Department of Energy
Review
of the
National Spallation Neutron
Source Project

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Executive Summary

A Department of Energy (DOE) review of the Conceptual Design Report (CDR) for the National Spallation Neutron Source (NSNS) was conducted at the request of Dr. James F. Decker, Deputy Director, Office of Energy Research, of the DOE. The NSNS will be a new high-power spallation neutron source; initially, it will operate at 1 megawatt (MW), but is designed to be upgradeable to significantly higher power, at lower cost, when accelerator and target technologies are developed for higher power. The NSNS will enable a wide variety of unique neutron scattering experiments in materials science, solid state physics, engineering, chemistry, and structural biology.

The fifty-three member Review Committee met in Oak Ridge on June 23-27, 1997. They examined the projected cost, schedule, technical scope, and management structure described in the Conceptual Design Report (CDR). The CDR represented the combined efforts of a five-laboratory consortium—Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Lawrence Berkeley National Laboratory (LBNL), Los Alamos National Laboratory (LANL), and Oak Ridge National Laboratory (ORNL)—headed by ORNL. Members of the review committee were chosen for their scientific and/or technical expertise in design, construction, operation, and management of similar facilities worldwide.

The Committee validated the technical scope of the CDR. For each of the major components of the NSNS, the Review Committee determined that the project team had produced credible designs that can be expected to work well. What remains to be done is to integrate the design of these components. With the exception of the liquid mercury target, the NSNS Project will rely heavily on proven technologies and, thus, will face a relatively low risk to successful project completion. There is little experience with liquid metal targets, but preliminary studies indicate that a mercury target will be successful. The mercury target is already undergoing extensive R&D in collaboration with the Europeans and the Japanese using the high energy proton beams from the Alternating Gradient Synchrotron (AGS) at BNL and other facilities around the world.

The Total Project Cost (TPC) presented to the Review Committee in the CDR was \$1.266 billion in as-spent dollars. In general, the Committee felt that the laboratory consortium had presented a credible estimate for each of the major components but that value engineering might produce some savings. The TPC includes design work done in the year prior to the review, R&D, commissioning, and the line item construction cost. The Committee felt that increased R&D to develop the linac and advanced neutron scattering instruments for the user beam lines would enhance the capital investment in the NSNS.

The construction schedule presented to the Review Committee covered six years beginning in FY 1999. The Committee questioned whether all parts of the project could be completed according to this schedule. In particular, the linac and the conventional facilities appeared to have overly optimistic schedules. The NSNS project team was encouraged to reexamine these activities and to consider a more conservative seven-year schedule.

Another concern of the Committee was the management structure. The Committee commended the current management team for the significant and successful effort in organizing this project and leading it to the completion of the CDR. However, the Committee noted the absence of a small but critical cadre of permanent NSNS senior management personnel at ORNL. The major management recommendations of the Review Committee are:

1. Define the senior management structure of the NSNS project and fill key positions as soon as possible.
2. Establish a management group (at ORNL) composed of technically qualified personnel who will be responsible for each of the major parts of the project and who will review, integrate, and manage technical systems across the whole project.
3. Develop an accelerator physics group (at ORNL) as soon as possible to oversee the accelerator construction project and to assure optimization of accelerator performance for neutron scattering science.
4. Begin hiring neutron instrument scientists and engineers soon to drive the development of develop advanced instrumentation.

In summary, the Committee felt that this Conceptual Design Report was a very credible proposal, and that there is a high probability for successful completion of this major project within the proposed budget, although the six-year proposed schedule may be optimistic.

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REPORT
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1. INTRODUCTION

1.1 Background

The National Spallation Neutron Source (NSNS) will be a unique user facility for basic research, providing the world's most intense neutron beams for the study of the structure, excitations, and atomic arrangements of materials. In the NSNS, a beam of H^- ions will be accelerated to 1 GeV in kinetic energy using a linear accelerator (linac). The H^- beam will then be transported to an accumulator ring, where the H^- ions are converted to protons in the injection process, then accumulated and bunched into short pulses. This proton beam will then be deposited in a target of liquid mercury, where intense pulses of neutrons will be created and delivered to the users' experiments in several areas.

The preferred site for this facility is at Oak Ridge National Laboratory.

Neutron beams are unique and increasingly essential tools broadly applicable to the physical, chemical, and biological sciences, as well as materials technology and nuclear medicine. Over the past decade, neutron probes have made invaluable contributions to the understanding and development of many classes of new materials ranging from high-temperature superconductors to fullerenes. The most rapidly developing area is the use of cold neutrons in the science of polymers and complex fluids—materials with enormous industrial importance and applications. The many awards given in recent years for achievements in neutron scattering research attest to the growing importance of neutrons in United States science and technology. Other essential uses of neutrons for technological purposes include radiation damage studies for fission and fusion reactors, depth profiling of near-surface impurities, and residual stress measurements in metals, ceramics, as well as composite materials.

Over the last 20 years, the United States has fallen alarmingly behind Europe in the availability of up-to-date neutron sources and instrumentation. The major research reactors of the U.S. Department of Energy (DOE), the High Flux Beam Reactor (HFBR) and the High-Flux Isotope Reactor (HFIR), were built more than 30 years ago. A rapid decision and funding process leading to a new, non-reactor-type neutron source with advanced performance is essential to assure that the nation retains a world-class position in the above mentioned areas, which are of great importance to its economic strength. The NSNS will require about \$1.3 billion in project funds over a period of approximately six years.

Construction will provide substantial new employment opportunities, including many in high-technology areas. The NSNS will serve the country for about 40 years after completion. The new source will be of great value to the missions of a number of DOE organizations in addition to the Office of Basic Energy Sciences, such as the Office of Fusion Energy, the Office of Biological and Environmental Research, and the Office of Defense Programs. Furthermore, an advanced neutron source is increasingly important to the Department of Commerce and the Department of Defense, as well as to the National Institutes of Health and the National Science Foundation.

DOE has worked closely with scientists since the early 1970s in planning for their neutron source needs. In 1996, DOE's Basic Energy Sciences Advisory Committee (BESAC) strongly reaffirmed the need for a next-generation, pulsed spallation neutron source to meet the future needs of the scientific community. This assessment followed closely on the heels of a 1993 BESAC study, *Neutron Sources for America's Future*, which provided a comprehensive assessment of the needs and options for new neutron facilities that would provide the United States with sources competitive with those now in operation in Europe and Japan. This study also eloquently summarized the broad uses and future opportunities for neutrons in science and technology.

The 1996 BESAC report recommended design of an accelerator-based spallation neutron source that could begin operation at a beam power of approximately 1 megawatt, but with sufficient flexibility that it could be upgraded to as much as 5 MW in power in the future to meet the continually growing needs. The report also recommended that the source be highly reliable in its operations, with high availability so that users could run their experimental programs efficiently.

In response to this national need, DOE provided \$500,000 to ORNL in FY 1995 for initial scoping studies on the spallation neutron source. In the FY 1996 and FY 1997 budgets, DOE recommended and Congress appropriated \$8 million each year to begin work on this new source. DOE directed the funds to ORNL to initiate research and development (R&D) and a conceptual design.

To accomplish this task, ORNL has organized a collaborative design effort involving themselves, Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Ernest Orlando Lawrence Berkeley National Laboratory (LBNL), and Los Alamos National Laboratory (LANL). Other laboratories, United States industrial firms, and universities will be involved as the project matures. This collaborative approach was taken in order to access the best technical expertise available, to initiate a conceptual design process that made the most efficient use of the DOE work force and resources, to incorporate a number of previous feasibility studies by the collaborating laboratories, and to consolidate community consensus. In addition, memoranda of understanding have been signed with the European Spallation Source and several European laboratories to gain access to research results and technology developments that could further assist the NSNS design effort.

BNL, LANL, and LBNL are responsible for the accelerator system design, which will be coordinated by an accelerator design group at ORNL. ORNL is responsible for the coordination, installation, and operation of the new source; for project management; for conventional construction; for target design together with ANL; and for experimental-systems design. The goal of the NSNS collaboration is to complete the conceptual design so that a line-item request can be made to DOE for FY 1999.

The reference design proposed for the NSNS consists of a high-energy linear accelerator (linac) injecting 1 GeV H^- ions into an accumulator ring that produces short bursts of protons at extremely high

energies and power levels. These proton pulses would be directed onto a mercury target where, through the spallation process, neutrons would be produced. The neutrons would be moderated (brought to the desired energies) and guided into experiment areas for a wide variety of uses.

The conceptual design of the NSNS has taken two years to complete. The total cost of the facility will be about \$1.3 billion, and it should be in operation by the year 2005 if construction is initiated in FY 1999. The NSNS will produce the highest-flux pulsed neutron beams in the world. It is estimated that the facility will attract more than 1,000 scientists and engineers each year from universities, industries, government laboratories, and other nations.

The reference design is consistent with the recommendations of the 1996 BESAC panel. The approach is to design a spallation source that can be built in stages. The first stage will be a 1 MW source that can be upgraded to 4-5 MW in the future, as funds allow and users' scientific needs indicate. Initially, the target, moderator, and experimental systems will provide cold and thermal neutrons to 18 beam lines. The possibility of adding a second target station with its own complement of instruments for neutron scattering is left for the future. International workshops have been held to gain input for the target design and to select the proper radiation-resistant materials. An international collaboration has been formed to carry out R&D on liquid mercury targets using the proton beam from the Alternate Gradient Synchrotron (AGS) at BNL and other accelerator sources. An NSNS Neutron Users' Workshop was held in October 1996 to establish the desirable operating parameters and instrument designs that best meet the users' needs.

When completed, the NSNS will provide the most intense beams of neutrons in the world. The NSNS is designed to make future upgrades to higher powers extremely cost-effective, so that the United States should be able to stay at the forefront of neutron science for many years.

ORNL, the University of Tennessee (UT), and the state of Tennessee have initiated plans for a Joint Institute for Neutron Science. This institute will enhance the utility of both the NSNS and the High Flux Isotope Reactor at ORNL by providing meeting facilities, offices, laboratories, a communication center, and housing for scientists and engineers from universities, industries, and the international research community. It will also be a focus for expanding neutron science R&D with UT, other regional universities, and industrial collaborators, and will serve as an interface and economic development gateway for outside access to ORNL's neutron science facilities. Funds were included in the state of Tennessee's FY 1996 budget to begin design of the Joint Institute for Neutron Science.

1.2 Charge to the DOE Assessment Committee

In a February 6, 1997, memorandum to Daniel Lehman, Director of the Office of Construction Management Support Division (Appendix A), Dr. James F. Decker, Deputy Director of the DOE Office of Energy Research, provided the DOE NSNS Conceptual Design Report Review Committee with the following charge:

Because of the size of the potential investment in the National Spallation Neutron Source Project, its importance to the Department of Energy laboratories, its impact on the United States neutron sciences research programs, and its importance to United States participation in future international science projects, the Office of Energy Research will need to be able to substantiate to Congress and to elements of the Administration that its investment in the National Spallation Neutron Source Project is reasonable and likely to achieve the expected results within the planned cost and schedule.

Therefore, I request that you assemble a committee of experts charged as follows.

The National Spallation Neutron Source Conceptual Design Report Review Committee should assess the technical feasibility and expected performance of the designs proposed for the National Spallation Neutron Source. The committee should carefully review the cost estimates, identify uncertainties, and judge the overall validity of the estimates. Cost optimization should also be considered. The realism of the plans for meeting the required schedule should be carefully evaluated on the basis of the expected funding profile. The manner in which this work will be accomplished, including how it will be managed, should be reviewed and assessed. In summary, the committee is to review and assess the technical feasibility of achieving the proposed technical goals for the National Spallation Neutron Source, and the credibility of the associated cost and schedule estimates, and the adequacy of present and planned management arrangements to accomplish the scope of work.

1.3 Membership of the Committee

The committee was chaired by Daniel R. Lehman, Director of DOE's Division of Construction Management Support, Office of Energy Research. It was organized into ten subcommittees with members primarily drawn from DOE national laboratories, universities, and the DOE Office of Energy Research. In addition, the committee included observers from DOE and the National Science Foundation, support personnel, and a report coordinator. The committee membership and subcommittee structure are shown in Appendix B.

1.4 The Assessment Process

The review was planned and agreed to as part of the normal sequence of events in the formulation of a major DOE construction project. The agenda was developed with the cooperation of the NSNS project and DOE staff.

The review took place June 23-27, 1997, at Oak Ridge, Tennessee. The first day was largely devoted, in plenary session, to project-overview presentations by members of the NSNS project staff. These presentations were based on the conceptual design described in *National Spallation Neutron Source Conceptual Design Report* (NSNS/CDR - 1-3/May 1997).

