RECENT OPERATIONAL EXPERIENCE AT THE LANSCE FACILITY*

L. Rybarcyk#, Los Alamos National Laboratory, Los Alamos, NM 87545, U.S.A.

Abstract

The Los Alamos Neutron Science Center (LANSCE) consists of a pulsed 800-MeV room-temperature linear accelerator and an 800-MeV accumulator ring. It simultaneously provides H^+ and H^- beams to several user facilities that have their own distinctive requirements, e.g. intensity, chopping pattern, duty factor, etc.. This multi-beam operation presents challenges both from the standpoint of meeting the individual requirements but also achieving good overall performance for the integrated operation. Various aspects of more recent operations including the some of these challenges will be discussed.

INTRODUCTION

LANSCE is a multi-user, multi-beam facility that produces intense sources of pulsed, spallation neutron and proton beams in support of US national security and civilian research. It comprises a pulsed 800-MeV room temperature linear accelerator and 800-MeV proton storage ring and has been in operation for over 35 years. It first achieved 800-MeV beam on June 9, 1972. The facility, formerly known as LAMPF, routinely provided an 800 kW beam for the meson physics program. Presently, the LANSCE user facilities include:

- Proton Radiography (pRad) which provides high resolution, time-sequenced radiographs of dynamics phenomena,
- Weapons Neutron Research (WNR) that provides a source of unmoderated neutrons in the keV to multiple MeV range,
- Lujan which uses the proton storage ring (PSR) to create an intense, time-compressed proton pulse which is used to provide a source of moderated neutrons (meV to keV range),
- Isotope Production (IPF) which is a source of research and medical isotopes for the US, and
- Ultra-Cold Neutrons (UCN) which is a source of sub-μeV neutrons for fundamental physics research.

The accelerator consists of separate H^+ and H^- Cockcroft-Walton based injectors that produce 750-keV beams for injection into the 100-MeV drift tube linac (DTL). Each low energy beam transport (LEBT) contains magnetic quadrupoles for transverse focusing, a single-gap 201.25-MHz buncher cavity for initial bunching of the beam, and a beam deflector for "gating" beam into the linac. The H^- LEBT also contains a 16.77-MHz buncher for producing high-charge, individual micropulses and a slow-wave beam chopper for intensity modulating the H^- beams. The H^+ and H^- beams are merged in a common LEBT that contains a single 201.25-MHz buncher cavity, aka main buncher (MB), which performs the majority of the bunching for the standard linac beams and quadrupole magnets to achieve the final match into the linac. The DTL is an Alvarez style 201.25-MHz linac comprised of four independently powered tanks. The tanks contain magnetic quadrupoles in a FODO lattice. Following the DTL is a 100-MeV beam transport, aka the Transition Region (TR), which allows for independent matching, steering and phasing of the H^+ and H^- beams into the next linac. It also contains a kicker magnet for extracting 100-MeV H^+ beam for the IPF. Since there are currently no users of 800-MeV H^+ beam, this magnet is operated in DC mode. Following the TR is the 805-MHz coupled-cavity linac (CCL) which accelerates beams up to 800 MeV. It consists of 44 independently powered modules, which have either two or four tanks. Each tank consists of a large number of identical accelerating and side mounted coupling cells. The magnetic quadrupole doublets, which are located between tanks, are arrayed in a FDO lattice. Beam steering magnets are located in the LEBT, TR and post linac beam transports.

Following the linac is a beam switchyard that employs DC magnets to separate the H^+ and H^- beams. Pulsed kicker magnets are then used to direct H^- beam during some macropulses to the pRad or UCN facilities. Unkicked H^- beam pulses are directed toward the PSR or WNR facilities.

The proton storage ring (PSR) is an 800-MeV accumulator ring. It is a 10-sided FODO design with a 90.2 m circumference and employs a single ferrite loaded RF cavity operated at h=1. Two ferrite-loaded inductive inserts are employed to provide additional space-charge compensation of the beam. Direct H^- injection with injection painting is used in combination with a hybrid-boron-carbon (HBC) stripper foil[1] to achieve low-loss operation with better than 95% injection efficiency. The HBC foil produces acceptable first-turn losses with very good lifetime. Typically, the PSR operates at 20 Hz and provides beam to the Lujan spallation neutron target with one bunch containing >3.3x10[13] protons.

