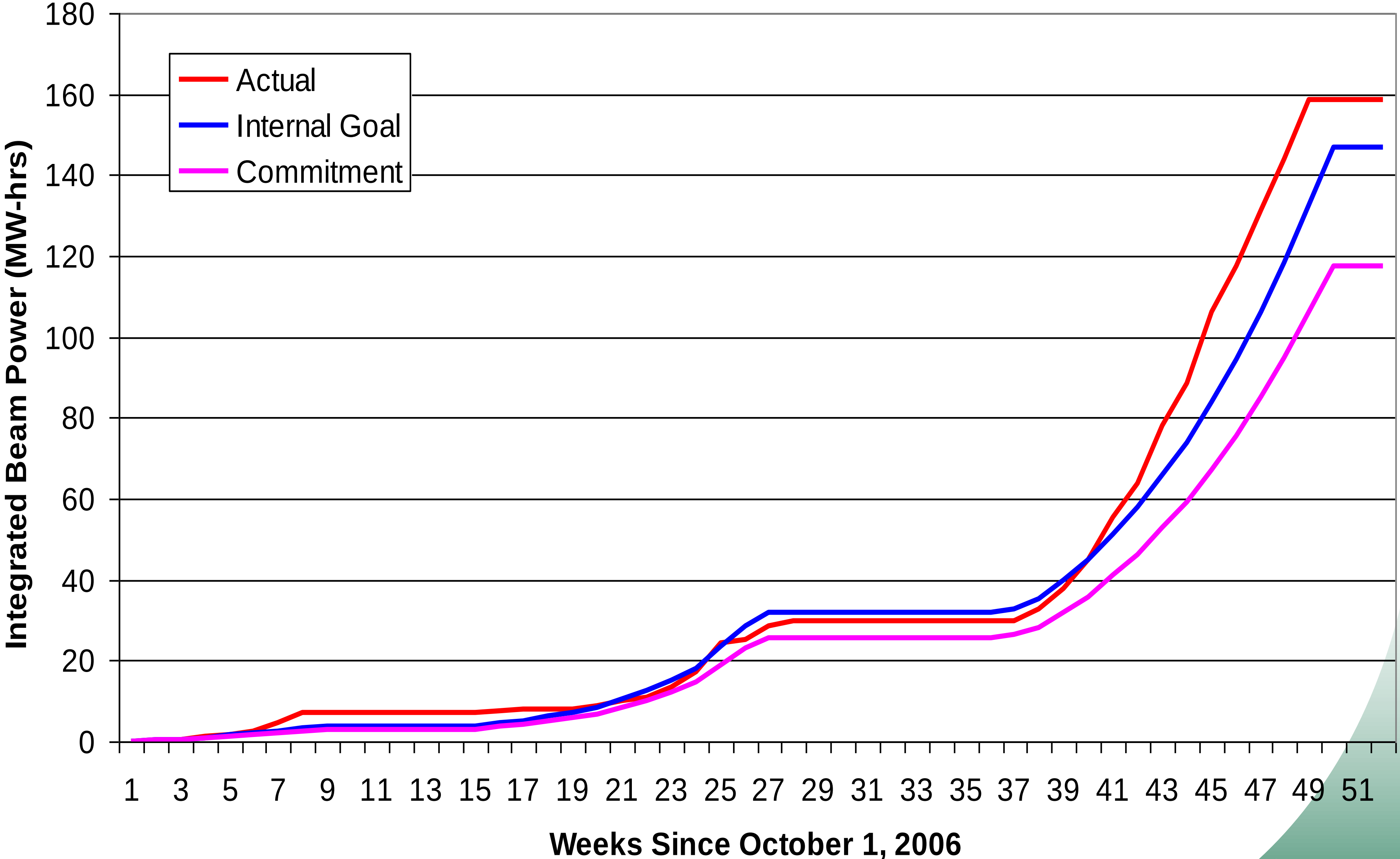
Beam Power History Since October 2006



