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BNL-AGS COMPLEX AS A SPALLATION TARGET TEST-BED*

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1 INTRODUCTION

The Brookhaven National Laboratory-Alternating Gradient Synchrotron (BNL-AGS) accelerates protons for high energy physics experiments up to a maximum energy of 24 GeV. The BNL-AGS complex consists of a LINAC (200 MeV), which feeds into a Booster synchrotron (1.5 GeV), and finally the main AGS ring (24 GeV). The Booster has a quarter of the AGS circumference, and thus four Booster pulses can be stacked into the AGS for acceleration up to the maximum desired energy. In principle, the AGS can deliver protons to multiple targets in a single or multiple pulses over an energy range of 1.5-24 GeV. Fig 1 shows the history of the AGS intensity improvements, indicating the major upgrades. It can be seen that a major improvement was introduced when the Booster was brought on line, since the space charge limit is reduced at this energy, allowing for the dramatic increase in intensity. The peak intensity of 6.3×10^{13} protons per pulse represents a world record for a proton synchrotron.

The next generation short-pulse spallation neutron source (SNS) as currently planned will operate with an average proton power of 1-5 MW, and a repetition rate of 2-50 Hz. The required proton pulses will be 1-10 μs long, implying approximately 100 KJ per pulse. Plans for such sources are being formulated in Japan, Europe, and the United States. The combination of a short pulse and the large amount of energy per pulse implies the creation of thermo-mechanical enhanced thermal stresses in the target which could lead to catastrophic target failure. In order to validate the mechanical integrity and neutronic performance of these new target designs it will be necessary to carry out a series of experiments using proton pulses which have prototypic pulse lengths and energy content per pulse. In addition, the pre-moderator, moderator, and reflector arrangement needs to be optimized for the new operating conditions.

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1.1 *Target Requirements*

The essential requirements for most user-optimized experiments at a SNS are thermal neutron pulses 10-20 μs in duration with as high an amplitude as possible and with minimum background due to gamma rays and high energy neutrons. These requirements in turn require proton pulses with 1-10 μs duration,[1] impinging upon a heavy metal target assembly capable of repeatedly (2-50Hz) absorbing about 100 kJ of energy in a few μs without failure due to fatigue or thermal-mechanical stresses, together with a reflector/moderator which slows the spallation neutrons to thermal energies with minimal increase in the neutron pulse width. These target requirements are to a certain extent contradictory and require careful optimization. Reflectors and moderators pose their own problems, and have been discussed in great detail in other system designs, [2-4] and will not be discussed here.

Examples of target designs that have been proposed include water-cooled tantalum or tungsten/rhenium alloy plate structures, particle beds of appropriately sized tungsten spheres, and circulating liquid mercury. The first configuration, while the most conventional, is believed to be susceptible to failure due to thermal-mechanically induced stresses, a fault that the last two designs attempt to mitigate. Current SNS facilities operate at proton energies below 1 GeV, but next-generation designs are planned to operate the 1-10 GeV range.[5] Generally speaking, accelerator designers prefer to increase the proton energy rather than the proton current to achieve higher power. Numerical simulations provide several observations on target behavior as proton energies increase. (These simulations represent substantial extrapolations of real measurements, and need to be validated with actual measurements).

i. the neutron production cross-section is nearly proportional to the proton energy--thus the total number of neutrons produced at a given proton

beam power decreases only slightly with increasing proton energy (~15% in going from 0.8 to 7 GeV);

ii. since the range of protons increases as their energy increases, neutron production is spread over a longer length of target, thereby reducing somewhat the brightness of the primary neutron source;

iii. the spatial power density in the target is reduced at higher proton energy because of the increased range of both the protons and their reaction products (neutrons and pions);

iv. the production of interstitial gases (hydrogen and helium) in the thin target window - a primary cause of window failure - decreases with increasing proton energy (about fourfold decrease in going from 0.8 GeV to 7 GeV in a nickel window).

As the above short discussion shows, neither the proton energy nor the target design for next-generation SNS are as yet optimized. Therefore, and experimental facility which can deliver short, intense proton pulses over a range of energies (the AGS is able to operate over most of the interesting range, 1.5 GeV - 7.0 GeV) would be valuable in evaluating options and validating selections.