On the second and third days, members of each subcommittee met with their NSNS counterparts to discuss the details of the scope, cost, schedule, and management of each system. The presentations were well prepared and the discussions were highly informative. The next two days focused on subcommittee working sessions, committee deliberations, and the drafting of this report. The draft report was reviewed by NSNS staff for accuracy on points of fact. The preliminary results of the assessment were discussed with NSNS project management and staff at a closeout session on the afternoon of June 27. The report was subsequently reviewed by members of the CDR Review Committee, and edited before publication.

Comparison with past experience on similar projects was the primary method for assessing technical requirements, cost estimates, schedules, and adequacy of management structure. Although this project requires some extrapolations, similar accelerator projects provide a relevant basis for comparison. In the United States, these include the Fermilab Tevatron, the Superconducting Super Collider (SSC), the Continuous Electron Beam Accelerator Facility (CEBAF), the Advanced Photon Source (APS) at Argonne, the Brookhaven Relativistic Heavy Ion Collider (RHIC) projects and the Fermilab Main Injector (FMI).

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2. OVERVIEW OF DESIGN

2.1 Background

The NSNS will be an accelerator-driven spallation neutron source proposed for construction at Oak Ridge National Laboratory to serve more than 1,000 user scientists each year. The structures and behavior of a wide variety of the increasingly complex materials that are of scientific and engineering interest today—ranging from polymers, ceramics, metals, magnets, and superconductors to biological macromolecules and complex fluids—will be studied with its powerful neutron beams.

The facility will consist of a front end with an ion source to produce a beam of H^+ ions at a current of approximately 35 milliamperes, which will be accelerated to 1 GeV kinetic in energy by a robust linear accelerator, and in turn, this beam of H^+ ions will be converted into a proton beam and injected into an accumulator ring to bunch the proton beam into short (600 nanosecond) pulses. This proton beam of about 1 MW will then be deposited into a liquid mercury target to generate neutrons. The neutrons will be moderated to achieve low (1 millielectron volt) energies suitable for probing structures ranging from 1-100 angstroms in materials. At 1 MW, the NSNS will be the world's most powerful spallation neutron source, about six times the 160 kW power of ISIS in the United Kingdom, currently the most powerful source. The NSNS will be built with the ability to be upgraded to 4-5 MW and with the ability to add a second target station and complement of neutron instruments.

2.2 Design Requirements/Feedback from User Community

The process involving the scientific community that has settled on the functional requirements for the NSNS has been long, deliberate, and evolutionary. There were rapid advances in neutron science not long after the first neutron sources were built and used in the United States. As improved cold neutron sources, neutron guides, and advanced instrumentation have been developed, the applicability of neutron scattering to a much broader range of science became apparent. The Europeans were the first to capitalize on these advances and built fully-equipped, new research reactors and accelerator-based sources that have given them the competitive edge for the past 20 years. Furthermore, while new science and industrial applications have increased the demand for more intense sources, existing sources worldwide began declining as aging facilities were shut down. All these factors underscore the need for next-generation neutron sources, and consequently, there are intense planning efforts for new sources in Europe and Asia as well as in the United States.

The NSNS design concept, and the design activities in Europe and Japan, also mark a trend away from the more traditional steady-state research reactors to accelerator-based sources for neutron scattering. The accompanying illustration (Figure 2.1) provides some insight to trends in the developments in neutron-production-oriented reactor and accelerator facilities, starting with the discovery of the neutron by Chadwick. This figure compares the peak thermal neutron flux versus the year the facility began or is scheduled for operation. It should be noted that this figure compares peak fluxes for

Development of Neutron Science Facilities

both steady-state and pulsed sources. Even though the pulsed sources have high peak fluxes, they lack the integrated neutron flux of steady-state sources; and while peak flux is an important parameter for neutron scattering, total flux is needed for such uses as isotope production. This figure shows that while reactor sources have leveled off in performance, accelerator-based sources show considerable promise for even higher intensities in the future. Advances in accelerator design and technology, new approaches to targets and instrumentation design and measurement techniques, and increasing difficulty in gaining acceptance for nuclear reactors have all contributed to this trend toward using accelerators for the new sources being planned.

The functional requirements for the NSNS have been set by recommendations by the scientific community and DOE, obtained through distillation of the many assessments and events dating from the 1970s that firmly established the need and justification for a new neutron source. From these studies and recent user meetings, the requirements the community would like designed into the NSNS are:

- The community prefers a short-pulse (~ 1 μ sec) spallation neutron source that begins operation at a beam power of 1 MW but has sufficient design flexibility to be upgraded to significantly higher powers in the future. These requirements arise from the realization that a source more intense than 1 MW is desirable, but funds and technology may not be available at present. However, if flexibility is included in the original design, future upgrades can be accomplished much more economically than by building a new, more powerful source from scratch, and can be accomplished in stages to keep interruptions in the research program shorter than six months.
- The community requires a source that is highly reliable and available for experiments. This need has prompted NSNS to employ reliable and low risk technologies in the design. Although the mercury target is a new concept, it has features superior to solid targets which will be necessary for higher power upgrades.
- The community would like two target stations, one operating at about 60 Hz and one at about 10-20 Hz. This preference is driven by the need for more instrumentation than can be accommodated in one experiment hall, and by the need to tailor the beam lines, moderators, and instruments to the beam frequency. The NSNS will provide the 60 Hz target first and work with the community for a second target hall as soon as practicable.
- The community has considered the merits of long pulse sources (~ 1 ms) and requested that the NSNS design not preclude this as an option at some time in the future. This request has been accommodated.

2.3 Reference Design

Neutron scattering requires low-energy (millielectron volt) neutrons, with de Broglie wavelengths commensurate with the size of the structures being studied. Pulsed, accelerator-based sources offer advantages over reactors, as the ease of obtaining sharp pulses of protons ($\sim 1 \mu\text{s}$) onto a neutron-producing target leads to easy determination of the neutron wavelengths by time-of-flight measurements. Proton energies between 1 and 5 GeV prove optimal for neutron production via spallation reactions in heavy-metal targets. The production rate of neutrons is directly related to the power deposited on the target and yields 20-30 neutrons per incident proton at 1 GeV. Pulse repetition rates of between 10 and 60 Hz cover the range of experimental requirements.

These specifications map readily into accelerator configurations based on linacs accelerating H^- pulses of around 1 ms length, multiturn stripping injection into a ring that serves primarily as a pulse collector/compressor, with single-turn extraction onto a target. Powers in the megawatt range (time-average) are close to current technology limits for a single ring, requiring the stacking of around 1,000 turns and storing around 1 to 2×10^{14} protons in each pulse.

Designing targets for these high powers is difficult. It is generally believed that a 1 MW target is relatively straightforward, but the shock loads, radiation damage, and heat dissipation requirements on a 5 MW target will require further development. Current wisdom points to a liquid metal such as mercury as the best material. Achieving millielectron volt neutron energies requires placing the moderators close to the target; both ambient temperature (water) and cryogenic (liquid hydrogen or liquid methane) cells are to be employed. A single target will produce neutrons for many experiment lines; typically about 18 ports are instrumented and can run simultaneously.

To address the needs expressed by the neutron community, the NSNS team examined the relative merits of several technology options, including a full-energy linac plus accumulator ring versus a lower-energy linac plus rapid cycling synchrotron. While it was realized that the synchrotron option might be less expensive, the reduced technical risks and flexibility for future upgrades of the full-energy linac and accumulator made this option a superior choice for keeping pace with evolving needs.

To determine relative costs, a cost-model code was developed at ORNL and validated against parameters from several studies and recent construction projects at LANL, BNL, ORNL, and ANL. This code was employed to perform a detailed comparison between the accumulator and synchrotron options and showed that the synchrotron-based facility would indeed be slightly (around 10 percent) less expensive. However, the relatively modest cost for upgrading the 1 MW accumulator-ring scenario to 2 MW, and the flexibility of the accumulator option for additional upgrades to significantly higher powers and long-pulse operation, more than offset that saving.

As a result of these studies, NSNS has concluded that a full-energy linac injecting into an accumulator ring is the best combination of technologies for the accelerator system. A liquid mercury rather than a solid target was chosen initially because this appears to be the best option to accommodate higher power upgrades in the future, but as design activities have progressed, it is now concluded that this is the superior choice even at 1 MW power levels. A 60 Hz target was selected for the initial experiment system to accommodate the majority recommendations from the Users' Workshop (held in Oak Ridge, October 31-November 1, 1996), although a clear need was expressed for both high- and low-frequency targets in the near future.

A schematic representation of the layout of the 1 MW phase of NSNS is shown in Figure 2.2. This layout shows the plan for the facility, along with the support buildings and target building. The beam originates in the ion source in the front end building at the left of the figure, is accelerated in the linac, accumulated and bunched in the ring structure, and is extracted and transported to the target building at the extreme right.

2.4 Accelerator Reference Design Parameters

The performance parameters for the NSNS accelerator system reference design are listed in abbreviated form in Table 2.1. The first column of parameters is for the initial stage of the NSNS that would operate at a power of 1 MW. The second column shows those parameters that would be changed for the NSNS to operate at the upgraded power of 2 MW. As discussed in following sections, the NSNS is designed so that the upgrade to 2 MW mainly requires increasing the ion source current to 70 milliamps and boosting the radiofrequency (rf) power to the existing linac structure to accelerate the additional beam, and this can all be accomplished quite economically.

NSNS Site Plan

NSNS

Table 2.1 National Spallation Neutron Source Performance Parameter

Reference design parameter	Initial 1.0 MW	Upgrade to 2.0 MW
Pulse repetition rate	60 Hz	
Peak ion source H ⁻	35 mA	70 mA
RFQ capture-bunching factor	>80 percent	
Linac length	493 m	
Linac duty factor	6.2 percent	
Linac final beam energy	1.0 GeV	
Accumulator ring circumference	220.7 meter(s)	
Ring controlled injection loss	<10 percent	
Ring orbit rotation time	841 ns	
Pulse length at ring injection	546 ns	
Kicker gap at ring injection	295 ns	
Ring filling fraction	65 percent	
Number of injected turns	1225	
Ring filling time	1.03 msec	
Protons per pulse on target	1.04E+14	2.08E+14
Protons per second on target	6.3E+15	1.25E+16
Time average beam current on target	1.0 mA	2.0 mA
Beam power on target	1.0 MW	2.0 MW

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3. TECHNICAL SYSTEMS - EVALUATIONS

3.1 ACCELERATOR PHYSICS

3.1.1 Summary

The Accelerator Physics subcommittee evaluated technical issues related to beam dynamics in the front end, linac, ring, and target subsystems in the accelerator chain that forms the NSNS complex. In the sense that most of these issues involve more than one of the accelerator subsystems, the subcommittee reviewed the technical system integration of the proposed design. The committee did not evaluate cost or schedule aspects of these issues.

The committee did not find any "show stopping" physics issues in the conceptual design of the NSNS. The multi-laboratory project collaboration deserves praise for developing a design that is basically sound.

Nonetheless, the conceptual design of the NSNS is at a stage in which value engineering has yet to be applied in a rigorous way to the beam dynamics performance of the complex as a whole, in order that costs may be reduced while maintaining end-user performance. Analyses and simulations incorporating realistic imperfections (such as errors and misalignments) also need to be actively pursued and completed in a timely fashion.

NSNS is primarily a user facility designed and built to provide neutrons to experimenters. Availability and predictability are of the utmost importance to the users. A nominal availability rate of 85 percent has been mentioned. The definition of required total system availability is not clear, however, and it is not apparent that it has been translated into performance requirements (MTBF, MTTR, et cetera) (see Glossary) for each subsystem. Nor is it clear that Reliability, Availability, and Maintainability (RAM) have been taken into consideration for each subsystem.

Integration of accelerator physics design issues across accelerator section boundaries is, at this stage of the project, a fundamental management problem. There is almost no appropriate expertise currently resident at ORNL. Accordingly, the management findings and evaluations, included below, make their way directly into two of the four recommendations, and indirectly into the other two.

3.1.2 Technical Scope

Findings

NSNS is a large, complex facility built from multiple subsystems, with responsibility for each lying at one of the five laboratories. It is, therefore, important that a complete set of requirements be developed for

each subsystem, which are traceable to top level requirements. These system requirements must be sufficient to fulfill the performance needs, but, in order to minimize costs, also restricted to that which is necessary. A clear distinction needs to be made between requirements and goals, and also between required and expected values for the design or performance parameters. For example, this distinction needs to be applied to the emittance budget, reliability budget, expected misalignments, and beam line vacuum requirements.

While NSNS will originally be built for 1 megawatt (MW), it is planned to be easily upgradeable to 2 MW with only minor modifications to the hardware (besides the addition of more rf power), and later to 4 MW. Toward this end, all accelerator physics studies—for the front end, linac, and ring—ought to be performed at 55 mA of beam current instead of 27 mA. All subsystem components that will need removal, modification, or replacement along the 1 to 2 to 4 MW upgrade path ought to be clearly identified and evaluated to minimize future upgrade costs.

