PARAMETER AND COST MODEL FOR SPALLATION NEUTRON SOURCE STUDIES

J. D. Galambos and D. K. Olsen
Oak Ridge National Laboratory, Oak Ridge TN, 37831-8218

Abstract

A Spallation Neutron Source Systems Model has been developed to facilitate parameter and cost studies of accelerator-based spallation neutron source (SNS) systems. This model includes modules for all pertinent components and processes, such as accelerators and rings, target (neutron source), experimental facilities, conventional facilities, construction costs, pre-operational costs, etc. Present accelerator modules include room temperature linacs, accumulator rings (AR) and rapid cycling synchrotrons (RCS). All the modules in the model are linked together via an optimizer to facilitate overall trade studies. The model has been developed for and used by the National Spallation Neutron Source (NSNS) project to be built in Oak Ridge.

1 BACKGROUND

For the National Spallation Neutron Source [1] design, there are several accelerator options capable of satisfying the requirments of the neutron scattering community. These requirments are a pulsed neutron source having at least 1.0MW of proton beam power, a pulse rate of 30-60Hz, a pulse width $\leq 1\mu s$, clear upgrade paths to higher power, low technical risk, and high reliability. Conceptual designs already exist for partial-energy linacs with rapid cycling snnchrotron systems [2] and for full-energy linacs with accumulator ring systems [3,4]. The Spallation Neutron Source Systems Model was developed to evaluate and compare these designs on a performance and cost basis and to determine an optimum configuration.

The model contains linkable modules for all the major systems, including linac, ring, target (neutron source), experimental systems, conventional facilities, and costs. By linking these modules, self-consistent trade studies can be conducted to compare different accelerator concepts on a common performance and cost basis. Typically, the cost and physical parameter estimations use simple scalings, derived from detailed studies and cost estimates. The optimization package includes constraints to provide for “minimum cost” and “maximum performance” type design studies. The model can be run without optimization, in a “benchmark” mode to permit comparisons with existing designs and cost estimates.

The details of this model are described in Ref. [5] and are briefly reviewed in Section 2. Results comparing AR and RCS options for the NSNS are presented in Section 3.

2 MODEL DESCRIPTION

2.1 Accelerator Options

The accelerator is the major factor in the cost and neutron production capability of a SNS. Present modules include room temperature linacs, accumulator rings, and rapid cycling synchrotrons. These modules constain: the dependence of average current on peak ion source current, on chopping fraction, on loss estimates, and on duty factor; the dependence of linac power requirement on shunt resistance, on linac length, on beam power, and on accelerating gradient; the dependence of ring RF requirements on ramp rates and on beam currents; the dependence of peak magnetic fields on energy and on bend radius; the dependence of magnet aperatures on emittance, on margins, and on beam current; and the dependence of ring magnet power on aperature, on magnetic field, and on length.

2.2 Conventional Facilities

Although the conventional facilities for a 1MW spallation neutron source are significantly pre-determined, there are a number of scalings that do impact the cost. These include the site power requirements for the linac, ring, target, and moderator cryogenics; the building and tunnel areas and lengths; and the site preperation area.

2.3 Pre-Operations Models

Pre-operational costs are a non-neglibible component of the Total Project Cost (TPC) estimate. Personnel requirements are based on experience at other accelerator facilities, and are found to scale weakly with power. The estimate of utility costs during startup is based on the accelerator requirements. These values are also used to estimate life-cycle-costs over the expected plant lifetime.

2.2 Cost Models

The Cost module derives costs using input from all the other modules. This involves several hundred scalings, mostly derived from benchmarks with existing SNSs or from more detailed design studies. Overheads

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and burdens are also included as appropriate. Estimates from this simple cost scaling method have proven accurate, when compared to subsequent detailed “bottoms-up” studies.

2.4 Optimizer and Driver Shell

The Spallation Neutron Source Systems Model is a C++ code, utilizing the SUPERCODE driver shell [6]. SUPERCODE is an interactive programmable shell that includes a non-linear constrained optimization package and other tools. Typically problems are solved by specifying: (1) a set of constraints, (2) independent variables to be iterated, and (3) a Figure-of-Merit to be optimized.

3 RESULTS

Results of minimum cost verses power level are presented here for both AR and RCS based SNS systems. The costs presented here were calculated in 1996. The TPC from recent detailed estimates is ~15% higher than these results, primarily due to an increase of project scope since the completion of this study.

3.1 *Problem Formulation*

The primary fixed assumptions used in these calculations are listed in Table 1, and the major constraints are shown in Table 2.

Table 1: Fixed Assumptions for cost vs power studies.

Linac:
- Single ion-source (no funneling)
- 80% RFQ capture/bunching factor

Ring:
- One ring
- Ring harmonic number = 1
- 3% injection loss
- AR lattice is NSNS like: Superperiodicity = 3
- RCS lattice is IPNS-U like: Superperiodicity = 4
- Synchrotron accelerating duty factor = ½ i.e. simple sinusoidal wave form
- Ring acceptance / Beam emittance = 8

Balance-of-Plant
- One target station
- Four neutron scattering instruments

Table 2. Constraints on calculated quantities.

Constraint

H^- injection current: $\leq$ 105 mA@ 1% f_{duty}
$\leq$ 37.5 mA@ 6% f_{duty}
Linac chopped time = 65% orbit time
$\tau_{Inject} \leq 2$ msec
$\tau_{Inject} \leq$ 1.5% of ring cycle time
Tune shift $\leq$ 0.15 (at injection)
Dipole field $\leq$ 1.1 T
dB/dt $\leq$ 120 T/s
Ring Length $\geq$ 200 m
Dipole gap = $2\sqrt{\alpha_{ring}\beta_{dipole}}$ +v.v. (1)
Quad bore = $2\sqrt{\alpha_{ring}\beta_{quad}}$ + v.v. (1)
RF cavity field $\leq$ 20 kV/m

1 - Vacuum vessel =1cm for AR, = 3cm for RSC

To find optimal solutions, the variables listed in Table 3 are allowed to vary within the indicated bounds. The Total Project Cost (TPC) was used as the Figure-of-merit.

