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UPGRADE OF LOS ALAMOS ACCELERATOR FACILITY AS A FUSION PROTOTYPIC NEUTRON SOURCE*

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Abstract

The Fusion Prototypic Neutron Source (FPNS) is considered to be a testbed for scientific understanding of material degradation in future nuclear fusion reactors [1-3]. The Los Alamos Neutron Science Center (LANSCE) is an attractive candidate for the FPNS project. The Accelerator Facility was designed and operated for an extended period as a 0.8-MW Meson Factory. The existing setup of the LANSCE accelerator complex can nearly fulfil requirements of the fusion neutron source station. The primary function of the upgraded accelerator systems is the safe and reliable delivery of a 1.25 mA continuous proton beam current at 800 MeV beam energy from the switchyard to the target assembly to create 1 MW power of proton beam interacting with a solid tungsten target. The present study describes existing accelerator setup and further development required to meet the needs of FPNS project.

LANSCE ACCELERATOR FACILITY

The LANSCE accelerator started routine operation in 1972 as a 0.8 MW average proton beam power facility for meson physics research, and delivered high-power beam for a quarter century [4]. Layout of the existing LANSCE accelerator facility is shown in Fig. 1. The accelerator currently delivers beams to five experimental areas. The accelerator is equipped with two independent injectors for H^+ and H^- beams, merging at the entrance of a 201.25 MHz Drift Tube Linac (DTL). The DTL performs acceleration up to the energy of 100 MeV. After the DTL, the Transition Region beamline directs a 100 MeV proton beam to the Isotope Production Facility (IPF), while the H^- beam is accelerated up to the final energy of 800 MeV in an 805 MHz Coupled Cavity Linac. The H^- beams, created with different time structure by a low-energy chopper, are distributed in the Switch Yard (SY) to four experimental areas: the Lujan Neutron Scattering Center equipped with a Proton Storage Ring (PSR), the Weapons Neutron Research facility (WNR), the Proton Radiography facility (pRad), and the Ultra-Cold Neutron facility (UCN).

FPNS BEAM REQUIREMENTS

The primary mission of FPNS is to provide a damage rate in iron samples of 8-11 dpa/calendar year with He/dpa ratio of ~10 appm/dpa in irradiation volume of 50 cm^3 or larger with irradiation temperature 300 – 1000^{o} C and flux gradient less than 20%/cm in the plane of the sample. To create a test volume with a sufficiently high neutron flux, a 1.25 mA time-averaged current of 800-MeV protons must be delivered to the target. To achieve this current,

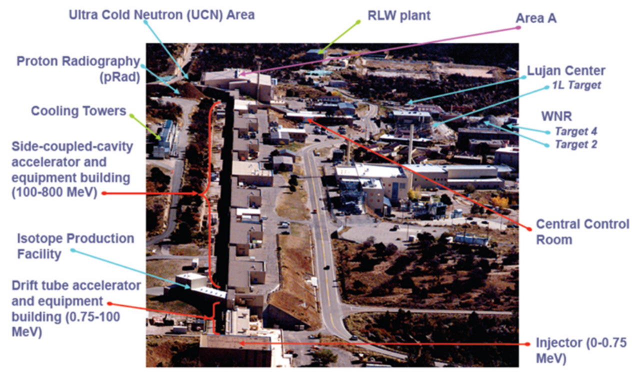

Figure 1: Layout of Los Alamos accelerator facility.

FPNS must receive beam at 78 Hz, with a beam peak current of 18.87 mA during the macropulse. Parameters of FPNS beam are presented in Table 1. Studies proposing the use of LANSCE for fusion material irradiation date back to 1981 [5, 6]. Operation with pulsed beam current of 21 mA was successfully demonstrated as a test for the proposed LANL Long Pulse Spallation Source, delivering H^+ beam with energy 800 MeV, average current 315 μA and reliability of ~88% for 12 hours [7].

Table 1: Parameters of FPNS Beam

Average beam power	1 MW
Beam energy	800 MeV
Peak current	18.87 mA
Average current	1.25 mA
Repetition rate	78 Hz
Beam pulse length	850 μs
Beam FWHM size at the target	2 mm
Raster	Circular
Minimal rastered beam radius	3.2 cm
Maximum rastered beam radius	4.3 cm
Target irradiated area	25.92 cm^2
Beam current density on the target	48.2 μA/ cm^2
Non-uniformity of target irradiation	< 3%
Number of protons at the target per year	$9.55 \cdot 10^{22}$
Total beam delivery	3400 hours / year

The design proposed to upgrade the LANSCE facility for FPNS project employs an innovative annular target with the fusion materials irradiation region occupying the central flux trap inside the annular target [8, 9]. Estimations of interaction of 1 MW proton beam with the target indicate the ability to generate a neutron flux of 10^{15} n cm^{-2} s^{-1}, which is sufficient to generate a damage rate in iron of 20.6 dpa per full-power year averaged over a 53-cm^3 volume. The calculated He-to-dpa ratio in this volume is 14.6 appm/dpa, near the desired value of 10 appm/dpa.