The upgrade to 4 MW calls for duplicating the front end and drift tube linac (DTL) and funneling at 20 MeV. Besides the cost associated with duplicating the front end, funneling is technologically challenging and will require much additional R&D. Since an upgrade to 4 MW might not happen for another 10 years, advances in H^- sources, radiofrequency quadrupole accelerators (RFQs), medium energy beam transport systems (MEBTs), and linac physics may take place, so by that time, funneling might not be the only technical option for a 4 MW upgrade.

Beam losses and collimators. Preliminary studies have been performed on beam loss mechanisms in the linac in the (almost) complete absence of misalignments and other errors. Space charge and beam mismatches were shown to be the primary mechanisms of halo generation. Gas collisions converting H^- to H^0 were shown to be a major contributor to local radioactivation in the linac. Both analytical and simulation results suggest that the chosen margin for beam halo—9 sigma for the Drift Tube Linac (DTL)/coupled cavity drift tube linac (CCDTL) and 11- 14 sigma for the coupled cavity linac (CCL)—provide the design goal of <1 nA/m. Comparison to Los Alamos Neutron Scattering Center data gives further confidence. One concern here is the strongly non-uniform character of loss distributions, which requires further study for NSNS. Another concern is the need to incorporate realistic errors and correction schemes in the simulations.

It appears that beam losses represent the main potential performance limitation. The committee generally endorse the approach that has been adopted for beam loss handling in the High Energy Beam Transport System (HEBT), ring, and Ring to Target Beam Transport Line (RTBT), via momentum selection and halo collimation. In principle, the collimation scheme presented should allow the design goal of 2×10^{-4} total beam loss to be achieved. Nonetheless, the scheme needs further optimization with respect to collimator locations, the number of collimators, the need for momentum cleaning in the ring, etc. The collimator design is pretty solid, but needs further stress analyses and optimization of efficiency and cost.

Beam-loss-induced component radiation damage and radioactivation need detailed consideration.

The committee recommend the generation of a map, based on further analyses and simulations, of expected accumulated doses and residual dose rates for all major components from front end to the target and beam dumps. This would replace the single "magic" number for a fraction of the beam to be lost. It would also aid in the early choice of optimum component materials, and in developing maintenance and replacement approaches.

Worst-Case Beam Accident. A worst-case full beam accident is well defined from an Environment, Safety, and Health (ES&H) standpoint at 25 Rem/h on shielding and 1 Rem/h off-site, although it is not clear why the off-site accidental limit is 10 times higher than at other laboratories such as Fermilab and the SSC. A definition of the worst-case scenario for machine components is also absolutely vital, since a ~30 kJ beam can cause serious damage to equipment. The committee recommend identifying failure modes for major components, and the resulting consequences, as soon as possible.

Arguments were presented as to why the linac and compressor option is superior to the rapid-cycling synchrotron option. The committee concur that the former option is more flexible and has a lower risk, although previous reports have suggested that it may be more expensive. We, therefore, suggest there is no longer a need to vigorously investigate the synchrotron option.

The H^- charge exchange scheme for injection into the accumulator ring was presented as a work in progress. The proposed painting scheme did not appear to be optimized in terms of minimizing either the number of foil traversals or the space charge tune shift. In particular, the maximum space charge tune shift in the simulations was significantly larger than that quoted in the parameter list. It is also twice as large as that in the ESS design. The committee realizes that there is no hard limit for space charge tune shift, and, therefore, agree that simulations should be upgraded to include the detailed nature of the space charge forces. However, in order to determine an upper limit on the tune shift, it is important that the simulations include lattice closed-orbit errors, other linear errors, chromatic effects, and nonlinear magnetic field terms. It is also highly desirable to benchmark the simulations against an existing ring such as the Los Alamos Proton Storage Ring (PSR). These simulations are challenging but high in priority, since demonstrating the goal of hands-on maintenance requires accurate tracking at the level of 1 part in 10,000.

The shortness of the storage time in the ring mitigates the effects of the 40 ampere circulating current, making wall-impedance-driven instabilities less of a concern. However, the user community should be polled to make sure there will never be any applications which require storage times much longer than 1 millisecond.

It is becoming well established that the fast instability which limits the performance of the LANSCE PSR is related to electron trapping in the proton beam. The committee will therefore refer to it as the e-p instability. This instability is not observed in ISIS, and was successfully overcome at the Intersecting Storage Rings (ISR) at CERN. The latter example is particularly apt since the highest circulating current achieved at the ISR is twice as large as proposed in the SNS ring. The key to a design which is safe with regard to the e-p instability is control of electron sources. The ring design

group has made an exhaustive analysis of such sources and has designed the ring with various source suppressing features. Nevertheless, progress in understanding the PSR instability translates directly to a reduction of risk on the one hand, and the relaxation of electron source suppression features on the other.

The LANSCE linac and PSR are the most relevant machines with which to compare the NSNS linac and ring. Many lessons have been learned from them. As far as we can tell, these lessons are being implemented in the NSNS ring design. However, this in itself does not ensure that the loss goal will be met. There needs to be a tighter collaboration between the ring designers and those at LANSCE who are involved with the PSR upgrade and machine experiments. This may result in proposals from the NSNS ring designers for beam studies at the PSR. Such experiments should be supported with adequate resources. The committee noted with some concern that such a collaboration is not explicitly mentioned in the NSNS Research and Development Plan.

The Fermilab recycler is a 3-kilometer-circumference, 8 GeV proton storage ring currently under construction, using permanent magnets almost exclusively. Fermilab already has preliminary experience operating an 8 GeV transfer line to the recycler, also using permanent magnets. Permanent magnets are very attractive in terms of reliability, maintainability, and operating costs for fixed energy applications in the NSNS, in particular in the HEBT and RTBT lines. It may be advantageous to extend the use of permanent magnet quadrupoles in the NSNS linac beyond the DTL section. While permanent magnets may prove to be inappropriate for the ring, this option has not yet been properly evaluated.

Evaluations

To summarize, the committee reached the following technical conclusions and recommendations:

1. *Develop and distinguish between "expected" and "required" parameters (for example, emittances and error misalignments).*
2. *Begin error and correction studies and simulations of the front end, linac, ring, etc.*
3. *From expected operational loss rates, develop equipment lifetime and activation estimates.*
4. *Define a worst-case full-beam accident to machine components, including:*
 - *Minimum beam spot sizes on foils, collimators, beam windows, dumps, and targets.*
 - *Component integrity, coolant and mercury spillage, and other consequences.*

- *Semi-quantitative estimates of the probabilities of such events.*
5. *Further develop the collimator design, with the respect to the use of tungsten, aperture immobility, number, location, and cost:*
 - *Consider an adjustable jaw option which allows drastically better halo control, especially with the project upgrades.*
 - *Consider replacing the tungsten with steel or copper of slightly increased length, significantly reducing the cost and residual dose rates*
 6. *Further optimize the ring lattice and beam gymnastics (for example, magnet aperture reduction, 2-D and momentum painting*
 7. *There is no longer any need to study the rapid cycling synchrotron option with a large effort.*
 8. *Consider the use of permanent magnets in HEBT, RTBT, the ring, and also in linac quadrupoles beyond the DTL.*
 9. *Pursue ALL accelerator physics studies in the front end, linac, ring, etc., with 55 mA beams. Identify hardware which will need removal, modification, or replacement in upgrades from 1 to 2 to 4 MW.*
 10. *Investigate alternative routes to 4 MW besides funneling.*

3.1.3 Management

Findings

Technical system integration cannot be effectively performed without technical knowledge of the systems being integrated. This technical knowledge includes (but extends beyond) accelerator physics. Accelerator physicists are essential to technical design integration, either in centralized fashion as a single Accelerator Physics or Accelerator Development group, or decentralized as individual members of multiple groups. Currently there is only minimal presence of accelerator physicists at ORNL, although, of course, there are many at the collaborating laboratories. It is essential that a core group of Accelerator Physicists be built up at ORNL as soon as possible.

The project should establish a Machine Advisory Committee, which evaluates accelerator technology issues almost exclusively, and which is independent of the funding agencies. The Relativistic Heavy Ion Collider (RHIC), the Main Injector at Fermilab, and the Large Hadron Collider (LHC) are examples of current accelerator construction projects which benefit from such committees. In these three examples the committee members are chosen from outside the project, report to project management, and meet once or twice per year.

Evaluations

Consider establishing an independent technical Machine Advisory Committee which would meet once or twice a year and maintain good communication with the ESS design effort.

3.1.4 Recommendations

1. *Assemble a core Accelerator Physics/Design group at ORNL as soon as possible. This core group would refine and "own" the designs and the requirements of all accelerator subsystems, and would be responsible for design integration from the ion source to the instruments. The core group would also provide continuity from the design stage through commissioning to operations.*
2. *Continue to study, and preliminarily resolve, expected beam loss rates and the ability to perform hands-on maintenance in the ring, HEBT, RTBT, and the linac (in order of concern). Beam losses may fundamentally limit the performance of the NSNS.*
3. *In collaboration with the users, define and quantify the expected availability and predictability of beam delivery to the experimenters. Translate these top level requirements into subsystem requirements, and investigate ways to increase the cost effectiveness of reliable beam delivery.*
4. *Increase active involvement of NSNS in LANSCE linac and PSR accelerator studies, in FY 1998 and beyond, to increase confidence in natural extrapolations from the observed performance of LANSCE to the expected performance of NSNS. Attempt to reduce conservative safety factors in the NSNS design, when and where possible.*

3.2 FRONT END

3.2.1 Summary

The Front End (FE) includes the ion source, RFQ linear accelerator, low- and medium-energy beam transport systems (LEBT and MEBT) and ancillary controls and services to produce the H^- beam and do the initial acceleration. The boundary between the FE and the linac is defined to be where the MEBT meets the drift tube stage of the linac, with the exception that the fast chopper in the MEBT is the responsibility of the Linac group. The FE is required to deliver an H^- beam to the linac at an energy of 2.5 MeV, a current of 28 mA and an emittance of $0.175 \pi\text{-mm-mrad}$ (rms, normalized). The RFQ, LEBT, and MEBT are designed and will be built for 56 mA to provide an upgrade path for the facility from the initial 1 MW to 2 MW.

Approximately one third of the work on the FE is research and development (WBS 1.1.1). This is appropriate. The technical scope that is proposed is complete and adequate. The technical design is conservative and should meet the 1 MW requirement. The design of the RFQ should be revisited to ensure that it is adequate to support the 2 MW upgrade requirements. The costs have a solid basis, with most major cost items based on previous work done or vendor quotes. The schedule appears to have adequate float to handle contingencies; the front end is not on the critical path for the facility and the proposed milestones appear achievable.

3.2.2 Technical Scope

This front end subsystem has to provide, with high reliability, a 28 mA peak current, 2.5 MeV H^- beam to the entrance of the drift tube linac at 60 Hz, with a 1 ms pulse width, and with a normalized rms emittance $\leq 0.175 \pi\text{-mm-mrad}$. The beam must also be chopped in this section to provide clean 295 ns gaps in the pulse at 1.2 MHz, with less than 10^{-5} of full current remaining in the gaps. To achieve this, the project will do the necessary R&D, and then design and build an H^- ion source, a low energy beam transport (LEBT) section to match the beam from the source to the RFQ, an RFQ to accelerate the beam to 2.5 MeV, and a medium energy beam transport system (MEBT) to allow room for beam chopping and matching into the DTL. Each of these subsections will be discussed in more detail below.

H^- Ion Source

The project chose to use a cesiated volume H^- source, with an RF driven multicusp plasma generator. The parameters required of the source are 35 mA, 65 keV extraction, normalized rms emittance $\leq 0.15 \pi\text{-mm-mrad}$, and 6.2 percent duty factor. This combination of parameters has not yet been achieved simultaneously in any H^- source, but based on present status, it is viewed as a low risk. The project has done

initial R&D using the SSC volume H^- source, and are now beginning testing of their own first R&D source. They

have also begin designing a second R&D source, after which they will design and build a prototype source. Finally they will build 3 final sources to be delivered to ORNL. The sources thus far have achieved:

- 35 mA at < 1 percent duty factor, 30 kV extraction,
- Plasma generation at 50 kW (approximately the required power), and 6percent duty factor, with no extraction, and
- Demonstration of the feasibility of sufficient electron suppression, but not at the required H⁻ current.

As mentioned previously, the project has just begun testing the first R&D source, and has all the power supplies needed so that this source could very well demonstrate all the 1 MW requirements (35 mA, 6 percent duty factor, 65 kV, required emittance, with controlled dumping of electrons). The project will also study pre-chopping on this source. What would remain would be achieving the required reliability and lifetime.