Table 3. Variable input parameters.

Bound:	Lower	Upper
Linac CCL length	---	---
Linac CCL accelerating gradient (Mev/m)	1.5	3.5
Linac macro duty factor	---	0.10
Ring long drift length	---	---
Ring drift length	---	---
Dipole length (m)	1.	5.
RF Voltage (V)	---	---

3.2 AR Results

Using this formulation, the minimum cost AR SNS was found as a function of power level on target. Results are shown in Fig. 1 for three different choices of linac energy. The cost, the maximum linac power, and the operating cost, all increase with linac energy. It is not possible to achieve a 1MW power level at a cost below $1B, with a linac energy of 1GeV. This energy level is critical, since spallation neutron production drops rapidly at energies below ~800MeV. Although the cost increase with beam power at fixed energy is slight,.the available ion source current limits the maxium attainable power. To achieve higher powers with the given ion source constraints other options, such as funneling, are required.

3.2 RCS Results

Figure 2 shows minimum cost versus beam power for a RCS SNS having a pulse rate of 30Hz and a final energy of 3GeV. The cases shown have injection energies of 400, 600 and 800MeV. Again there is only a slight cost increase with increasing power, but a large increase with injection energy due to the associated cost increase of the linac. As the beam power increases, more protons must be accelerated in the RCS. For a fixed tune shift, this requires increased beam emittance, which in turn increases the magnet aperature requirement, and the cost. These effects are especially pronounced at 400MeV injection energy.

Figure 3 plots the minimum TPC as a function of the final beam energy for RCS pulse rates of 15Hz, 30Hz, and 60Hz. Low extraction energies lead to cost penalties because higher currents and linac RF power are required. This leads to enhancement in the emittances requiring increased ring apertures. For high energies, costs increase due to the increased *B*ρ and increased ring circumference. A slight cost benefit is obtained by increasing the repetition rate. This results from smaller ring apertures due to lower peak beam intensities at higher repetition rates. A limit of 2GeV on the extraction beam energy is necessary in the 60 Hz case because of the dB/dt limit.

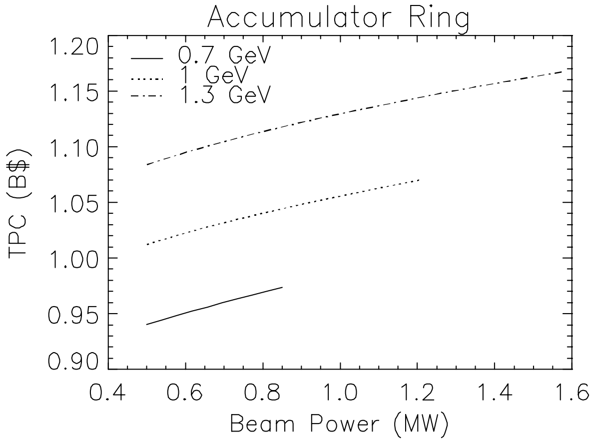

Figure 1. Minimum AR option TPC vs. beam power for different linac energies

4 DISCUSSION

A flexible parameter and cost model has been developed to investigate possible configurations for the NSNS. The model gives more accurate relative cost diferences between options than absolute costs. For a device of NSNS magnitude, a small (< 10%) cost difference exists between AR and RCS options for comparable performance. The model does not include several important considerations, such as technical risk, reliability, and upgrade options. Since the cost difference is small, the choice between the AR and RCS options for NSNS has been made on these other considerations.

11 ACKNOWLEDGEMENTS

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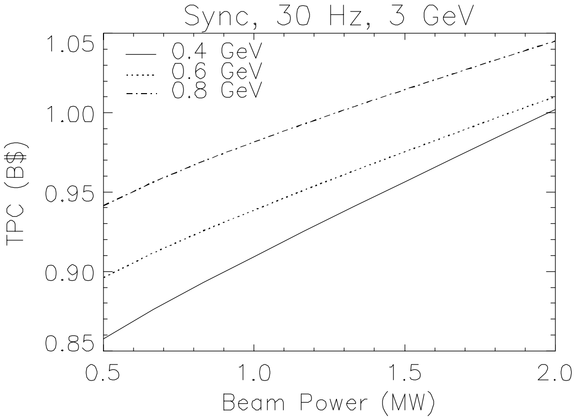

Figure 2. Minimum RCS option TPC vs. beam power for different linac Energies

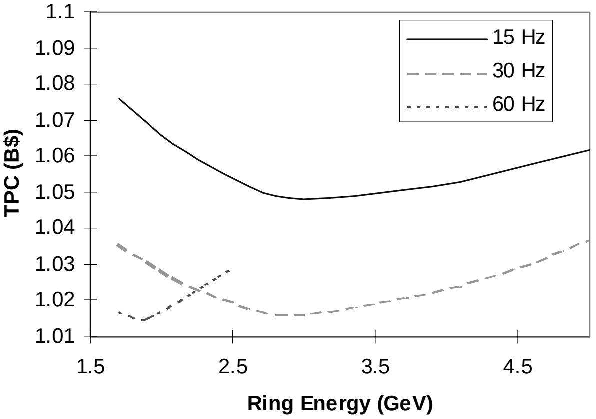

Figure 3. Variation of the minimum cost source with ring energy for a 1 MW RCS SNS.