RECENT OPERATIONS

The accelerator was designed to operate at 120 Hz. However, for the last several years has operated at 60 Hz due to limitations of the Burle 7835 power triode used in high-power amplifiers in the DTL. Typical beam macropulse length is 625 μs which at 60 Hz requires ~5% linac RF duty factor. Peak beam currents are ~13 mA. Table 1 contains a summary of the typical beams parameters for the various user facilities presently in operation.

*Work supported by DOE under contract DE-AC52-06NA25396.
#lrybarcyk@lanl.gov

Table 1: Typical parameters for LANSCE linac beams. Note: All beams are 800 MeV, H^- except for IPF which is 100 MeV, H^+.

Area	Rep Rate [Hz]	Pulse Length [μs]	Chopping pattern	Iavg [μA]	Pavg [kw]
pRad	~1	625	60 ns bursts every ~1 μs	< 1	< 1
WNR (Tgt4)	40	625	1 μ–pulse every ~ 1.8 μs	≤2	~ 1.6
Lujan	20	625	290ns/358ns	100-125	80-100
UCN	20	625	Lujan-like to none	< 5	< 4
IPF	≤30 in pulsed mode	625	NA	250	25

Operating Schedule

The CY2010 schedule is representative of recent operating years. This year began with a ~4 month long extended maintenance period. During this time major tasks are undertaken, e.g. the Lujan target-moderator system was replaced during this most recent period. Following the extended maintenance, the facility moves into the annual start-up/turn-on phase. During this time personnel safety and machine protection interlock checks and beam tuning activities are performed that bring all areas to production beam operations. This year the first ~19 days were spent bringing all systems up to 100-MeV operation and IPF into production status. The next 24 days were used for dedicated IPF production and the completion of turn-on for the 800-MeV beams. The next 6 months are scheduled for production beams in 5½ blocks of time. Each full block lasting between 24 and 29 days, which includes sole use time. Each cycle may contain 1-2 days of machine development time directed towards specific beam and accelerator physics measurements that are mostly incompatible with production operations. Between production cycles, are shorter, i.e. few to several day, maintenance periods and an H- source recycle. The next extended maintenance period is scheduled to start on December 21, 2010.

Beam Reliability

During production operation, beam reliability (hours-delivered divided by hours-scheduled) is carefully tracked for each user facility. A semi-automated logging system is used to keep track of beam-off events and their durations, with a resolution of 1 minute. Operations personnel provide area and system assignments to those downtime events. The data are then post-processed on a daily basis using automated routines to produce the detailed summary of beam and system downtimes.

Presently, Lujan beam operation is the highest-power and most complex operation at LANSCE. For this reason, reliability information will be presented for this beam. For the annual production periods between January 2008 and August 2010 overall Lujan beam reliability is given in Table 2.

Table 2: Recent Lujan beam reliability figures.

Lujan Beam	2008	2009	2010 through Aug.
Schedule time (hours)	3532	3330	1392 (3072)
Beam Reliability (%)	77.6	85.3	78.3
Linac Reliability (%)	83.9	93.4	84.2

One way of viewing beam trips at a high level is by the frequency of beam trips versus the duration of the trip, without regard to system. These results are shown in Table 3. This can help illuminate whether overall trends in the type of trips from nuisance to severe show improvement or not.

Table 3: Recent Lujan beam trip rates versus duration.

Average number of Lujan beam trips per day for beam off time …	2008	2009	2010 through Aug.
from 1sec to 1 min	No data	No data	No data
from 1 min to 1 hr	1.0	1.0	1.6
from 1 hr to 3 hr	0.46	0.48	0.41
greater than 3 hr	0.35	0.24	0.31

Another approach is to divide the trips associated with each accelerator system into two categories: "nuisance" and "significant". The nuisance trips are short duration and can be quickly corrected by an operator or system expert. I have defined nuisance trips to be those which last 10 minutes or less. In general, they don't contribute much to the total downtime. All other trips fall into the significant category. These are trips whose duration is long enough that a system expert is almost always involved. Separation of trip events into these two categories can help to trend system performance and event severity associated with the different types of events. A graph of the trip rates by calendar year for significant events versus accelerator system is shown in Fig. 1.