The source must be able to operate for three weeks before needing maintenance, and must have a total life of approximately one year. In order to achieve reliable operation, either extraction of electrons must be suppressed or the electrons must be dumped in a controlled fashion. This must be done without increasing the source emittance significantly. The project has began very important 3D modeling studies of H⁻ extraction/electron suppression with the computer codes TOSCA 3D and ARGUS 3D.

To ensure reliability, the committee suggests that shutting off the ion source not be used as a method of inhibiting the beam for equipment protection or personnel safety. There are several other methods which would be equally effective, without the risk of compromising source reliability. The committee also suggests that it would be valuable to have an ion source test stand at ORNL. Many of the required components will already be at ORNL as spares, so we suggest that the few remaining items be funded out of either the project or pre-operating funds.

To summarize, the project has a very good R&D plan, and is quite far along in source development. The committee feels confident that the 1 MW source requirements will be met, and actually thinks there is a high probability that the 2 MW requirement (70 mA) could also be met during this phase.

Low Energy Beam Transport (LEBT)

The LEBT is a 10 centimeter(s) long section which electrostatically matches the beam from the ion source into the RFQ. This electrostatic matching is unconventional, but the design is sound, and it has clear advantages (primarily the prevention of space charge neutralization). The project has done preliminary tests of the concept using an H⁻ beam, and found good agreement between calculated and measured emittances. Simulations of the matching at 35 mA (corresponding to the 1 MW phase of SNS) and 70 mA (2 MW) looks good. A potential problem with this design would seem to be handling of the gas flow from the source over such a short distance, but Monte Carlo simulations indicate that this will not be a problem. A prototype of this LEBT will be tested with the second R&D source in FY 1999. The LEBT would have to be redesigned if either the "backup" Penning or

Multicusp/converter H^- source had to be used, but we view this as highly unlikely and thus not a concern. The committee were satisfied with the design and plan for testing of this LEBT.

Radio Frequency Quadrupole (RFQ)

The RFQ accelerator must accept the 65 keV beam from the LEBT and accelerate it to 2.5 MeV with minimal increase in transverse emittance. The proposal calls for the building of a prototype RFQ, under the R&D WBS, which will be delivered to ORNL in time for the commissioning of the first stage of the linac. This prototype will be followed by the "deliverable" RFQ that will replace the prototype prior to start of beam commissioning of the CCL part of the linac.

The proposed RFQs are approximately 4 meter(s) long, and are manufactured as 4 brazed sections, each approximately 1 meter(s) long. The sections will be made of Glidcop AL-15, a high-strength copper alloy that does not anneal at normal gold-copper-alloy brazing temperatures. The cavities will be tuned to resonate at 402.5 MHz, and it is proposed to use pi-mode stabilizers, as used at KEK in Japan, to suppress dipole modes. The LBNL team has an excellent track record in RFQ design and building, although this one will enter new regimes of length-to-wavelength ratio and duty factor. A conservative approach was taken in the mechanical and thermal design, and the 6 percent duty factor should be easily accommodated. The current capabilities are very adequate for the 1 MW NSNS design which calls for 28 mA output current from the RFQ. The calculated transmission drops from approximately 95percent to < 85 percent as the output current is increased from 28 mA to 56 mA, leaving little margin for the upgrade of the NSNS to 2 MW.

Before manufacturing the first RFQ sections, one or more high-power "sparker" cavities will be constructed. These will give valuable information to verify the manufacturing process for the RFQ and to provide some verification of the adequacy of the RF seals, couplers, etc.

Once the final RFQ is installed, the prototype will be available for other purposes. It provides long-term assurance for NSNS, since if something happened to the production unit, the prototype could be substituted while repair or replacement was arranged. However, chances are it will never be required as a substitute, while it would be very valuable as a testbed for a 2 MW front end. If there were to be a spare RF system available at NSNS, such tests could be done there. Without such a system, it may be cost-effective to move it back to LBNL, where there is an existing RF system, and do the development there.

The building of a prototype front-end early in the project is the right decision.

Further analysis is recommended to ensure that there is sufficient margin at the output current required for the upgrade of NSNS to 2 MW. Historically, RFQs have operated at a few percent lower transmission than calculated; a design goal of 90 percent transmission at 56 mA of output current should be considered.

The sparker tests are important and should not be short-changed by, for example, building the sparker as a dipole instead of a quadrupole. The slight additional cost that arises from making test cavities that closely model the proposed RFQ geometry and assembly procedure is likely to be returned many-fold when actual RFQ sections are built.

In addition to being a spare for the installed RFQ, the prototype RFQ will remain as a valuable resource for development of the upgraded front end needed to get to 2 MW. Consideration should be given to where this development could be done and plans made accordingly.

Medium Energy Beam Transport (MEBT)

The MEBT transports the beam from the RFQ to the DTL. The design of (and in fact the need for) the MEBT is completely driven by the need for fast beam chopping. One must provide sufficient length for a chopper, which then requires adding quadrupoles to transform the strongly diverging beam from the RFQ into a non-divergent beam to drift through the chopper. This added length then forces one to add rebuncher cavities to maintain the bunch structure between the RFQ and DTL. The MEBT proposed by LBNL is 3.6 meter(s) long, containing a chopper and antichopper, 18 quadrupole magnets, 3 rebuncher cavities, and various beam diagnostic devices. While the simulations presented seem to indicate that this is an acceptable design, we are glad to hear that LBNL is taking another look at the design and mechanical layout. The magnet apertures in this 3.6 meter(s) line are 2 centimeter(s) diameter, somewhat tighter than usual. The committee also suggests that they revisit the simulations in longitudinal phase space. The committee feels that the diagnostic devices that intercept the beam should be looked at again with regard to handling the high beam power density.

Beam Chopping

The fast beam chopping takes place in the MEBT. There is a chopper, followed by an "anti-chopper." The anti-chopper corrects the motion of the partially deflected bunches which are in the rising and falling edges of the chopper, returning them to the beam axis. This anti-chopper will have to be very carefully matched with the chopper, to avoid any ringing on the pulses. The chopper device and power supply are being built by LANL, and the design was covered in the linac section. LBNL plans to pre-chop the beam before the RFQ, which helps achieve the required beam shutoff to the 10^{-5} level, and also reduces the beam power that has to be dumped by the MEBT chopper.

The prechopper, which is in the LEBT, has two stages. One prechopping stage will use the plasma electrode of the ion source. This has only been demonstrated in a very preliminary test, and the scheme is expected to have relatively slow (100 ns) rise and fall times. The difficulty here is that this prototype electrode drew several hundred amperes of electrons, so a fast switching supply able to provide approximately 100 V, 200 A would be required. Design changes may alleviate this problem. The second prechopper stage deflects the beam before the RFQ, using a split electrode in the LEBT. The prechopper could achieve approximately 30 ns rise and fall

times, but has been demonstrated only in a very preliminary test. Since these prechoppers work earlier than, and have slower fall times than, the fast chopper, both will require trigger pulses which come before those of the fast chopper to maintain the fast leading edge on the beam pulse. The committee feels that the attempt to prechop is very worthwhile in order to reduce off-axis H⁻ beams, and while success is not guaranteed, there is a reasonable probability that both prechoppers can be made to work.

3.2.3 Cost

The total cost for the FE Systems (WBS 1.3), as presented in the NSNS cost estimate in 1997 dollars (including contingency) is \$19,825k. The base cost is given as \$15,645k. FE R&D (WBS 1.1.1) is an additional \$6,356k (\$5,527k base cost). Base cost for all items in the NSNS cost estimate and the FE presentation agreed when NSNS costs for overhead and tax were included.

The LBNL group responsible for the FE has had considerable long-term and recent experience with ion source development and RFQ construction, so their costs are well supported by recent experience and, in most cases, vendor quotes. Although the contingency may appear high, this is due to the one-of-a-kind nature of all of the components and a strong contingency (30 percent) given to the two largest components: the ion source and the RFQ.

The klystron RF system to be provided by LANL is estimated at \$1.5 million. If a refurbished station from the old GTA project at LANL could be used, this cost could be reduced substantially.

WBS 1.3.8.3 (Construction Management) was questioned as being very large (\$3,843k), while WBS 1.3.8.1 (Management and Physics Support) had no cost. It is believed this is an error and should be reversed.

The subcommittee had no disagreement with the FE cost estimates.

3.2.4 Schedule and Funding

The FE is not on the critical path except for having deliverable beam for DTL commissioning in FY 2002. This gives five years to develop and build the FE. Starting from this time and working back, a very reasonable schedule for R&D, prototyping, construction and testing was presented. Funding is assumed to

begin in FY 1999. The profile (in 1997 dollars including contingency) for each year, FY 1999 through FY 2004, is \$2.6, \$4.3, \$5.6, \$4.9, \$2.0, and \$0.4 million, respectively. Both the schedule and funding profiles should be adequate.

3.2.5 Management

The FE team is within LBNL's Ion Beam Technology group, in the Accelerator and Fusion Research Division. It is led by a Team Leader who is responsible to the NSNS management. Within this Division and group are considerable expertise and personnel for carrying out this project. Both Laboratory and Division management appear sensitive and responsive to the NSNS project.

The FE team leader is supported by a physics group for ion sources and for beam and systems analysis. Under the team leader is a project manager who coordinates the Engineering, Design, and Inspection (EDIA) effort with an electrical systems engineering leader and a mechanical systems engineering leader.

Since the FE must interface with the Linac, a single-person contact with LANL has been established to provide coordination. This, appears to be working very well. They also have good contacts with the other laboratories.

This management, which has been in place for the present design and R&D stage, appears to be functioning well.

3.2.6 Recommendation

The design of the RFQ should be revisited to ensure that the beam current capability has adequate margin to support the 2 MW upgrade requirements. It is suggested that the design goal be ≥ 90 percent transmission at the output current and emittance required for 2 MW on target.

3.3 LINAC SYSTEMS

3.3.1 Summary

Technical

The design of the NSNS linac is well advanced and appears to meet all project goals. Calculated beam losses in the linac are less than 1 nA/m and the projected output specifications meet the input specifications of the Ring System. RF Systems choices are conservative and based upon existing technologies. Normal-conducting RF structures have been selected over superconducting ones, and the committee endorses this choice. The RF structures are similar to those used in the Los Alamos Neutron Scattering Center (LANSCE), except for the 20 - 95 MeV section, which uses a new design called the coupled cavity drift tube linac (CCDTL). The committee believes there is moderate risk in the CCDTL structure, and recommends additional R&D in FY 1998. Additional FY 1998 R&D funding is also recommended for RF Systems. All other technical systems are similar to existing designs and pose little risk. The committee believes that the 2 MW beam upgrade is well developed and should be implemented at the start of construction if funding permits.

Cost

Overall, the cost of the linac is well estimated and is similar to that of other large linacs.

Schedule and Funding

The proposed schedule appears to be overly optimistic. It does not allow enough time for engineering before procurement starts, and it assumes unrealistically short procurement and contracting times. In addition, production of RF Systems and RF Structures (which are both on the critical path) may be affected by lack of manufacturing capacity. The overall production plan was well thought out and detailed.

No obligations profile was presented. The proposed cost profile does not match the construction plan.

Management

The LANL proposed management structure and technical staff are adequate to meet the demands of the project. It is not clear that integration concerns have been addressed, and nor that a strong management structure is in place to oversee the entire NSNS project.

3.3.2 Technical Scope

Findings

The LANL team is proposing to design and build a 1 GeV, 1.1 MW proton linac that is upgradeable to 2.2 MW and 4.4 MW. The linac will accept a 2.5 MeV beam from the NSNS Front End and pass a 1 GeV beam to the NSNS Ring. In addition, the LANL team is responsible for the design and fabrication of a chopping system that is to be placed in the MEBT section of the Front End; RF power for the front end; and instrumentation to be placed in the HEBT section. The beam duty factor is 6.18 percent.

The proposed linac consists of RF structures, RF power, vacuum systems, magnet systems instrumentation, and mechanical systems. Control systems and personnel protection systems will be addressed in another section of this report.

The RF accelerating structures will be of three specific types. A 402.5 MHz Drift Tube Linac (DTL) will accelerate the beam from 2.5 MeV to 20 MeV. An 805 MHz Coupled Cavity Drift Tube Linac (CCDTL) will accelerate the beam from 20 MeV to 95 MeV, and an 805 MHz Coupled Cavity Linac (CCL) will accelerate the beam from 95 MeV to 1 GeV.

The RF power system is based on 1.25 MW and 2.5 MW klystrons with modulation anodes. In the 1 MW beam power configuration, 7 power supplies will drive 28 modulators and fifty-six 805 MHz, 2.5 MW klystrons in the CCL and CCDTL section of the linac. The Front End RFQ and the DTL will be powered by two 402.5 MHz modulators and three 402.5 MHz, 1.25 MW Klystrons.

The vacuum system is designed for 5×10^{-8} torr.

