Preliminary Report on the BNL Spallation Neutron Source Design Study.*

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Abstract

A preliminary study of a 5-MW pulsed neutron source is presented based on a 600 MeV H^- linac injector and 2 fast-cycling synchrotrons, each of 3.6-GeV final proton energy and 30 Hz rep rate.

We have considered several options for an intense pulsed spallation neutron source (PSNS) based on an intermediate current H^- Linac and fast-cycling proton synchrotron (FCS) with design objectives of 5-MW beam power, pulse duration ~ 1 μs, and 60 Hz total pulse repetition rate. A tentative architecture which satisfies these goals is schematically illustrated in Fig. 1, where we show a 600-MeV, 60 Hz, H^- Linac injecting into two identical FCS rings, each operating at 30Hz and independently powered 180° out of phase. The ring circumference of C = 363 m results in a pulse duration of τ = 1.3 μs from single turn extraction. A final energy of 3.6 - GeV is chosen so that the number of protons accelerated per ring can be reduced to $N_p = 1.4 \times 10^{14}$ protons/pulse, consistent with the bunched beam (B =.3) Laslett space charge limit for a beam of emittance $\epsilon = 200\pi$ mm - mrad and a space charge tune shift of $|\Delta\nu| = 0.21$. The extracted pulses from the rings are coalesced into a single external channel and then fast-switched onto two independent target stations T1 and T2 at a rate $R_1 + R_2 = 60$Hz; for example $R_1 = 10$Hz, $R_2 = 50$Hz.

The parameters of the Linac are summarized in Table I. The H^- ion source parameters are consistent with the present BNL source with peak pulse current of 80 mA and pulse duration $\tau_s = 464$ μs; however, further work is required to attain 60 Hz operation. Two RFQ's are operated in tandem to obtain an injection energy of E = 2 - MeV into an 88-MeV drift-tube Linac (DTL) and a 510-MeV side coupled Linac (CCL) to obtain a final Linac energy of 600-MeV. The RF frequency of the CCL, 1280 -Mhz, is the 32nd harmonic of RFQ1 and the injection frequency of the ring, 40 -MHz. The Linac configuration is similar to that of the SSC although our duty factor of 2.8% is larger.

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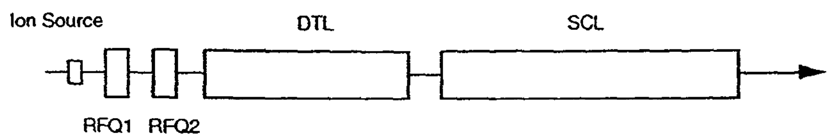
Table I. Linac Parameters

Final Kinetic Energy	600	MeV
Repetition Rate	60	Hz
Linac Beam Pulse	463.6	μs
Duty Cycle	2.8	%
Peak Current, in output	50	mA
Peak Power, to Beam	30	MW
Total Peak Power	60	MW
Beam Emittance	~ 1	π mm mrad
Δp/p of Beam (full)	~ 1×10^{-4}	



Ion Source (H-)	0.035	MeV	
RFQ1	0.2	MeV	40 MHz
RFQ2	2.0	MeV	160 MHz
DTL	90	MeV	320 MHz
SCL	600	MeV	1280 MHz
Synchrotron	3.6	GeV	40 - 50 MHz

The synchrotron ring is shown in Fig. 2 - a 2-superperiod FODO lattice with non zero dispersion straights for injection and near zero dispersion straights for sixteen 2-gap RF cavities. A ceramic vacuum chamber is planned for the ring with either a metallized interior surface or a metallic grid mesh similar to the ISIS design. The average circulating beam current at full energy is $<I> = 19A$, lower than that attained in earlier proton storage rings such as the ISR. The final RF frequency of ~50 MHz is approximately that of the FERMILAB main ring.