Beam Losses and Activation

For the high-power Lujan beam, losses at the LANSCE facility appear in the linac and PSR to 1L-target areas. The linac losses appear predominantly in tanks 1 & 2 of the DTL, the TR transport between the DTL and CCL and

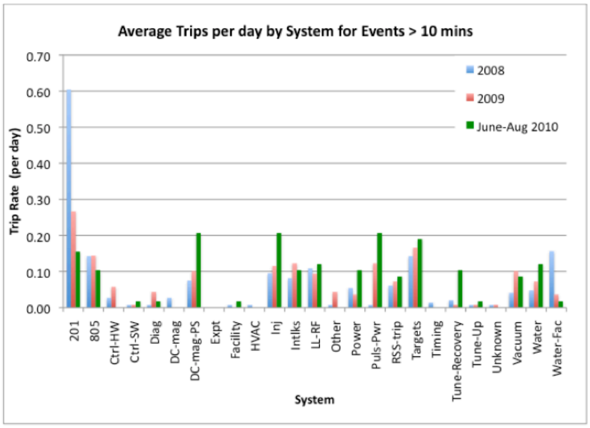

Figure 1: Average trips per day by System for 'Significant' events.

a few locations in the CCL. Capture losses due to incomplete bunch formation prior to beam entering the linac produce the ~20% beam loss in the upstream portion of the DTL. Beam losses in the TR and upstream end of the CCL are associated with transverse and off-energy tails in the beam and correspond to a fractional beam loss <0.2%. The beam losses in the remainder of the CCL occur mostly about one-forth of the way down the structure where the transverse focusing period of the lattice doubles. From modules 13-48 the fractional beam loss is estimated to be <0.1%. Except for several locations in the CCL where the activation levels can reach several tens of mRem per hour (at 30 cm several hours after cessation of production beam operation), most of the linac components only shown activation levels of a few to several mRem/hr following beam operation.

The PSR is quite a different matter. Because of the small fraction of the 800-MeV beam that is not completely stripped at the injection foil and the foil scattering of the beam, there are significantly higher levels of beam loss and activation in the PSR. Typically, the fractional beam loss ranges from 0.15% to 0.4% with historical values closer to the low end. This beam spill results in locally high activation levels around 1500 mRem/hr @ 30 cm with a higher average in the injection region of between a few tens to greater than a few hundreds of mRem/hr. Outside of the injection region where a ~25% of the total beam spilled is lost somewhat uniformly around this other ~2/3 of the PSR circumference, the activation levels can reach a few hundred mRem/hr but are typically between ten and a hundred mRem/hr at 30 cm following production beam operation.

OPERATIONAL CHALLENGES

Challenges exist is many aspects of the accelerator operation. In this section three operational challenges are presented and work that is ongoing to address them.

Higher H^- Beam Currents

In general, there is a always desire to increase beam for the user programs. Depending upon the user program, the impact of higher beam currents can help to realize better signal to noise or improved throughput. There are several ways to increase beam, either by increasing operating days, duty factor or peak current from the ion source. The first two represent significant increases in operating cost to the program. The cost increases are roughly proportional to the beam increase. For the latter, however, once implemented, has a much lower operating cost.

Presently, the AOT-ABS Injector team is working on a multipronged approach to increasing the peak current from the existing H^- ion source, which would result in more beam for the user programs. The H^- beams are created in a multi-cusp field, filament driver, cesiated surface converter ion source. This source presently operates at 60 Hz and ~5% duty factor with a H^- peak current ~16 mA , an electron/H^- ratio ~4 and a normalized rms emittance of 0.022 π cm-mr. Under these conditions the tungsten filaments (Kamis Inc.) have a lifetime of ~35 days.