The magnet systems consist of focus/focus/defocus/defocus (FOFODODO) lattice of SmCo₅ permanent magnet quadrupoles placed inside the drift tubes of the DTL. The CCL and CCDTL magnets use a focus/defocus (FODO) lattice of electromagnetic quadrupole magnets.

Instrumentation is placed throughout the linac and the HEBT to commission the linac, verify linac proper operation and setpoints, determine the cause of and help recover from off-normal operation, and verify proper beam preparation for ring injection. The current proposal is for 380 instruments in the linac.

Evaluations

3.3.2.1 RF Systems

The chosen frequencies are 402.5 and 805 MHz. A complete analysis of the power generator options gives a baseline decision to choose a conventional 2.5 MW modulation anode klystron for both systems. This uses a floating - deck modulator. The committee agrees with this approach. It ties in very well with LANSCE experience, and the team can proceed rapidly when the project commences. However, they have also investigated a

somewhat different approach, using a cathode-pulsed klystron driven by a modulator with an insulated gate bipolar transistor (IGBT) switch. This technology is relatively new but has been used successfully in commercial transmitters. It has many advantages: it would alleviate the risks associated with a mod-anode tube and would provide an easier path for the upgrades to 2 and 4 MW of beam power. The committee recommends that R&D funds be made available in FY 1998 to study this option.

3.3.2.2 RF Structures

The choice of types of accelerator structures and frequencies appears appropriate. The committee agrees with the choice of normal-conducting instead of superconducting cavities for this application. The transition energies from one structure to another based on shunt impedances and costs are appropriate. Beam loss within the accelerator must be kept below a value near 1 nA/m and it appears this design should achieve that goal. End-to-end beam simulations indicate good performance and beam quality—well within the requirements of the accumulator ring.

The CCDTL structure that is used from 20-95 MeV is a structure of new design. Although its RF properties have been well studied a powered structure has not been built or operated. A one-meter cw section is being built for testing in another program and may provide some engineering information. The committee feels it is critical that a powered model relevant to this project be tested as soon as possible from additional FY 1998 R&D funds.

Good performance by the beam chopper is needed in order to achieve a 2.5 ns risetime to avoid partial chopping of pulses. Partially-chopped pulses do not appear to be a problem for the linac, but could contribute to losses in the ring. The new meander two structure appears to have the necessary bandwidth and a fast pulsed-power supply needs to be developed. The committee recommends that this device be tested with beam as soon as possible on the Front End prototype being constructed at LBNL.

Because of the projected long life of this linac, the committee recommends that prudent practice would be to avoid water-to-vacuum braze joints wherever possible. The LANSCE structures have operated for 25 years with only minor leak problems, but experience at other accelerators has not been as good. It also would be wise to consider the effect of a relatively major water leak into the linac and how the facility would recover from it.

The CCL is designed so that the number of cavities within a module can be varied for each power upgrade. This is achieved by ending cavities with coupling cells that can be either blanked off or connected to bridge couplers. This novel way of adding flexibility must add some technical risk. Consideration should be given to starting the project in the 2 MW configuration to avoid one reconfiguration task.

3.3.2.3 Magnet Systems

The Magnet Systems cover the focusing quadrupoles, power systems, and all I/O cards, for the CCL and CCDTL Linacs. The gradients for the focusing magnets are reasonable and conservative. However, the tight physical constraints require the current density in the windings of the electromagnets to be quite high (3000 A/cm²). This is achievable, but it would be wise to consider reducing the current density, as it could cause an unacceptable mean time between failures (MTBF).

3.3.2.4 Vacuum Systems

The vacuum systems design appears to be adequate and complete. The vacuum systems use proven commercial components, are very conservatively designed, and should prove to be very reliable. There is very little risk (technical, cost, or schedule) in this element.

3.3.2.5 Beam Diagnostics

The Beam Diagnostics planned for the NSNS Linac are sufficient to perform their intended purposes of guiding the beam through the linac and verifying linac performance. The bulk of the diagnostics are beam toroids, stripline Beam Position Monitors (BPMs), and Beam Loss Monitors (BLMs). These devices are all well proven and very reliable. There are also several innovative beam diagnostic devices planned to verify the performance of the beam chopping system, a critical requirement for the NSNS Linac. The reviewers see no technical risks in the beam diagnostics systems.

3.3.2.6 Water Systems

The water systems provide cooling water to the linac structures, RF systems, and magnets. Temperature control units interface with the linac structures to maintain the correct resonant frequency. The resistance of the water in the magnet systems must be maintained high enough to avoid significant current leakage to ground on all magnets. Consideration should be given to providing fast shutdown of flows when leaks occur. Also, adequate metering should be provided to protect equipment that is critical or very sensitive to partial or full blockages of cooling passages. The designs presented appear to be adequate for this stage of the design.

3.3.2.7 Mechanical Systems - Alignment and Support

The alignment systems used for estimation for the NSNS Linac consist of commercially acquired equipment. Detailed discussions with the civil design team have not occurred, and a definitive set of requirements for monument placement and surveying has not been developed.

The linac structural support is estimated to include the work necessary to design, construct, and install the mechanical support for the linac structures in the linac enclosure. The interfaces to other linac technical areas' equipment and support requirements are defined. Very little detailed design has been accomplished. Both materials and EDIA are estimated on the basis of experience with similar facilities.

At this stage of conceptual design, the cost estimates for both survey and mechanical support are typical for these areas. Little detailed design has been done because significant or unusual problems are not expected. Discussions, organized by NSNS management, for project-wide survey and alignment requirements should begin soon so that an adequate array of survey monuments is included in the civil specifications.

Other Assessments

The preconstruction operations/R&D funds are inadequate to support an early preliminary design review, necessary for the aggressive construction schedule. Klystron and power supply options need to be developed in industry and tested, and some of the linac structures, especially the CCDTL, should be built and tested at high power.

The committee believes that the 2 MW beam upgrade is well developed and should be implemented at the start of construction if funding permits. The 4 MW beam design option is not as advanced, and the funnel design is in the pre-conceptual stage. Considerable work is needed on the 4 MW beam option.

3.3.3 Cost

Findings

The total cost for the linac systems is \$287,442,000. Of this amount, 44 percent is for material purchases, 9 percent for installation, 28 percent for EDIA, and 19 percent for contingency.

Evaluations

RF Systems. This subsystem costs in base cost, EDIA, and contingency are well estimated. LANSCE assured the committee that adequate resources would be made available at the appropriate time with minimal impact from competing projects.

RF Structures. The estimated base costs of the structures appear to be reasonable and adequate when compared to the cost of other large linacs. Much of the EDIA will be done by the project construction manager. The overall EDIA seems too large for this subsystem. The CCDTL may need a larger contingency, especially if the early R&D is not performed.

The base costs for the magnet systems should be adequate. EDIA are covered as part of the CCDTL and CCL and not listed under this WBS. The amount of EDIA in the CCDTL and CCL areas should be adequate to cover these activities as well.

Vacuum Systems. The vacuum systems cost appears to be reasonable and adequate.

Beam Diagnostics. The budget for the beam diagnostics appears to be reasonable and credible.

Water Systems. The cost of the water systems appears to be reasonable and adequate. There should be little cost risk associated with this system.

Mechanical Systems - Alignment and Support. Cost estimates based upon previous experience are appropriate.

Management and Physics Support. Cost estimate is well documented and supports the CDR staffing estimates. The travel budget of \$965,000 is justified to support monthly travel rotating among the five participating laboratories for the life of the project.

3.3.4 Schedule and Funding

Findings

The schedule analysis entitled "Preliminary Schedule Assessment" was presented. This bar chart purports to show that it is feasible to complete the linac, including installation and testing, by September 30, 2003. This "success oriented" analysis is based upon the assumptions of a successful R&D program, very prompt engineering design reviews and approvals, and rapid completion of procurement contracting. It also assumes double-shift manufacturing for several years in critical areas, aggressive testing of completed components, and if taken at face value, a very rapid obligation of funds. The committee was not shown an obligation profile driven by the schedule.

Evaluations

This "Preliminary Schedule Assessment" is unrealistic. It seems to assume an R&D program which has not yet been financially authorized, and a very rapid development of engineering and procurement packages. For the RF systems and the RF structures, there appears to be insufficient time for placing major procurements and obtaining timely deliveries over a six-year construction schedule.

The construction of the CCL structures is the critical path for the linac. The plan assumes setting up a factory at an industrial partner with the purchase of several large brazing ovens. The structure production plan appears to be too aggressive and should be scrutinized carefully. The times allocated for design appears to be very compressed and probably inadequate.

No obligations profile was presented. The proposed cost profile does not match the construction plan.

3.3.5 Management

Findings

LANL is responsible for the design and fabrication of the NSNS Linac. The LANL proposed management

structure and technical staff are adequate to meet the demands of the project. LANL has the manpower necessary to fill management and technical positions assuming that future projects at LANL do not reduce the available staff. LANL plans to employ industry and utilize a construction manager supplied by ORNL to meet the demands of an aggressive schedule and staffing constraints. It is not clear that integration concerns have been addressed and that a strong upper management is in place to oversee the entire NSNS project.

A monthly collaboration meeting is held to address ongoing activities, to communicate activities to be performed in the near future, to determine status of action items from past meetings, to add action items as needed, to make project-wide decisions, and to assess the status of technical work.

The linac cost estimate reflects a method of acquisition that calls for the project CM to purchase, inspect, and accept approximately \$58.7 million of technical equipment in nine WBS areas. In some instances this is planned to follow earlier purchases made directly by Los Alamos. In some instances, the entire purchase is listed as being accomplished by the CM.

Evaluations

A more formal guarantee from the LANL Director about the commitment of LANL to place highly qualified personnel on the NSNS project to bring the project in on schedule is required.

The complexity of integration between the linac, front end, ring, and conventional facilities requires significant attention. In many cases the linac design overlaps the designs of the front end and ring. It is essential that the interface parameters be specified and one person in project management have the responsibility to resolve disputes.

The management and technical staff members working on the NSNS project at LANL should be working on the project full time. The use of "fractional people" should be minimized.

It is apparent that the proposed schedule requires significant commitment from the Department of Energy NSNS management (Oak Ridge Field Office) to keep the project from being delayed unnecessarily. High level change orders must be processed quickly (in less than one or two weeks), ES&H documentation must be in place prior to installation of the Linac, funding profiles must be guaranteed that match the Linac funding needs, and political roadblocks must be removed in a timely fashion to ensure the Linac is built within schedule, cost, and scope.

Critical path R&D appears to be underfunded by DOE in FY 1998. This can result in schedule slippage with respect to timely placement of orders at the very start of project funding.

The purchase of technical equipment by the CM was purported to be advantageous on the basis of overhead minimization, i.e., cost reduction. It is not explained, however, how to minimize the difficulties of having a third party being at once the purchasing agent, quality and technical inspector, and person responsible for rejection

of unsatisfactory performance. The costs associated with such difficulties could exceed the purported savings, and the impact of unsatisfactory vendor performance on schedules could be severe. The use of staff intimately familiar with the technical performance requirements and specification for inspection and acceptance of technical components would appear to be critically important.

3.3.6 Recommendations

1. *Review and revise the schedule to provide realistic times for the procurement process and seek workarounds for the lack of klystron vendor production capacity and the development of manufacturing facilities for the Linac structures.*
2. *Preconstruction operations/R&D funding should be increased from \$5 million to \$12 million in FY 1998. This increase will allow necessary R&D for RF systems and the full power tests of the CCDTL structure. This increase in R&D funding will also provide for increased manpower to advance the date of the linac Project Design Report (PDR). An early PDR will support the timely placement of critical path procurements and will define conventional facility requirements.*
3. *The Linac needs to be more tightly integrated into the NSNS project management as a whole.*
4. *The NSNS management at ORNL needs a core management and technical group (at ORNL) to direct the project. This group should be formed by early FY 1998.*

3.4 RING SYSTEM

3.4.1 Summary

The Ring Systems Group has produced a credible 1 MW design for the High Energy Beam Transport section (HEBT), the Accumulator Ring, and the Ring to Target Beam Transport Line (RTBT). However, the group now needs to iterate the design doing the necessary cost-benefit analysis and value engineering essential to producing a cost optimized design. Specifically:

- a. Consider making more components outside BNL.
- b. Consider reducing the costs associated with installing (and in some cases re-assembling) components at ORNL.
- c. Review the design of the lattice and beam lines again using cost-benefit criterion.
- d. Consider using permanent magnets in the HEBT in order to reduce both construction and operations costs.
- e. Consider beam-loss design criteria which meet ALARA requirements in a more cost-effective manner.

ORNL will be responsible for the facility, and needs to provide the overall leadership of the project. To this end, ORNL needs to have a core team of neutron scattering users and accelerator designers and builders who can make informed decisions across the entire project. Specific suggestions for accomplishing this include:

- a. ORNL needs to get technical maintenance and operations people intimately familiar with the equipment before it is operational.
- b. ORNL management will have to make decisions which are compromises, and in order to make the best informed decisions, ORNL needs to have an advisory group in order to get independent expert advice. These issues will include compromises between the needs of the project and the needs of operations.