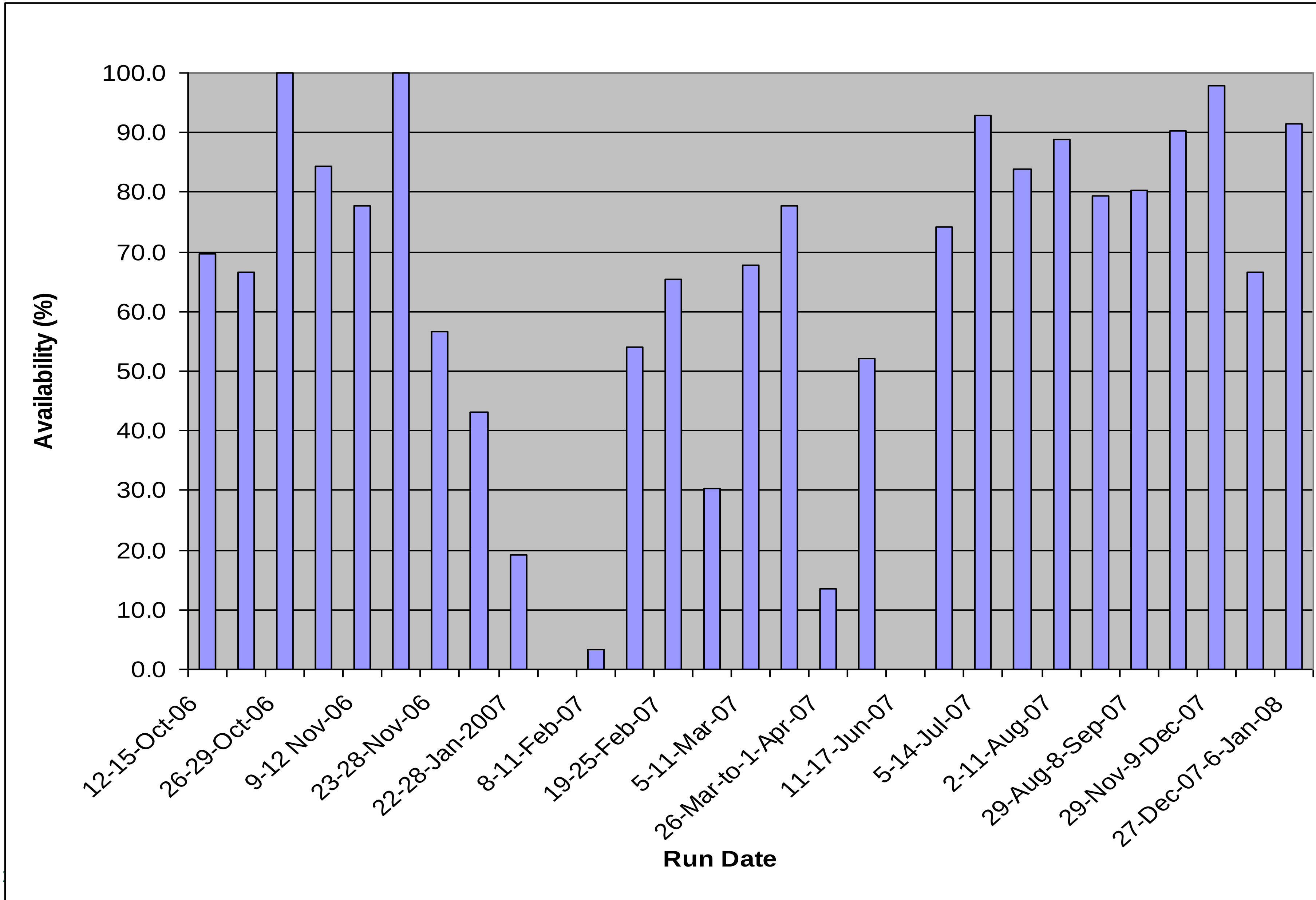
Integrated Beam Power History Since October 2006