The first activity is aimed at increasing the operating temperature of the plasma chamber walls. Experimental evidence from tests performed on our ion source test stand showed an increase in H^- beam current of ~3 mA (with no emittance increase) resulted when the temperature of the chamber wall cooling loop was increased by 30°C. It is believe that an elevated wall temperature increases the cesium vapor pressure, thereby enhancing the sputtering of H^- ions from the converter surface.

The next activity will be to improve the temperature uniformity of the converter. The present converter is cooled with water that contacts only the central portion of the backside of the converter, thereby allowing a large thermal gradient to develop across its surface. A new design has cooling channels that will provide cooling to the perimeter of the converter and is expected to reduce the thermal gradient by a factor of three. This reduction in temperature gradient across the converter is expected to result in more uniform hydrogen coverage, thereby increasing the yield of H^- ions.

The third activity will introduce a third filament into the source. The expectation is that by increasing the emission area of electrons, the discharge current and plasma density would increase, thereby resulting in an increased production of H^- beam current.

Improving Performance Under Multi-beam Operations

LANSCE employs both H^+ and H^- beams in normal operations. One benefit of this approach is that, in general, both species can be simultaneously accelerated through the linac in the same macropulse, provided the rf peak power is available. This is an efficient operating mode since only the incremental beam power is required in addition to what is already provided to accelerate the first beam. However, because the beams must transit through a common LEBT upstream of the DTL, the operation of this transport can compromise the quality/intensity of one or both beams. This is the case for the IPF (H^+) and WNR (H^-) beams, which utilize this macropulse sharing mode, but are distinctively different. The IPF beam is unchopped and operates at an average current of 250 μA and requires a relative high gap voltage (~12-15 kV) in the single-gap MB buncher located in the common LEBT for optimal performance. In contrast, the WNR beam is chopped to individual micropulses with 1.8 μs spacing and typically operates at a few microamps of average current. Each WNR micropulse is formed from a 20-25 ns long stream of charge bunched by the 16.77 MHz cavity. Optimal performance for the WNR beam requires the MB to operate at much lower gap voltage of ~2-7 kV. While the H^+ ion source has plenty of peak current capability, the H^- does not, so any loss of H^- beam current cannot be made up through source adjustments. Therefore a solution to improve the WNR performance under suboptimal operation of the MB is sought.

A debuncher cavity located at the end of the H^- LEBT appears to be a good candidate for improving WNR and IPF beam performance under shared macropulse operation. Results from beam dynamics simulations of the WNR micropulse beam indicate that this debuncher cavity could offset the deleterious effects of the MB under share macropulse mode and restore the WNR beam current to over 90% of it's optimal performance intensity.[3] Because the effectiveness of the debuncher diminishes the further away it is from the MB, it is critical that it be located at the end of the H^- LEBT. Unfortunately, this is the location where the H^+ and H^- LEBT's merge into the common transport, where space is very limited. Although our standard reentrant pillbox style cavity won't fit, a 201.25 MHz quarter-wave cavity is very compact and probably will. At this beam energy the gap to gap distance is only ~3 cm and the length along the beam axis ~8 cm. The cavity is somewhat less electrically efficient than the TM_{010} cavity but has a better transit-time factor and is small enough to fit in the desired location.

Maintaining Performance for Micropulse Operation at Large Pulse Spacing

Experimenter's using flight paths at the WNR facility employ time-of-flight techniques to measure energies of neutrons produced in reactions under study. The spacing (typically 1.8 μs) between arrival time of the proton pulses on there neutron spallation target dictates the range of neutron energies that can be observed. Recently, there has been interest in performing measurements at lower neutron energies, which implies larger separation between arrival time of sequential proton pulses on target. The usual way to implement this increased pulse spacing is to remove one or more pulses from the sequence generated at the low energy injector. Unfortunately, this reduces the average beam current, which then increases the time it takes to collect a specific amount of data. Large pulse spacing reduces the current to impractically small levels. A new technique call "pulse-stacking" was recently demonstrated and has the potential to address this issue. The technique uses the PSR to "stack" individual WNR micropulses with the goal of accumulating charge into narrow bunches for extraction with large pulse-to-pulse separation of sequential beam pulses on target. For the neutron energies of interest, the pulse spacing ranges from microseconds to milliseconds. To effectively carry out this type of program in an efficient manner would require several upgrades. The first would be a higher harmonic rf system for simultaneously producing multiple high-charge, circulating bunches and maintaining them with ns pulse widths. The second would be a new solid-state modulator for the fast extraction kicker that would produce fast risetime operation and provide on-demand bunch extraction to meet the range of pulse separations under consideration. Finally, incorporating a new kicker in the extraction transport line that would allow simultaneous Lujan and WNR operation from the PSR.