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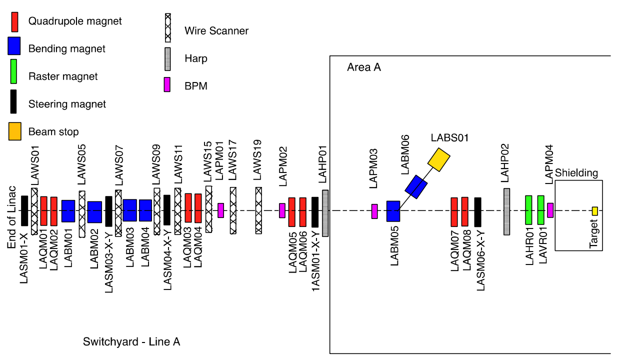

Figure 2: Beamline from the end of accelerator to FPNS target.

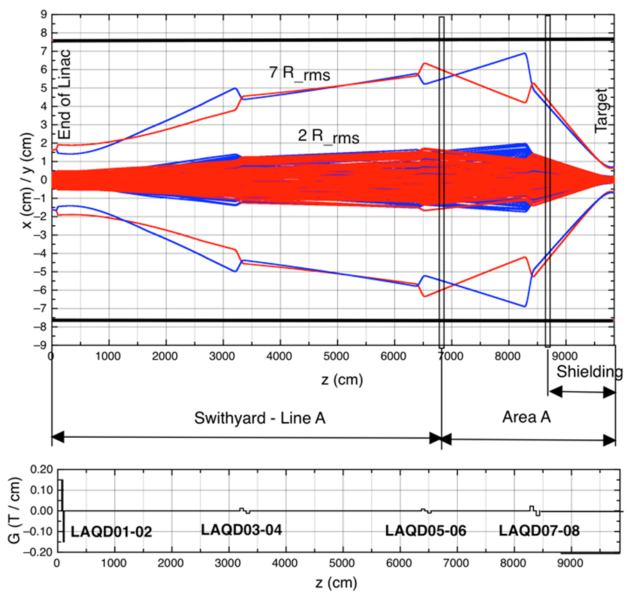

Figure 3: Particle tracking of FPNS beamline.

ACCELERATOR RF REQUIREMENTS

The present project does not require any specific upgrade of accelerator RF systems. Recent completion of the LANSCE Risk Mitigation Project [10] included significant upgrade of RF power feeding the DTL [11]. Three out of four 201.25 MHz amplifiers (Modules 2-4) were replaced with newly developed RF power systems based on TH628L Diacrodes [12]. A new digital low-level RF (dLLRF) control system was installed for the 201.25 MHz RF systems, and end-of-life CCL klystrons were replaced to ensure further stable beam operation. Upgrade of the dLLRF for the 805 MHz RF systems will be required to accommodate both existing feedforward and adaptive feedforward modes working through the CCL. Also, dLLRF for bunchers should be installed.

Operational beam duty factor is a combination of that of the most powerful beams delivered to the various experimental areas: (FPNS) 78 Hz x 850 μs + (IPF) 20 Hz x 662 μs + (PSR) 20 Hz x 625 μs = 9.2%. The drift tube linac RF gate requires an additional 250 μs to each of the beam gates to allow the low-level RF control system to lock and stabilize amplitudes and phases of DTL tanks within the level of 1%, 1° correspondingly. It results in the following value for DTL RF duty factor: (FPNS) 78 Hz x 1100 μs + (IPF) 20 Hz x 912 μs + (PSR) 20 Hz x 875 μs = 12.2%. The coupled-cavity linac requires 120 Hz x 950 μs RF pulse setup for all beams, which translates into a CCL RF duty factor of 11.4%. Because the DTL duty factor limit is 15% and that of the CCL is 12%, the proposed setup is within the acceptable limits. Thermal and structural analysis of Drift Tube Linac was done in Refs. [13, 14], and that of Coupled-Cavity Linac in Ref. [15].