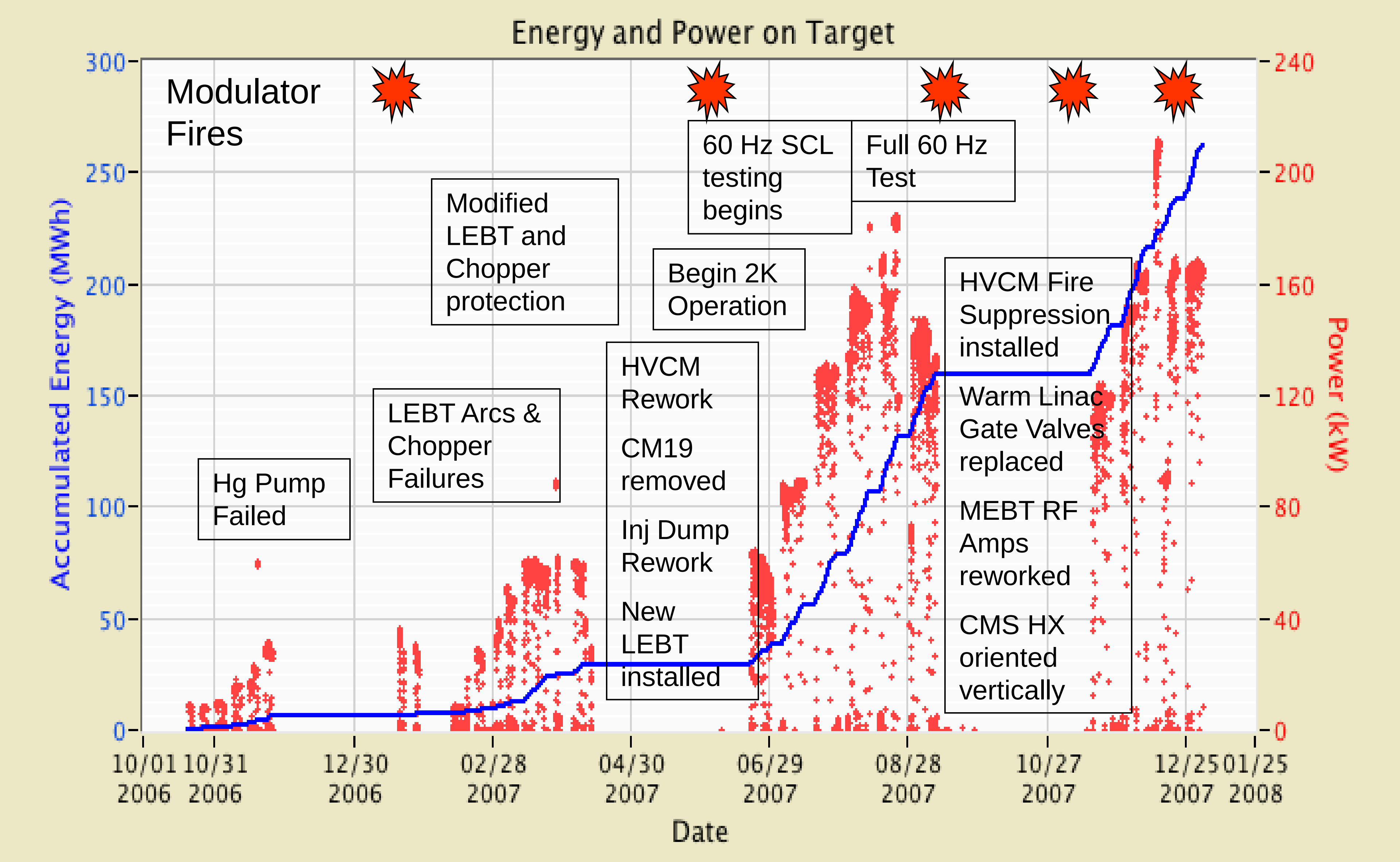
FY07 Integrated Beam Power Performance



Beam Availability (Hours Delivered/Hours Scheduled Neutron Production)



Significant Events



Challenges: Ion Source and LEBT

- **Low-Energy Beam Transport and Chopper Systems**
  - Excessive LEBT arcing destroyed LEBT chopper pulser electronics due to inadequate protection
  - Dominated downtime for 2007
  - Crash program improved chopper protection and reduced arc rate with new LEBT design and has solved this problem
- **Ion Source**
  - It has been difficult to routinely achieve the peak current required in the ramp-up
- **Risk to Ramp-Up: Ion source/LEBT may not provide required current with good reliability at high duty factor**
- **Mitigation:**
  - We have been pursuing a very aggressive testing program on the Ion Source Test Stand to
    - Further develop the baseline source and its operation (cesiation recipes, optimized outlet geometry, …)
    - Develop an external antenna source
    - Develop an external Cs reservoir system
    - Develop and prove electrostatic LEBT modifications
  - We are developing a magnetic LEBT to replace the electrostatic LEBT