1.2 AGS Operation as an SNS Driver

For the operation of the AGS as a driver for a pulsed neutron source, a maximum proton energy of 7 GeV is being considered. This energy is slightly lower than the transition energy and therefore any complications and possible beam losses that result from crossing the transition are avoided. The Booster intensity is expected to deliver 0.25×10^{14} protons per pulse, thus the AGS intensity after the accumulation of four Booster beam pulses is expected to be about 1.0×10^{14} per pulse. This level of beam intensity is a reasonable extrapolation, since the current performance of 6.3×10^{13} protons per pulse is mainly limited by the complications of crossing the transition energy, which is not needed for this application.

The maximum repetition rate that can be achieved with the present accelerator complex is about 1.25 Hz. The total beam power impinging on the spallation target is then 140 kW. The 7 GeV proton beam pulse can be extracted either all at once or divided up into 2, 4, 8 or even more beam pulses separated by tens of μs with a correspondingly somewhat reduced repetition rate. If all of the 7 GeV beam is extracted at once the total energy per pulse impinging on the target is 112 kJ; higher than the energy per pulse deposition of a 60 Hz 5 MW spallation source.

Extra equipment required for this application includes a new fast extraction system necessary because of the larger beam size at the lower energy compared to the regular running energy and the extension of a beam line connecting the AGS to the new spallation target station. The low repetition rate of the AGS is advantageous because it will allow peak-power testing of targets which are prototypes for targets operating at higher repetition rates (e.g. 60 Hz) with correspondingly higher average power. The low repetition rate is also an advantage for neutron scattering experiments, since it minimizes frame overlap from successive pulses, a particularly important consideration for cold neutron experiments.

The beam power delivered to the spallation target could be increased by up to a factor of two by elimination of the 500 ms wait needed to accumulate 4 beam pulses from the Booster. This would be accomplished by accumulating the four Booster beam pulses in a separate low energy 1.5 GeV storage ring in the AGS tunnel. With such an accumulator ring, the AGS could cycle at a repetition rate of 2.5 Hz, which is also the maximum rate corresponding to the maximum repetition rate of the Booster of 10Hz. With such an accumulator the complex can deliver 280 kW of proton beam power to a spallation neutron target. The parameters for the AGS complex are summarized in Table 1.

Table 1. Parameters for the AGS Complex as a driver for a spallation neutron source

	Rep. Rate (Hz)	Protons/ Pulse	Beam Energy (GeV)	Ave. Current (μA)	Beam Power (kW)
Present AGS Complex	1.25	1.0×10^{14}	7	20	140
AGS + 1.5 GeV Accumulator	2.5	1.0×10^{14}	7	40	280

1.3 BNL-AGS Capabilities and Initial Test Program

A comparison of two proposed SNS target requirements and the potential output of the BNL-AGS is shown on Table 2. This comparison shows that for the two important parameters, pulse width and energy per pulse, the AGS is a close match. It would thus be possible to carry out "go-nogo" tests on proposed target configurations. These tests would eliminate those target designs which have poor mechanical performance. Once an acceptable mechanical design has been achieved, its neutronic characteristics, using prototypic proton pulses can be validated.

An initial simple test program can be envisioned to initiate this testing activity. This program would consist of using the mercury target concept, proposed by the European spallation source (ESS) group as a first test article. The National pulsed spallation source being designed at ORNL is also proposing to us a mercury target, and thus these experiments could help both projects. The two major activities would consist of modifications to the AGS, and construction of the targets. The AGS would require a full aperture fast extraction system and re-building of an old beam line. The ESS target group would have to design and construct fully instrumented target assemblies. Results from these experiments will validate calculational techniques for predicting dynamic behavior of target systems containing liquids. The overall cost of such an experiment would be modest, since existing beam lines and equipment would be used; only the fast extraction system would be new.