Magnet systems are well defined and supported by beam optics analysis. Cost estimates appear high when compared to actual costs from other recently completed machines. The estimates are being driven by the Project-mandated beam loss constraint, as well as by a "green field" condition; that is, additional costs incurred when the system is being installed at a remote location rather than an already developed site. In general, the unit prices of the magnets are comfortable.

3.4.2 Technical Scope

The beam transport and ring systems must compress the 1 ms long beam pulses arriving from the linac at 60 Hz repetition rates into 560 ns pulses and deliver them to the target with low beam loss. The design of such a system, which requires a small accumulator ring operating at very high intensity (2×10^{14} protons/pulse for 2 MW) represents a major challenge. The design presented successfully demonstrates that the performance specifications can be met, although it is still at a preliminary stage. Further analysis and optimization is needed, as suggested in the proposed R&D Program. Particular areas of concern are the ring lattice, the H^- injection system and the HEBT magnet design.

Concern with the ring lattice stems from its complicated nature (many elements and irregular beta functions) which makes it relatively costly. Excluding the beam lines, the cost of this ring (1 GeV, 1 MW) is \$80 million; for comparison the European Spallation Source proposal quotes ECU 83 million for two rings for 1.33 GeV, 5 MW operation.

The inclusion of four dispersionless straight sections in the ring's FODO lattice requires 48 quadrupoles, somewhat fragmenting the space and demanding 32 separate dipoles. Moreover, different cell lengths in the arcs and straights lead to beating of the beta functions and the need for quadrupoles of 4 different designs and 6 strengths. By comparison, each ESS ring uses 15 dipoles and 15 focusing triplets (2 quadrupole designs).

The committee seriously questions the need for the cranes in the beam enclosures. These cranes increase the cost of the beam enclosures.

Evaluation

Review the ring lattice design, with particular reference to:

- Simplification by reducing the numbers and types of different elements with a view to reducing costs.
- The need for zero-dispersion for H^- injection.

Extend tracking studies to include magnet errors and misalignments and their correction.

3.4.2.1 HEBT System

The HEBT begins (from a charged-particle-optics standpoint) in the middle of the last linac quad and ends at the carbon stripping foil in the ring. Its functions are to optically match the linac output to that required at the stripping foil; to provide the site-related, geometric relationship between the linac and the ring; and to control beam losses by collimation of the transverse phase space and momentum spread. In addition, an acceleration segment has been included to provide for the possibility of longitudinal phase-space painting for ring injection.

The system presented met the design requirements at the level specified. However, alternative optical solutions could be explored. For example, a 2I achromat (I represents an identify transfer matrix) could be used instead of the I; and one could also consider a 90 degrees instead of a 60 degrees phase advance per cell. In addition, alternative to the ring magnet quadrupoles as designed could be considered.

The system presented was well done for this stage of the project and will provide a good basis for further, more detailed analyses.

Evaluation

First and foremost, design specifications for this segment must be set which are consistent with the other project elements.

System optimization should be done by, for example, considering alternative optical solutions and the cost-effectiveness of using ring quads in lieu of other alternatives.

The use of permanent magnet devices should be considered, in order to reduce both construction and operation costs.

3.4.2.2 Injection System

The proposed H^- injection scheme meets basic requirements but requires further analysis before final acceptance. There are concerns in the following areas:

1. The choice of zero momentum dispersion
 - complicates the overall lattice design
 - requires 5 horizontal bump magnets (not needed for painting with non-zero dispersion).

2. The use of a focusing quadrupole as a bump magnet
 - requires a special 30 centimeter(s) aperture quadrupole.
 - raises concerns over aberrations in the fringe field of this short quadrupole, since the circulating beam is well off axis.
 - restricts the beam acceptance near the foil and H⁻ septa.
3. The present painting scheme, in which horizontal and vertical bumps are directly correlated, may not be optimal. Studies elsewhere have found anti-correlation to give smaller tune shifts and fewer foil hits.
4. Allowing 2 percent of the H⁻ beam to miss the foil and be dumped is not required in other injection schemes.
5. The predicted operating temperature for the H⁻ stripping foil (<3000 K) is much higher than the norm at existing accelerators (<2400 K), and raises concerns about foil lifetime and distortion, if the H⁻ beam spot size cannot be increased. This is of even greater concern for 2 MW operation.
6. The painting simulations have made a good start, but need to be extended to 10⁶ particles to ensure accurate inclusion of space-charge effects. The 4 MW case needs special attention because the shorter pulse makes longitudinal painting more difficult.

Evaluation

The H⁻ injection scheme needs to be revisited. The present design has led to some cost increases which the committee does not believe are necessary.

Review the pros and cons of zero-dispersion injection.

Review problems associated with using a quadrupole as a bump magnet and compare alternative schemes.

Extend painting simulations to have:

- more particles.
- better approximations.
- horizontal-vertical correlation.

Initiate stripping foil R&D program to validate operating conditions.

3.4.2.3 Magnet System

The scope of the magnet system is well defined and is specified in sufficient detail to allow a magnet design effort to proceed. Magnets are conventional copper/steel electromagnets and their conceptual designs are based on good accepted industrial practices.

Some R&D will be needed to verify integrated field quality due to the large bore of the magnets.

Based on BNL's experience in building magnets, there is low risk in the magnet systems.

Magnet systems are well defined and supported by beam optics analysis. Cost estimates appear high when compared to actual costs from other recently completed machines. The estimates are being driven by the Project-mandated beam loss constraint, as well as by the "green field" condition. In general, the unit prices of the magnets are comfortable.

Evaluation

1. Initiate a number of Magnet Design Reviews in combination with a strong cost reduction effort.
2. Develop a detailed assembly and installation plan in partnership with appropriate NSNS engineers.
3. Evaluate the risks/savings of doing all magnet assembly at ORNL. This would include magnetic measurements and girder/magnet/vacuum beam tube assembly.

3.4.2.4 Power Supply

The ring power supply system proposed is complete and satisfies the requirements for flexible control of guide field and tune. The technology employed is well known and no R&D is proposed or needed to complete the project. BNL's extensive experience in this area justifies the low contingencies and minimizes risk.

3.4.2.5 Vacuum System

The technical requirements for the beam line and ring vacuum systems are defined with sufficient detail to support system design. Some R&D effort is needed for the evaluation and development of the titanium nitride coating process for the ring chambers. Additional R&D may be required on developing a bakeout process for the installed ring vacuum components. The design concept as proposed presents no apparent risks.

3.4.2.6 RF System

The RF systems are based on similar designs produced at BNL. The challenge for the RF system design is the large beam current resulting in significant beam loading.

Evaluation

In order to avoid the high current Robinson instability the effective shunt impedance must be reduced. Three techniques have been considered in the conceptual design report: direct RF feedback, one-turn-delay feedback, and feed-forward beam current cancellation. The design team has chosen to pursue one-turn-delay feedback, reserving the feed-forward beam current cancellation as a contingency plan. The committee feels that the direct RF feedback choice should receive more consideration. If beam dynamics issues indicate that the increased performance available from this method is needed, in-tunnel amplifiers can be shielded from radiation.

3.4.2.7 Diagnostic Instrumentation

The beam line and ring diagnostics contain the normal complement of devices found in rings of this sort. A challenge in the ring diagnostics will be changing the gain of the electronics to track the very large change in current while beam is being accumulated.

Evaluation

The present design contains a large number of Beam Position Monitors (BPMs) and Beam Loss Monitors (BLMs) which are included to cope with the high current. This should be reevaluated to assess whether the additional units actually improve the ability to observe and control losses.

The beam position monitors need to have single-turn capability, and multiturn data storage capability as is standard on other modern storage rings.

3.4.2.8 Extraction

The rings systems group needs to identify single-point failures, think through the implications of such failures, and incorporate improvements in the reliable and cost optimized design. An example of such a single-

point failure which was briefly discussed in the presentations is the premature firing of an extraction kicker.

The group needs to aggressively pursue single-point failure scenarios and redesign the lattice, beam lines, or other equipment to avoid damage.

3.4.2.9 RTBT System

The RTBT begins (optically) in the middle of the ring quad between the fast extraction kickers and ends at the neutron production target. Its functions are to optically match the ring output to that required at the neutron production target, to provide the site-related, geometric relationship between the ring and the neutron production target, and to control beam losses by collimation of the transverse phase space emittances.

The presentations demonstrated that project personnel have the expertise and talent to successfully complete this project. Issues such as abort-kicker failure scenarios, power supply regulation problems (particularly with the 15 degrees bends), and damage protection in these instances remain to be investigated.

The system presented was well done for this stage of the project and will provide a good basis for further, more detailed analyses.

3.4.2.10 Ring Control System

The committee endorses the choice of EPICS as a basis for building the controls system. The various laboratories have organized and are meeting to discuss integration issues. This effort appears to be off to a good start. There is a concern that the writing of application programs for the different accelerators at different laboratories could lead to a lack of coherency between them. All involved should continue to work to achieve a common look and feel.

Evaluation

Conservative design issues are present in controls as well. The large number of diagnostic devices and the desire to put individual applications into different Input/Output Controllers (IOCs) has led to what seems like an excessive quantity of IOCs.

The overall synchronization scheme for the facility should be developed now.

3.4.3 Cost

Finding

The cost of the ring systems presented to the committee, including HEBT, accumulator ring and RTBT, was

\$144.9 million. This includes \$25.0 million of contingency (21 percent) and all overheads, but no escalation to account for inflation. With escalation of \$19.8 million, the total cost to the government is \$164.8 million. The ring system subcommittee assessment is that the estimated cost is high, because there has not yet been an opportunity to iterate the design and carry out cost optimization and value engineering studies. The review committee estimates that the base cost should be reduced by approximately \$9.4 million (from \$120.0 million to \$110.6 million) and the contingency reduced by \$2.9 million (from \$25.0 million to \$22.1 million). The fact that the NSNS estimate of contingency of 21 percent was further reduced, even though it would ordinarily be considered low for machine technical components at this stage of design; this reflects the committee's belief that there remains significant opportunity for further cost reduction. The committee's revised estimate, with 20 percent contingency and no inflation, is therefore \$132.2 million before inflation and \$150.9 million with inflation.

3.4.3.1 HEBT

The costs are evaluated elsewhere. It is noted, however, that the costs for this area would benefit from a careful requirements review, consideration of alternative optical schemes, and value engineering.

3.4.3.2 Injection System

The magnet and power supply costs are considered under those headings. The foil mechanism (\$1.09 million) seems expensive for construction, although development may be costly.

3.4.3.3 Magnet System

Cost estimates appear to be slightly high. They have been developed based on a reasonable mix of vendor quotes, extrapolation from existing hardware and shops/engineering estimates. Current estimates are based on BNL's procurement of magnet components, with assembly and acceptance testing being done with in-house labor. Schedules and spending profiles are reasonable showing acceptable ramping up of work. Staffing for the NSNS effort match the long term AGS/RHIC staffing plans very well. Experienced engineers, designers and technicians will be available for the magnet systems effort if current NSNS construction schedules remain in place.

Contingency estimates are prepared by the responsible engineers and are reasonable for this point in the conceptual design.

3.4.3.4 Power Supply

The base cost for the power supplies seems relatively high. The phase-control power supplies proposed can, for the most part, be procured as complete units from industry. Estimates by the review committee would indicate some savings in this area. Further cost savings may be obtainable through the use of pulse-width modulated (PWM) supplies for the corrector systems. Given the short time the beam is in the machine and the

advances made in PWM technology over the past five years, the performance of this type of power supply should be achievable. BNL should also work hard on reducing the costs of interfacing the correctors to the control system. The present estimate of \$3k per power supply seems much too high.

EDIA also appears to be relatively high, given that the technology is well known, many power supplies can be procured from industry, and BNL has had extensive experience with these systems.

3.4.3.5 Vacuum System

Detailed cost estimates with supporting documentation were presented. Estimates were based on a reasonable mix of vendor quotes, extrapolation from existing hardware, RHIC work in progress, and shops/engineering estimates. Costs are within a reasonable band for the conditions imposed. As in magnets, costs reflect a "green field" condition.

Contingency estimates are prepared by the responsible engineers and are reasonable at this time of the conceptual design.

3.4.3.6 RF System

The cost for the proposed RF systems appears to be adequate.

3.4.3.7 Diagnostic Instrumentation

The committee feels that the base cost of the diagnostic equipment is reasonable. Concern is expressed in two areas: the amount of EDIA, and the cost of relocating devices to ORNL.

As discussed elsewhere, it is felt that the diagnostics design has not been cost optimized. For instance it may be possible to reduce the number of Beam Position Monitors (BPMs) and Beam Loss Monitors (BLMs) without reducing the ability to observe and control losses. While this may not be a large cost driver in this WBS category, it strongly impacts the cost of controls.