We have also done preliminary studies at 1-GeV of a target configuration capable of sustaining the 5-MW beam power. As shown in Table II, a target consisting of either hexagonal rods or a particle bed of tungsten pebbles has been considered; an array of beds varying in thickness from 1cm to 5cm stacked axially in the beam direction provides the best heat transfer due to the more favorable area/volume ratio. Coolants studied were sodium, lead, helium and heavy water. Liquid sodium would provide the most attractive option in terms of lower pressure drop than liquid lead for axial flow.

Table II. Target Operating Conditions

- Power — 5 MW
- Coolant Outlet Temperature — ~800 - 900K
- Coolant Inlet Temperature — 300K or Metal T_{mp}
- Proton Energy — 1 GeV

- Rod Target:
  - Rod OD (cm) — 0.5
  - Rod Pitch (cm) — 0.53
  - Solid Fraction of Target — ~80%
  - Target Length (cm) — 37.5

- Particle Bed Target:
  - Particle OD (cm) — 0.5
  - Solid Fraction of Target — ~64%
  - Target Length (cm) — 47

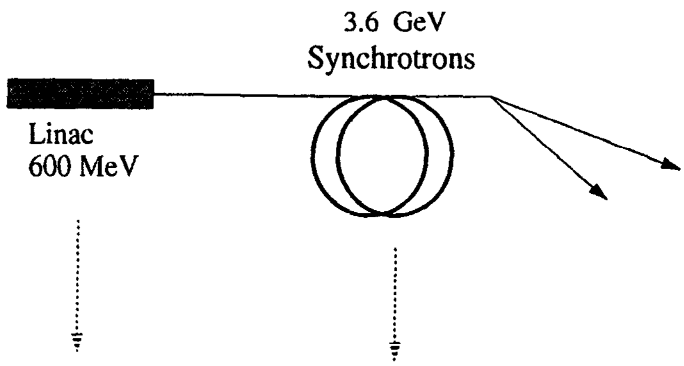
Rod Target

Coolant	ΔT (C)	ΔP (MPa)
Helium	500	1.17
Sodium	400	0.23
Lead	300	5.24

Co-axial Particle Bed Target

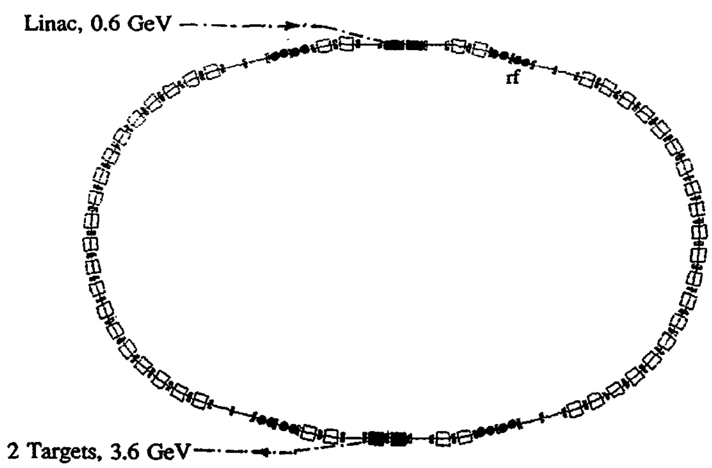
Coolant	ΔT (C)	ΔP (MPa)
Helium	-	-
Sodium	400	0.02
Lead	300	0.27

Initial neutronics calculations using the LAHET Monte-Carlo code have also been performed to compare neutron flux at higher energies to that expected at E_p = 1-GeV. In Fig. 3 we show the resulting integrated neutron flux (E_n<20-MeV) per incident proton at the surface of a 20-cm diameter tungsten rod for an incident 1 cm^2 beam of 1-GeV and 10-GeV protons, as a function of axial position along a 50-cm cylinder. Although the predicted flux per incident 10-GeV proton is less than 10 times that of an incident 1-GeV proton at the upstream end of the target, the higher energy proton gives more than 10 times of the 1-GeV flux at axial positions greater than Z=14-cm, and the axially integrated neutron flux is also greater than 10 times the 1-GeV flux. In Fig. 4 we show the radial integrated neutron flux per incident proton within a light water moderator at an axial position of Z=10 cm. The 10-GeV flux is comparable to 10 times the 1-GeV values at all radii. Comparable results at 3.6 - GeV are not yet available.