As a proof-of-principle test, however, a demonstration was performed with the existing hardware during a recent accelerator development period. To increase the charge per bunch delivered to the target a technique was used where the WNR micropulses were injected into the middle of the PSR rf bucket at a rate of one per turn. This was done for a total of 80 pulses before injection was suspended as the stored bunch began to spread. Eighty pulses provided high charge while maintaining a narrow circulating bunch. During the next ~½ synchrotron period the bunch width grew then shrank as the stacked beam bunch performed normal synchrotron motion. When the beam width reached a minimum, the next batch of 80 micropulses was injected at a rate of one per turn. This process was repeated one more time to achieve a total of 240 injected micropulses. Oscilloscope traces for the linac micropulses and PSR circulating current obtained during this demonstration are shown in Fig. 2. After the last micropulse was injected, the bunch was immediately extracted to the WNR neutron spallation target. The PSR h=1 buncher was operated near maximum voltage to decrease the synchrotron period and allow more total

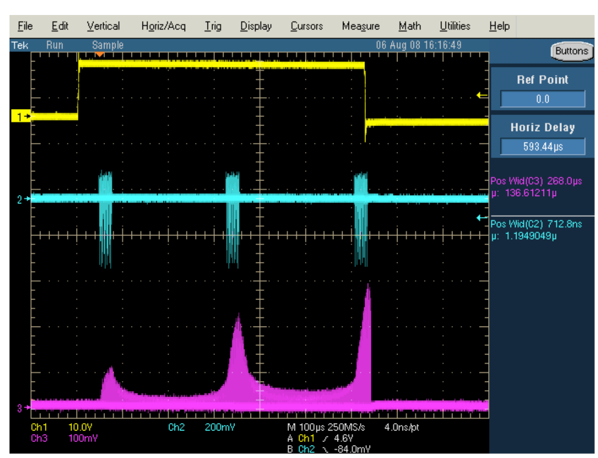

Figure 2: Beam gate (top trace), Linac micropulses (middle trace) and PSR circulating current (bottom trace) obtained during pulse-stacking demonstration.

charge to be stored during a standard linac macropulse. The average current at 40 Hz (25 ms pulse spacing!) was ~ 1μA, which was ~60% of the average beam current at 1.8 μs pulse spacing.

SUMMARY

LANSCE provides pulsed proton and neutron beams to several user facilities whose missions include defense applications, isotope production and research in basic and applied science. Presently, the H^- and H^+ beams range in power from power from <1 to ~100 kW with varying pulse formats tailored to meet experiment requirements. Present day operations include over 3000 hours per year of scheduled beam to the various user programs with recent beam reliability around 80%. Three operational challenges presently receiving attention are increasing H^- beam current to the user facilities, optimizing dual species operation and improving performance for widely spaced micropulse beam.

REFERENCES

[1] T. Spickermann et al., "Comparison Of Carbon Stripper Foils Under Operational Conditions At The Los Alamos Proton Storage Ring", Proceedings of HB2008, August 25-28, 2008, Nashville, TN, pp 262-264.

[2] K.F. Johnson et al., "H^- Ion Source Development for High Performance", to be published in Proceedings of Linac10, Sept. 12-17, 2020, Tsukuba, Japan, 2010.

[3] L. Rybarcyk and S. Kurennoy, "Use of a Debuncher Cavity for Improving Multi-beam Operations at LANSCE", Proceedings of PAC09, May 4-8, 2009, Vancouver, BC.