3.4.3.8 Extraction

The base costs appear reasonable. However, costs associated with relocating the equipment to ORNL seem high. Also the EDIA associated with the design of the magnet system appears to be excessive.

3.4.3.9 RTBT System

The costs are evaluated elsewhere. It is noted, however, that the costs for this area would benefit from a careful requirements review, consideration of alternative optical schemes, and value engineering.

3.4.3.10 Ring Control System

Because of the choice of EPICS, much of the controls design already exists. The ring controls cost is based primarily on purchasing Input/Output Controllers (IOCs) with standard boards, and providing software. The base cost is reasonable. The designers are encouraged to find ways to reduce the cost by reducing the number of IOCs.

3.4.4 Schedule and Funding

Findings

The funding profiles for ring systems provided to the committee were in the form of spending profiles. The amounts shown were, for their respective fiscal years 1999 through 2004, \$8.4, \$14.5, \$25.1, \$25.7, \$17.0, and \$9.4 million, totaling \$100.1 million. It was not specified whether these were costs plus commitments per year as would be normal, and they were not linked to DOE budgets and funding to specify whether they derive from Budget Authority or Budget Obligations. In fairness to the NSNS project team with regard to the full perspective of the uncertainty, it is not yet clear at the Federal level whether this project will be fully authorized and funded at the start (FY 1999), as is current executive branch policy (the DOE proposal is based on this), or whether funds will be obligated year by year, as has been recent practice.

Information on schedule was provided at level II of the WBS structure only. This was in the form of bar charts for R&D, Title I, Title II, procurement and construction, installation and testing, and commissioning, and is consistent with information provided on other schedules projectwide. A first attempt at a level III schedule with milestones was presented, but had not been coordinated with the rest of the NSNS project, nor was it resource loaded.

Evaluation

The funding profiles needed for in-depth, resource-allocation-type scheduling and PERT-type project interconnection analysis need to be provided as soon as possible, and the schedules need to be developed as part of a project-wide scheduling activity directed by the ORNL-NSNS Project Director or his current equivalent. These need to be backed up by a procurement plan that focuses on the major (largest) cost items to be procured for the ring system and which must include lead times needed to prepare procurement

packages and get them through the approval process. At this time, there are really only a broad set of project schedule goals; these need to be turned into a set of resource loaded schedules at a detail level consistent with the requirements of a Conceptual Design Report as soon as possible.

3.4.5 Management

Findings

The management of the R&D, design, construction and installation of the ring systems, that is, the HEBT, the Accumulator Ring, and the RTBT, is the responsibility of Brookhaven National Laboratory (BNL) under the central project management of the NSNS at ORNL. Within BNL, the ring systems effort will be managed by a project office in the existing AGS Department. The office would retain its identity, structure and responsibilities when the AGS Department is merged into the proposed Accelerator Collider Department some time around 1999.

The specific obligations and responsibilities and other determinations required for BNL to do the ring systems work will be set forth and agreed to in a formal memorandum of understanding (MOU) between ORNL and BNL, and in the annual or semiannual modifications to that memorandum that will be used to implement specific work activities.

While at this stage of the proposed construction project, an organization to build the ring systems has not been formally established, a group has been assembled to carry out R&D and design studies and prepare needed documentation such as the Conceptual Design Report. This group is viewed as the core which will naturally evolve into the team that will build the ring systems at BNL and install them and assist in their commissioning at ORNL.

An organization chart for management of the BNL work was presented to the review committee, and tentative identification of specific persons to lead the group, manage subsystems and execute other appropriate management responsibilities was provided.

A number of suggestions and thoughts were provided to the committee concerning coordination of the BNL work with ORNL NSNS management. These included formation of a machine advisory committee to advise ring-systems management on technical, cost, and schedule issues and on the need to identify persons on the ORNL management team who can negotiate technical requirements, tradeoffs, and changes.

Evaluation

The proposed BNL management structure appears credible and is appropriate for the activities. The personnel tentatively proposed to fill the management slots are experienced in this work and should be able to provide the management skills and leadership needed. The method of using MOUs to implement the work and to structure the agreements about what must be done annually has been applied quite successfully before, most notably and recently in the PEP-II "B Factory" three-laboratory construction project led by the Stanford Linear Accelerator Center.

The major areas of concern of the committee center on coordination of the BNL activities with the ORNL-based central management group. The subcommittee examining the ring systems group activities believe that a centralized machine advisory committee, staffed to represent all the important technical subsystems from Front End H⁻ source to neutron instrumentation in the experimental areas, and which reports to the NSNS Project Director, is essential.

Further, the need for core expertise, available early in the project, in the Project Director's Office in ORNL, is essential for critical design tradeoffs, cost efficiencies, and conflict resolution among major subsystems.

Finally, while a credible organization chart showing needed functional elements and tentative staffing was presented to the ring system subcommittee, there were at least two notable vacancies. Discussion with the BNL staff lead to the conclusion that the currently planned management staff would benefit from the addition of two more persons well-qualified in charged particle beams or related technologies.

3.4.6 Recommendations

1. *ORNL needs to recognize it will be responsible for the facility, and needs to provide the overall leadership of the project. Thus, as soon as possible, ORNL needs to have a core team of neutron scattering users and accelerator designers and builders who can make informed decisions across the entire project.*
2. *The ring systems group has produced a credible 1 MW design for the HEBT, the Accumulator Ring, and the RTBT. The group now needs to iterate the design doing the necessary cost-benefit analysis and value engineering essential to producing a cost optimized design which does not compromise reliability.*
3. *The rings systems group should work with the other project groups to determine how the proposed 85 percent overall uptime of the facility can be increased.*

3.5 NEUTRON SOURCE SYSTEM AND TARGET RELATED R&D

3.5.1 Summary

The technical scope of the target systems had been reviewed recently by a team which largely included the same people now on the subcommittee, and the project proved to have responded positively to almost all the recommendations of that review. Consequently, the current review did not bring to the surface any major shortfalls or deficiencies. The most significant recommendations relate to the R&D program proposed, to the safe commissioning of the neutron generating target, and to keeping the hazard category low.

In general, cost estimates were found to have been carried out carefully and with the necessary precautions relative to early vendor quotes. The total cost is considered adequate although some shifts have been recommended. The schedule for completion of the R&D work is tight, but, provided it can be met, the total time allocated for construction and early commissioning is adequate with some flexibility in the schedule. A few minor management issues need to be resolved and careful interface control throughout the project needs to be secured. The committee compliments the design team for their excellent efforts.

3.5.2 Technical Scope

Target Systems (WBS 1.6) comprise all systems within the project in which significant amounts of proton beam are deposited. This includes the main neutron producing target system plus three auxiliary beam dumps, as well as the heat removal systems whose coolant may become activated (primary circuits, plus secondary circuit in the case of the liquid metal target, which has its own primary circuit). While the neutron producing target is rated for a power deposition of 1 MW with an identified upgrade path to 2 MW and the prospect of 4 MW, the auxiliary beam dumps (linac, ring injection, and ring extraction) are rated for 200 kW average power (averaged over 1 second).

Findings

- The technical scope is adequately defined and broken down into a workable structure.
- No showstoppers could be identified for the technical solutions proposed, but some of them need to be qualified in an aggressive R&D program.
- The Hazard Category of the target station may be driven by a few spallation products.
- Some interface issues with the users and the rings group need to be clarified.

Evaluations

The technical parameters of the subsystems are adequately defined with respect to their performance requirements. The overall scope of WBS 1.6 has been defined carefully and is workable. The interfaces to other subsystems have been defined adequately and in away that makes them relatively easy to control (e.g., radioactive/inactive cooling system, steel/concrete boundary, proton beam window, etc.).

Some more attention should, however, be paid to other boundary conditions such as external impacts (e.g., seismic) or ES&H needs. The committee fully approves of the decision to adhere rather strictly to the mission given to the project, namely to design for 1MW of beam power, while respecting the upgrade path to higher power. The project team took this into account in a cost-effective way by laying out all cooling loops for 2 MW and the shielding (including its cooling) which would be difficult to retrofit for 4 MW. The power upgrade will not affect the auxiliary beam dumps, because the only one that will be in use continuously is the ring injection dump, whose rating is more than a factor of 2 over the 1 MW level. (A second ring and two more dumps will be required for the 4 MW upgrade).

The design requirements of each major component need to be established and agreed upon before the start of preliminary design. The target system design must give special attention to assure that the needs of the users will be met. Also, safety and seismic requirements need early resolution because of the large impact on costs (especially for shield support). Furthermore, the design team should include operator input early to ensure a maintainable and robust design.

The concept chosen for the neutron producing target, namely a flowing liquid mercury system, is novel, but is in line with what similar projects with even higher power ratings (ESS and the Japanese Neutron Science Center) are proposing. The technical solutions envisioned are adequate, based on current knowledge, but aggressive pursuit of the key R&D issues to underline the feasibility is crucial. Currently no real show stoppers have been identified. However, a set of issues identified in the R&D program (control of the effect of pressure waves, corrosion under stress, and irradiation) must be resolved.

Areas to be revisited:

1. Justification for in-shield inserts between the inner tank and the shutter. The need to cool such inserts must be analyzed carefully because providing such cooling would be awkward due to the movable shutter downstream. If the users found such inserts indispensable, the design should include the necessary cooling.
2. Choice of reflector material. The choice of the reflector material has an effect on the neutron output. Currently beryllium has been selected because of superior integral yield, but most of the extra intensity is in the tails of the pulses. This is not necessarily what the users wants thorough parameter studies should be performed and discussed with the users. If a lead reflector proves acceptable, it will result in substantial cost savings and simplifications.

3. Commissioning of the target system. The loads on the target system result from the heat input, radiation, and the short duration of the power pulses. The short pulses may generate periodic stress on the container (pressure waves), while the heat and irradiation will affect the material properties, including possible corrosion effects. By commissioning the system with an uncompressed beam, the pressure wave effects could be eliminated, allowing more-relaxed performance testing of the cooling system. This would also allow an early investigation of radiation effects of the real system by removing the first target shell before it has been subjected to the pressure waves of the liquid.
4. Hazard category of the target station. The spallation products that drive the hazard category of the NSNS target station need to be identified. If the cost/benefit to the NSNS Project to be categorized as a Hazard Category 3 versus 2 is deemed significant, (Category 3 is preferable) the NSNS Target Station Design Team should devise an experiment to measure in particular those radionuclides that have a significant impact on the hazard category. These measurements should then be used to validate the predictive capability of the CALOR code system and develop normalization factors (conversion factors that reconcile calculated and measured data) that could be applied to the product buildup calculation. The funding for this effort should be prioritized within the R&D funds for the Target Station Design Team.

The greatest technical risk lies in the possibility of a very short lifetime for the target container. The consequent need for frequent exchange of the target containers would have adverse effects on the operating cost, the waste stream, and the availability of the NSNS. Adequate measures to control this risk have been proposed by the project and recommended in this review report.

3.5.3 Cost

The total project cost (TPC) for the target systems during the years 1999 through 2004—the duration of the project—has been estimated at \$129 million with prior years' cost up to 1998 of \$4 million, adding up to \$133 million. Out of this, \$28 million goes into R&D efforts to substantiate the concept chosen.

Findings

The target systems cost definition is generally well conceived and documented. The overall budget is considered adequate and contingencies in general match the degree of detail known at this stage.

Evaluations

The committee evaluated the R&D program costs and the design and construction costs separately. The two subsections below describe the results of the evaluations.

Research and Development Costs

The target systems R&D program provides the needed basis to proceed with the design. However, the committee finds certain proposed work unnecessary and some necessary work not included. The table below summarizes the changes we suggest. Deletions include out-of-beam mercury corrosion tests, physics code improvements, moderator pump development and steady-state thermal hydraulics. The most significant additions, which are changes in scope, are to enhance thermal shock testing, include in-beam corrosion tests of mercury circuit materials, and add activities that represent participation in an anticipated collaboration on "100 K" (thermal) moderator development. This latter is in response to users' needs that have not otherwise been addressed in the program. The R&D program should be moved forward, if necessary adjusting available effort, to provide more timely data for design. The net increase in funding requirements is \$741k, including the roughly estimated \$3 million cost for the in-beam corrosion tests.

As a percentage of TPC, R&D cost exceeds the 20 percent level, which seems high but is considered in view of the novelty of the target concept.