BEAM TRANSPORT SYSTEM

The beam-at-target requirements are dictated by neutronics considerations. Application requires minimization of the rastered beam spot on target, while keeping 7-rms beam size within existing beampipe radius of 7.62 cm (or one-rms beam radius within 1 cm). A round beam spot with 2.3 mm FWHM (1 mm rms) is painted onto an annular target. Beam-centroid jitter is expected to be at the level of 0.5 rms of beam size. The raster scheme is supposed to be sufficiently flexible to accommodate changes in the size of the painted annular spot as the design of the FPNS target evolves.

Figure 2 presents design of high-energy beam transport from the end of accelerator to FPNS target [16]. Figure 3 illustrates results of beam dynamics study of FPNS beam. The quadrupole doublet LAQD01-02 is common for both H^+ and H^- beams. The values of quadrupole gradients in that doublet of 1.5 kGs/cm are selected from a regular run of H^- beam. Four bending magnets LABM01-04 are installed to separate H^+ and H^- beams. They have been used at the time of simultaneous operation of both beams at the energy of 800 MeV. Quadrupole doublets LAQD03-04 and LAQD05-06 were part of 0.8-MW H^+ beam transport to Area A. Those magnets, together with existing beam diagnostics confirmed to be effective for providing reliable high-energy beam transport. An additional quadruple doublet LAQD07-08 provides small beam size at the target. The target area will be surrounded with shielding to prevent irradiation of upstream equipment by backscattered neutrons. The distance from the upstream shield wall to the target is selected to be 10 m. An additional 4 m of beamline is selected for placement of raster magnets. To be conservative, the beamline apertures are dimensioned to accommodate beam-centroid excursions at the target of up to 10 cm, both horizontally and vertically.

BEAM RASTERING

The purpose of beam rastering is to uniformly irradiate the target within a ring area of 3.2 cm < R < 4.3 cm. The raster scheme is supposed to be sufficiently flexible to accommodate changes in the size of the painted annular spot as the design of the FPNS target evolves. For example, a ring with minimum radius of R_{min} = 5.5 cm and maximum radius of R_{max} = 6.9 cm has been assumed in developing

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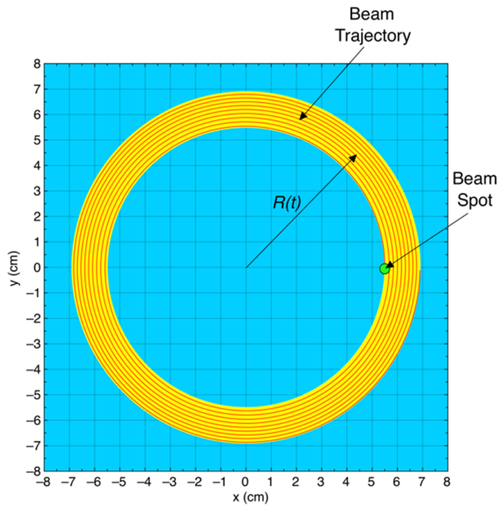

Figure 4: Irradiation of target by beam spiral rastering.

the beam optics design presented here, but this design can easily be adjusted to paint a ring with R_{min} = 3.2 cm and R_{max} = 4.3 cm, as assumed in the neutronics design.

Rastering is achieved through sinusoidal variation of a set of raster (steering) magnets in horizontal and vertical directions with variable field amplitude. Fields in the magnets are shifted by 90º to perform circular irradiation. Amplitudes of the fields are changing to assure beam centroid variation as:

$$\begin{pmatrix} R_x \\ R_y \end{pmatrix} = R(t) \begin{pmatrix} \cos(\omega t + \varphi_\circ) \\ sin(\omega t + \varphi_\circ) \end{pmatrix},$$

with dependence of beam radius *R(t)* on target given by

$$R(t) = R_{min}\sqrt{1 + \left(\frac{R_{max}^2}{R_{min}^2} - 1\right)\frac{t}{\tau}},$$

where τ = 850 μs is the beam pulse length, and ω is the raster frequency. In this case, an increment of irradiated area after each turn is kept constant $dS = 2\pi R(t)dR(t) = const.$ Uniform irradiation is achieved by overlapping multiple beam turns at target (see Fig. 4). Calculations show that sufficiently small beam non-uniformity at the target (less than 1%) can be achieved with ten beam turns at the target [16].

SUMMARY

This study concludes that an upgrade of the LANSCE Accelerator Facility for a 1-MW FPNS project is feasible. Expected performance of the RF systems for the Drift Tube Linac and Coupled Cavity Linac meet FPNS requirements. Development of the existing high-energy beamline to deliver 1-MW proton beam to the FPNS target requires marginal upgrade of the existing Line A.

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