Challenges: High Voltage Converter Modulators

- **At Project Completion**
  - NC Linac modulators operated routinely at 30 Hz
  - one SCL modulator had been modified (from baseline configuration) to operate at 60 Hz for 24 hours
- **In the last year we have implemented a number of improvements to allow operation at 60 Hz and to improve reliability**
  - enabled first tests of modulators and SCL at 60 Hz beginning in June 2007; first full 60 Hz test in August
- **Some modulator component failures have resulted in fires**
  - Installed $C0_2$ fire suppression system on each modulator
  - Program underway to rid modulators of combustible material and provide higher engineering margin
  - Modulators are dominating the downtime in FY2008
- **Risk: Poor availability at 60 Hz and/or high duty factor**
  - Due to target lifetime issues, beam power is limited to ~200 kW at 30 Hz! It is essential that we achieve routine 60 Hz operation to remain on-track
- **Mitigation:**
  - Two HVCM Accelerator Improvement Projects in progress: i) 60 Hz capability and reliability improvements, ii) HVCM Fire Mitigation
  - Modulator Test-Stand is nearing completion
  - Subcontract with SLAC to develop modulator utilizing higher-power IGBTs

Challenges: Superconducting Linac Cavity and Cryomodule Performance

- During SNS construction, 35 cavities (of 81) were tested at JLAB prior to installation
- At project completion
  - 11 (of 81) cavities were off-line in routine operation
  - All cavities had been tested up to 10 Hz
  - We had great concern with our ability to operate at repetition rates > 15 Hz
  - We had no local facilities for working on or testing cryomodules outside of the tunnel
- Since then we have
  - Constructed and commissioned an SRF Test Facility (Cleanrooms, RF test Cave, High power test stand, Cryogens tie-in to Central Helium Liquifier)
  - Regained use of 8 Cavities
  - Removed CM19 from the tunnel, repaired an inoperable cavity which required beamline intervention, successfully tested in test cave and met specification
- The linac output energy is 850 MeV due to
  - Six cavities unavailable to accelerate beam (one CM removed, 2 installed cavities inoperable)
  - High-beta cavities are operating on average ~2 MV/m below specifications
- Risk: Linac output energy will not reach 1 GeV
- Mitigation:
  - We are pulling the poorest performing CM to use as a test-bed for surface processing methods
  - We plan to increase the gradients of installed cavities by surface processing
  - We are manufacturing spare cryomodules to allow “change-out” of weaker CMs that will be reworked

Challenges: Beam Loss Management

- The SNS is a loss-limited accelerator; losses must be kept < 1 W/m to limit residual activation
- We measure higher than expected losses in the Ring Injection Region:
  - Due to a design oversight, we cannot simultaneously transport both waste beams cleanly to the injection dump while properly accumulating in the ring
  - An intensive program of measurements and simulations explained the problem; solution requires reworking Idmp line
  - We performed the first phase of rework in April 2007; next phase will be carried out in Feb down
- Other hot-spots
  - SC linac: longitudinal tails/halo outside SC acceptance
  - Injection straight in ring downstream of stripper foil
  - Extraction region due to lack of fast MEBT chopper
- Losses in most of the remaining portions of the accelerator are in line with expectations
- Active and aggressive accelerator physics studies have allowed increase in beam power with acceptable losses
- Risk: Losses will impede ramp-up progress
- Mitigation:
  - Accelerator Physics time built into schedule
  - Very comprehensive set of beam diagnostics to aid in understanding beam dynamics
  - Extensive online and offline modeling capabilities utilizing SNS design tools (ORBIT, PARMILA, IMPACT, …)

Other Challenges: Accelerator Improvement Projects

Integrated Beam Power Ramp Up Plan

- **Due to the complexities of the performance limitations and the upgrades required to address them, we have chosen to organize the ramp-up campaign as a project**
- **This plan contains ?? upgrade tasks**
- **The plan is expected to evolve as we continue to gain operational experience**


SNS 00000000-0000-R00

Beam Power Ramp-Up Plan
DRAFT

April 2007

Performance Highlights

- We are the world's highest power pulsed spallation neutron source
- We operate the highest energy proton/H- linac
  - Achieved design beam energy in 1.01 GeV demonstration run
- "Brightest" spallation neutron source: highest single pulse intensity, 6 kJ/pulse
- World Record proton intensity accumulated and extracted from a storage ring: 1.1×10^{14} protons
- Routine operation at 200 kW

Conclusion

- **It has been an incredible 1 ½ years since project completion**
  - **1 ½ years ago we were delivering 2 kW with 5 Hz operation**
  - **We are now the world's highest power pulsed spallation neutron source delivering 200 kW routinely with 60 Hz operation**
- **This progress has required extensive efforts on all fronts, from the Ion Source to the Neutron Moderators**
- **We are on-track with our plans for ramping-up the beam power, availability and operating hours**
- **We need your advice on several critical technical issues**

Our Success is Due to the Talent, Hard Work and Dedication of the SNS Staff!