Rep. Rate = 60 Hz	Rep. Rate = 30 Hz
Duty Cycle = 2.8 %	Circumference = 363.2 m
Source Current = 80 mA	Beam Power = 2.5 MWatt / ring
Aver. Power < 2 MWatt	Pulse Duration = 1.3 μs
	Intensity = 1.4×10^{14} pr.s /ring/pulse
	No. of Turns injected = 303 / ring
	Emittance @ Injec. = 200 π mm mrad
	rf Frequency = 40 - 50 MHz

Fig.1 Schematic layout of pulsed spallation neutron source, parameters.



5 MW system
Linac plus 2 equal Fast Cycling Synchrotrons (FCS's)

Linac	Energy	(GeV)	0.6
	Current	(mA)	50
	Rep.Rate	((Hz)	60
	Np/pulse		1.4E14
FCS's	Energy	(GeV)	3.6
	Circ.current	(A)	19
	Rep.Rate	(Hz)	30
	Np/sec	(1/s)	2*4.2E15
	Circumference	(m)	363.2

Fig.2 Lattice and parameters of spallation source ring.

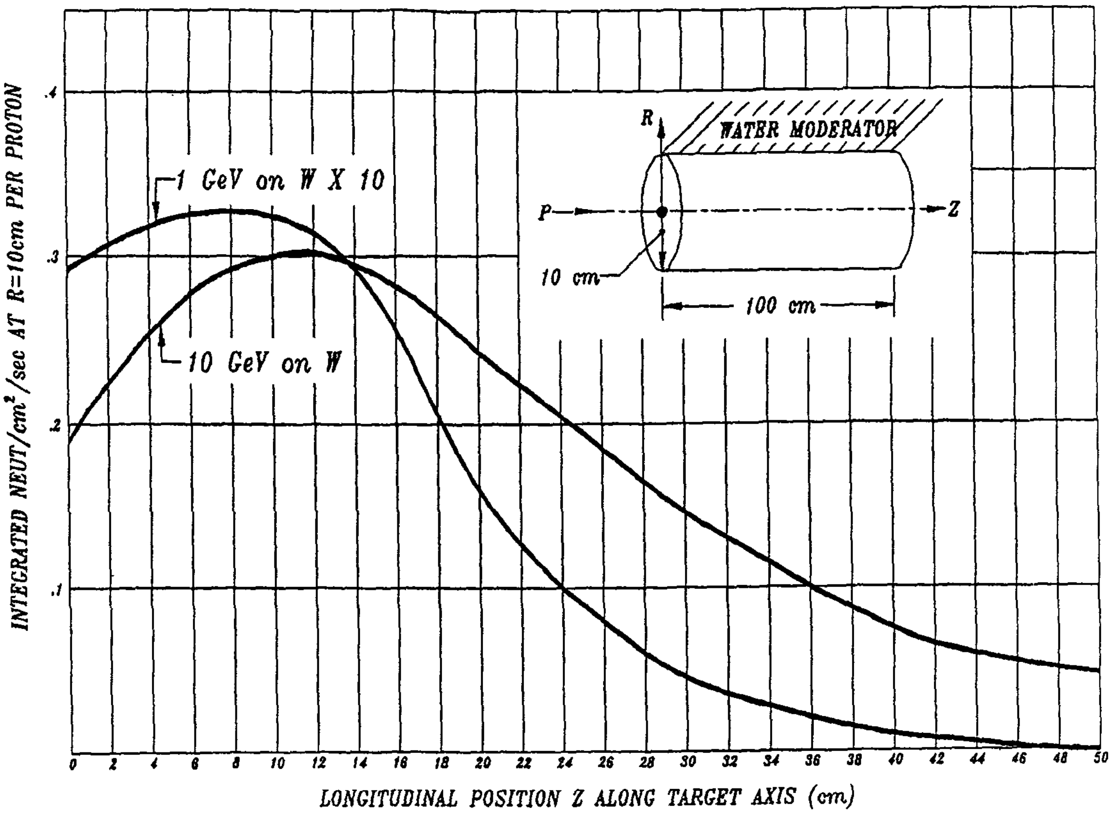


Fig.3 Integrated (E_n< 20 MeV) Neutron Flux at surface of 20 cm dia. tungsten target

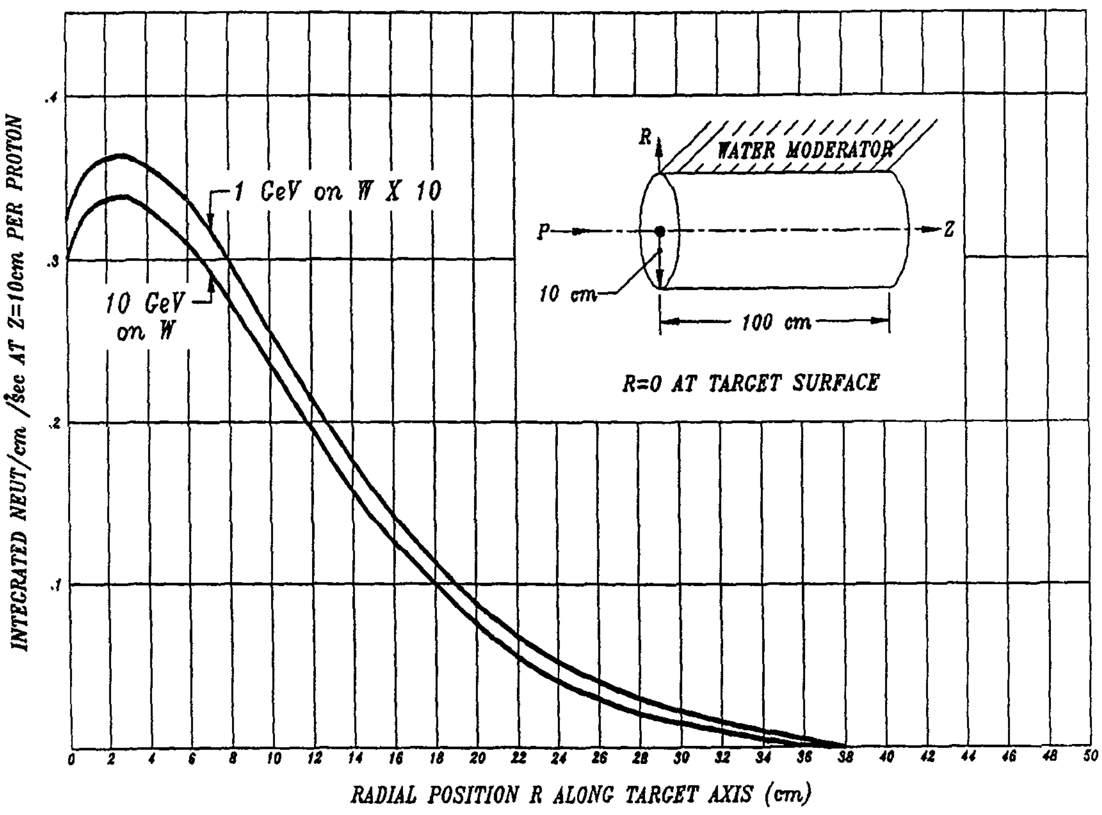


Fig.4 Integrated (E_n< 20 MeV) neutron flux vs. radial distance from tungsten target surface at Z = 10 cm.