The experimental program could be expanded from this initial phase to include more prototypic target-reflector-moderator assemblies to benchmark target station designs and validate calculational techniques. This expansion would include the construction of conventional facilities (building, heat removal, added electric supply etc.) project support, and limited experimental systems. Eventually, a significant pulsed source of cold neutrons could be created, since it is possible to operate the AGS at an average power of .28 MW and a repetition rate of 2.5 Hz.

2 CONCLUSIONS

The following conclusions can be drawn from this initial study:

- The BNL-AGS facility, with limited modifications, can be used to carry out "go-nogo" tests on targets requiring high energy short duration proton pulses.
- Experimental results can be used to validate mechanical design techniques.
- Additional modifications to the test area would result in a neutronic target test facility to optimize high power target designs and validate neutronic design techniques.
- The BNL-AGS presently delivers "ISIS-like" average power with pulse structure optimized for cold neutrons. With the addition of a target, moderators, and user instrumentation it could be developed into a significant user facility.

Table 2. Requirements for Proposed Sources and Potential BNL-AGS Capabilities

	ESS	ORNL	BNL-AGS
Proton Energy (GeV)	1.334	1.0 - 2.0	1.5 - 7.0
Average Power (MW)	5.0	1.0 - 5.0	.14 - .28
Energy/Pulse (KJ)	100	17 - 84	24 - 112
Pulse Length (μs)	1.0	0.5	2.4
Repetition Rate (Hz)	50	60	1.25 - 2.5

3 REFERENCES

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3. G. S. Bauer, et al., "Measurements of Neutron Flux from a Water Moderator with Proton - and Deuteron-Radiation on Lead and Uranium Targets," Report SNQ 1 HG/BN002. Julich (October, 1982).

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5. These include the European Spallation Source (ESS, MW, 1.33 GeV), a BNL design (5 MW, 3.6 GeV), ANL designs for IPNS Upgrades (1 MW, 2 GeV and 5 MW, 10 GeV).

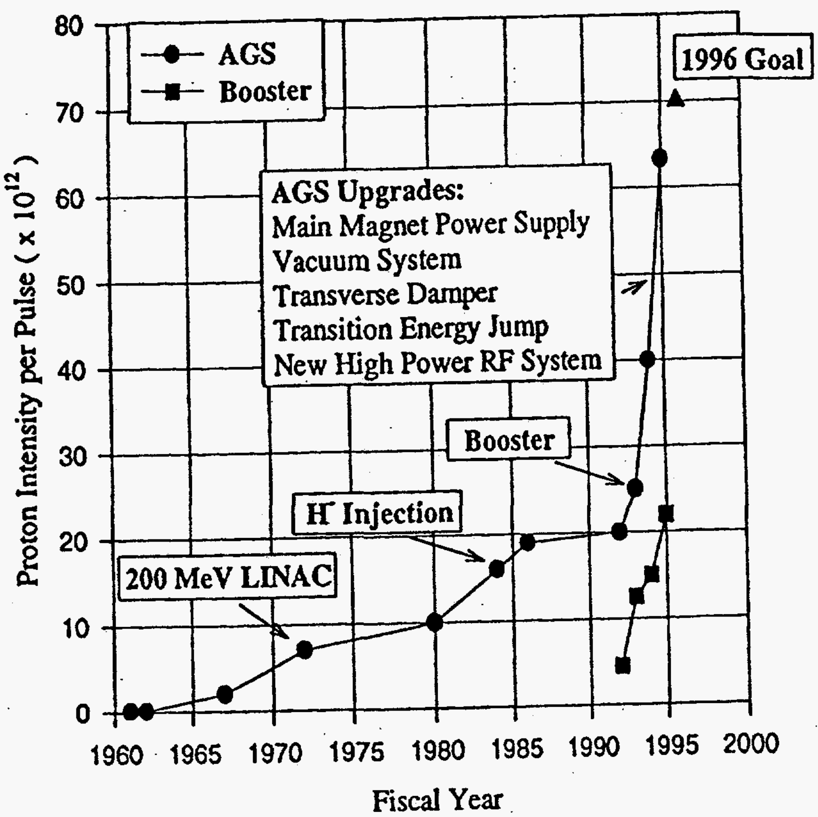

Figure 1 - BNL-AGSComplex Proton Intensity History