Outline

1. **Organization (2)**
   - **Mission, Scope**
   - **Org Chart**
2. **Overview of Accelerator Complex (5)**
3. **History, Construction and Commissioning (3)**
4. **Ramp-Up Plan (4)**
5. **Performance to date (4)**
6. **Challenges, Risks and Mitigation Plans (8)**

Performance Limitations: Equipment Reliability

- **Low-Energy Beam Transport and Chopper Systems**
  - We were plagued with excessive LEBT arcing which destroyed LEBT chopper pulser electronics due to inadequate protection in original design
  - Crash program to improve chopper protection and reduce arc rates has solved this problem
  - New, more robust, LEBT chopper design is nearing completion
- **High-Voltage Converter Modulators**
  - At project completion one SCL modulator had been operated at 60 Hz for 8 hours, after replacement of a number of components
  - In the last year we have performed a number of improvements to allow operation at 60 Hz:
  - Replace chokes, step-up transformers, added fault

Performance Limitations: Equipment Reliability

- Beam Chopper Systems
  - Repeated failures in LEBT chopper system due to HV arcs in electrostatic LEBT assembly
  - Original design did not include adequate Crash program to improve chopper protection and reduce arc rate was successful (Feb-May 2007)
  - New, more robust, LEBT chopper design is nearing completion
- High-Voltage Converter Modulators
  - A number of weak components limited MTBF to ~2700 Hrs
  - Began upgrade program for better fault detection, replacement of components with higher engineering margin, (FY07 AIP)
- Cooling Water Systems

Performance Limitations: Equipment Reliability

- Ion Source
  - Antenna failures
  - Improving monitoring and strengthening control system interlocks
- Cryogenic Moderator System Refrigerator
  - Thermal capacity degrades with time -- requires cycling every 30 days
  - we have not yet formally accepted the system
  - we are working with vendor to resolve performance issues
- Mercury Pump
  - Seal failed Nov. 26
  - Will replace pump in Feb/Mar 2008 downtime

Performance Limitations: Repetition Rate

High Voltage Converter Modulators

- At present, we can operate
  - normal-conducting linac modulators at full 8% duty (60 Hz, 1.4 msec)
  - Superconducting linac modulators at 4% duty (30 Hz, 1.4 msec)

Superconducting Linac

- Only 35 Cavities were tested at Jefferson Lab at 60 Hz
- We are operating with 11 unpowered SC cavities (out of 81), delivering a beam energy of 880 MeV
- 6 of those 11 cavities were turned off as a conservative measure in order to confidently operate at higher rep-rates (15 Hz)
  - Driven by concern over potential Higher-Order-Mode feedthrough failures; certain cavities show HOM waveforms that indicate pathological behaviour
- We are making use of the inherent flexibility in the SCL design to “tune around” unpowered cavities
- We are establishing cryomodule repair, maintenance and testing capabilities on-site (AIP Project)

Performance Limitations: Beam Power

Beam Losses

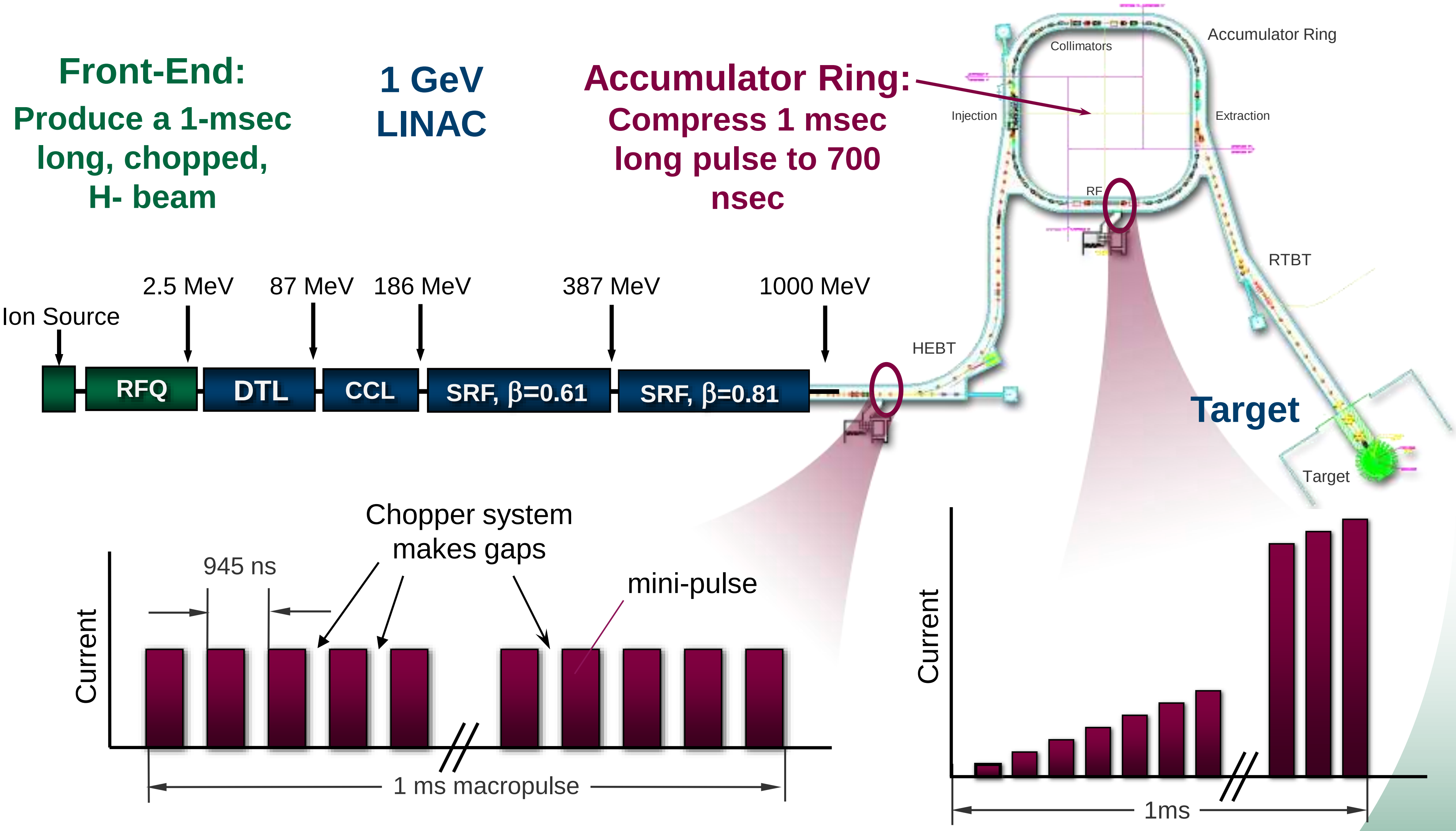
- The SNS is a loss-limited accelerator; losses must be kept < 1 W/m to limit residual activation
- We continuously monitor activation levels as the beam power is increased
- We measure higher than desired losses in the Ring Injection Region:
  - We are unable to simultaneously transport waste beams (from stripping process) to the injection dump and properly accumulate in the ring
  - We have continued operating by reducing beamsize on the foil
  - An intensive program of measurements and simulations has revealed weaknesses that are being addressed in this maintenance period
- Active and aggressive accelerator physics studies have reduced losses and activation while allowing increased beam power
- Losses in most of the remaining portions of the

SNS Accelerator Complex

Front-End:
Produce a 1-msec long, chopped, H- beam

1 GeV LINAC

Accumulator Ring:
Compress 1 msec long pulse to 700 nsec



Summary of Beam Parameters Achieved in Commissioning (by July 1, 2006)

Parameter	Baseline/ Design	Achieved	Units
Linac Transverse Output Emittance	0.4	0.3 (H), 0.3 (V)	π mm-mrad (rms,norm)
CCL1 bunch length	3	4	degrees rms
Linac Peak Current	38	> 38	mA
Linac Output Energy	1000	952	MeV
Linac Average Current	1.6	1.05 (DTL1 run) 0.004 (SCL)	mA
Linac H-/pulse	$1.6x10^{14}$	$1.0x10^{14}$	Ions/pulse
Linac Pulse length/Rep-rate/Duty Factor	1.0/60/6.0	1.0/60/3.8 (DTL1 run) .050/1/.005 (CCL run) 0.85/0.2/0.017 (SCL)	msec/Hz/%
Protons/pulse on Target	$1.5x10^{14}$	$5x10^{13}$	Protons/pulse
Repetition Rate	60	1	Hz
Beam Power	1440	5	kW

Beam Power History Since October 2006