Comments on Cost Estimate, WBS 1.1.4-7, 1.1.10 Target Systems R&D

WBS	Comment/ Recommendation	Project Cost Estimate	Committee Recomm. Cost	Change
1.1.4.3 Basic Physics models	Duplication of effort with LANL- APT code development program, not clear improvements needed for design	582	0	(582)
1.1.5.2 Thermal shock tests	Need to enhance effort to address critical issues	567	1300	733
1.1.5.3 Corrosion tests	Data exists from literature and shows no problem	941	200	(741)
1.1.5.4 Instruments and Control R&D	Most instruments in hand; no special requirements upon controls	731	400	(331)
1.1.5.6* In Beam Corrosion Test	Need to investigate effect of proton beam on corrosion and operation	0	3000	3000
1.1.6.2 Materials Compatibility	Combine with 1.1.5.3 and 1.1.5.6	1778	1000	(778)
1.1.7.2 Material Evaluation (moderators)	Need not obvious, cold moderators in use at design conditions	102	0	(102)
1.1.7.4 Alternative concepts	Proposed H ₂ -pump not crucial for performance improvement. Redirect in part to support 1.1.7.6	1558	600	(958)
1.1.7.6* Participate in Intl. "100K" Moderator Development	Respond to user needs for "100K" moderators	0	500 note, no contingency required	500
Total		6259	7000	741

*Recommended increase in scope of R&D program

Design and Construction Costs

The target systems design and construction costs are carefully estimated although we recommend some minor adjustments. The table below shows our suggestions, which result in no significant change in the total cost.

One high cost element is the bulk shielding, which we were unable to appraise in detail because of its current level of design. Meanwhile, we concur that the estimated cost should suffice to produce this system. Another large item is the target maintenance cell. Because of its level of maturity at this stage in the design, the amount of contingency should be increased to 30 percent. Because these items represent an opportunity for cost reductions, we recommend early attention to their details.

All other costs appear to be reasonable with a sufficient contingency. As a percentage of total component costs, the EDIA costs are high. However, this is reasonable considering many systems are first of a kind, and are very complex.

Comments on Cost Estimate, WBS 1.6 Target Systems

WBS	Comment/ Recommendation	Project Cost Estimate	Committee Recomm. Cost	Change
1.6.2.1 Ambient Moderators	Overestimate of cost; water circuit not included	495	300	(195)
1.6.2.2 Cryogenic moderators	Experience shows higher cost	2958	3500	542
1.6.2.3 Assembly and Test	Overestimate, all manpower	1336	1000	(336)
1.6.3.2 Middle plug	Change from Be to Pb reflector	2173	1200	(973)
1.6.4.2 Proton beam window	Design immature, cost underestimated	144	200	56
1.6.5.4 Neutron beam lines	Eliminate dummy beam plugs in unused beam lines	1647	500	(1147)
1.6.6.3 Helium gas system	Need to accommodate tritium production, consider vacuum atmosphere in vessel, accommodate water leaks	314	600	286
1.6.6.5 Installation and check out	Large number of complicated systems to check out	243	400	157
1.6.7.1 Maintenance cell remote handling	Need to increase contingency from 16percent to 30percent at this level of design maturity	1468	3000	1532
Total		10,778	10,700	(78)

3.5.4 Schedule and Funding

Starting in 1997, the schedule for the target systems provides for:

<u>Item</u>	<u>Duration</u>	<u>Overlap with Previous Item</u>
R&D Work	4 yr	-
Preliminary design	2 yr	2 yr
Detailed design	2 yr	0
Procurement & fabrication	3 yr	2 yr
Installation and commissioning	3.5 yr	2.8 yr

The funding profile given shows a very flat distribution:

<u>Fiscal Year</u>	<u>99</u>	<u>00</u>	<u>01</u>	<u>02</u>	<u>03</u>	<u>04</u>
Fabrication	1	8	20	27	17	3
EDIA	4	6	6	5	4	3
<u>R&D</u>	<u>9</u>	<u>7</u>	<u>5</u>	<u>2</u>	<u>0</u>	<u>0</u>
Total	16	21	32	35	21	6

Findings

The schedule is considered feasible for the allotted time, although the need to interact closely with the general facilities during construction may cause some timing problems. The rather flat funding profile, not exceeding 25 percent of the project cost in any particular year of a 6-year project, corroborates the view that there is some flexibility in the schedule to accommodate minor perturbations.

Evaluation

While the overlap of the preliminary design and some of the detailed design phase with R&D work may be acceptable, the committee advises a more aggressive schedule for the R&D work. This would help to secure the necessary data base for some of the decisions that must be made in the first three years to avoid redesign during the installation phase. Those two phases largely coincide, which is considered risky.

The committee concluded that the overall time allotted for completion of the work is adequate. Enough flexibility exists to move certain work packages in time in order to achieve a firm starting base and minimize the risk of late configuration changes. The flat spending profile corroborates this view. The total level of funds allocated to WBS element 1.6 seems adequate and largely based on thorough and well documented cost estimates. The timing between conventional facilities construction and target systems installation must be monitored carefully.

3.5.5 Management

The project proposed the following method of accomplishment.

- ORNL will perform preliminary engineering, prepare procurement specifications and follow vendor performance with factory and NSNS site inspections and tests.
- Vendor will perform detailed engineering, component fabrication and assembly, factory testing, and shipment to NSNS site.
- Construction management team will install and start up equipment.
- Exceptions include some target, moderator and instrumentation and control systems

Findings

The management of WBS element 1.6 and its related R&D effort is fully in the hands of ORNL staff, which eliminates some of the complications other WBS elements may face.

The organization structure established to manage this part of the project is basically adequate; some reassignments of tasks and clarifications of responsibilities, however, are necessary.

Required management tools to stay in control of the configuration schedule and cost of this relatively complex and diverse part of the project have been identified but not yet fully established. This needs to be a project-wide effort.

Evaluation

Interfaces between major WBS elements/major project systems require greater attention. This is especially critical for the interface between the users and the instrument designers, and the target station designers, but is also true to varying degrees with respect to other systems. Communications between systems designers need to be better established to ensure that people within different WBS elements/major systems (e.g., linac, ring, etc.) are aware of what is going on in other parts of the project, and to ensure that all parties are cognizant of their responsibilities and the expectations of other systems. Criteria defined at the interfaces need to be enhanced and formalized to accomplish project objectives, including well-defined milestones and linkages between interdependent tasks. The interface documents relating the target station and the beamstops with the conventional facilities should explicitly address the potential for the unintentional transport of radioactive materials outside of controlled regions.

There should be a clearly designated manager who is ultimately responsible for decisions and for ensuring adequate communications within the target station design team and with other elements of the project (e.g., linac, ring, etc.)

3.5.6 Recommendations

The following are the main recommendations concerning the target station. A number of comments passed on to the project team during the review are listed in the Appendix G.

1. *The project should focus its R&D program on issues of fundamental importance to the qualification of the novel mercury target concept.*

Activities that merely aim at improving existing predictive capabilities in the percent range or at verifying available information, or which are likely to duplicate efforts going on elsewhere, should be given lower priority. Instead, the crucial area of possible enhancement of liquid-metal, solid-metal interface reactions under stress and irradiation should be addressed urgently. All means to investigate this should be exploited with high priority.

2. *The project should consider a Pb reflector.*

Currently a beryllium reflector surrounds the target and moderators. Theoretical studies indicate that a lead reflector might give equivalent performance and possibly even better pulse shape at much lower cost. This question should be studied with high priority and in close interaction with the users.

3. *The project should aim at making early commissioning tests of the target system possible with uncompressed beam.*

It would be highly desirable to separate power load and radiation issues from pulse load issues. This could be accomplished by injecting uncompressed pulses from the linac into the target, either by bypassing the ring with a short section of beam line or by designing the ring extraction system such that it can be active over the full injection period. These issues should be discussed with the rings team and a trade-off study performed.

4. *The project should define a milestone for a solid-target decision.*

In view of the possibility that a backup solid target may have to be employed, a milestone must be clearly defined when this decision has to be made in order to assure that sufficient time is left to develop such a target for the 1 MW power level

and to incorporate necessary changes (e.g., an additional highly radioactive primary cooling water circuit).

- 5. The project should ensure that, during assembly, access to well equipped shops is secured. This is to minimize delays resulting from the need for adjustments and corrective measures.*
- 6. The project should evaluate the cost versus benefit of achieving a low hazard category.*

The issue is whether the facility is in Hazard Category 2 or 3. This might have a significant effect on cost and on operating procedures. Since there are a few spallation products driving the classification of the facility, this issue should be scrutinized carefully. If proven beneficial, efforts should be launched to keep the NSNS facility in Hazard Category 3.

3.6 EXPERIMENTAL SYSTEM AND INSTRUMENTS

3.6.1 Summary

The team which has put together the plan for the experimental facilities at the NSNS has done a remarkably good job, especially in light of the limited resources at their disposal. They have developed a reference set of spectrometers adequate for costing purposes and have presented a credible cost estimate. They have laid out a process for identifying, designing, and building spectrometers, which can be refined as more experience is gained from on-going upgrades of current facilities. The committee's major concerns focus on the need to ensure full instrumentation of the NSNS as quickly as possible and on the potential benefit to full exploitation of the NSNS from a much larger instrument R&D program than is currently envisioned.

3.6.2 Technical Scope

On the advice of the NSNS Steering Committee, the NSNS project is planning to make 10 neutron scattering instruments available to users on the first day of operation of the facility. Accordingly, the CDR describes a set of 10 reference instruments which covers a wide range of the types of science that will be addressed by the NSNS. This set of instruments was chosen in order to allow costs to be estimated and should not be viewed as the set that will actually be built by the project.

In fact, the 10 instruments are based on instruments already operating at other pulsed neutron facilities and therefore pose no significant challenges and contain no fundamentally new ideas in neutron scattering instrumentation. It is the opinion of this committee that a major new facility, such as the NSNS, should develop several instruments based on new concepts, invented through a vigorous R&D program, as discussed in more detail below. The committee also believes that it is essential that the NSNS project identify a method for developing additional instruments and ensure the commissioning of these instruments at the rate of 1 or 2 per year after the first 10 spectrometers are operational.

The CDR describes a set of reference instruments designed to operate on a 60 Hz target station. While this repetition rate is too high to allow optimal performance for many neutron scattering instruments, the committee concurs with the selection of 60 Hz as the repetition rate for this target station. This repetition rate will provide the highest possible average neutron flux, which is critical for several of the reference instruments, enabling completely new science to be done in areas where present facilities are severely flux-limited. Other reference instruments (6 of 10 reference instruments and likely a similar number of day-1 instruments) will operate productively, though not optimally, at 60 Hz either by limiting their bandwidth or by eliminating pulses (with choppers) to lower the effective repetition rate. However, the full potential of these instruments cannot be realized unless essentially zero background can be achieved between useful pulses, allowing a wide bandwidth to be accessed. This concern can and should be addressed in two parallel ways:

1. An aggressive R&D program to develop and test choppers that will achieve, as nearly as possible, zero background and/or efficient bandwidth control over the desired bandwidth for each instrument at the 60 Hz target; and
2. An attempt to identify funding (e.g., through NSF) for a future second target station with a low repetition rate. It should be noted that the most desirable repetition rate of a second target needs study and that a frequency of 10 Hz (discussed in some of the project documents) may not be optimal.

A second target station will be of particular importance to several scientific communities. For example, high-resolution, long-wavelength diffraction will be critical for studying the large structures encountered in drug design. *In situ* studies of reaction kinetics demands that the full bandwidth be accessed simultaneously, while maintaining high resolution and high count rate. An important area in polymer science is the study of the real-time kinetics of polymer conformations and structure at both short and long lengths, for which the full bandwidth of the neutron source must be used. Such studies are essential, for example, to the understanding of important industrial problems such as polymer processing. Measurements in highly restricted sample environments, such as the high pressure measurements of interest to geophysicists, must achieve a wide bandwidth at a single scattering angle. The study of small samples while maintaining high resolution requires a near zero background between pulses (which may be impossible to achieve with choppers alone).

The use of a second target station will allow moderators and instruments to be optimized for these needs. Thus, the affected instruments will be substantially more productive than if operated with choppers on a 60 Hz target station. The development of optimized cold moderators (e.g., liquid methane) will be much easier on a lower-repetition-rate target because of the reduced effects of radiation damage. Thus, the peak flux achieved may be a factor of two or three higher than would be implied by the peak proton power alone. Such opportunities for cold neutron scattering have not yet been fully exploited at any pulsed source.

A number of areas in which research and development will be needed to produce instruments of superior performance has been identified by the NSNS project, and the committee endorses this list. However, it is the view of the committee that the funding needed for instrument research and development has been seriously underestimated in the CDR and that it should be increased by a factor of 4 or 5. Such R&D has enormous leverage as has been demonstrated by previous projects (such as the construction of the Institute Laue-Langevin in Grenoble, France). The opportunity exists for the NSNS to considerably leverage technology developments of the past two decades such as advances in computer technology, novel nuclear and particle physics detectors, and optical elements that can focus neutrons beams. The vision should be to make the next quantum jump in performance, and only part of this can come from increased proton beam power on target. If an R&D budget of \$50 million for

instrumentation is regarded as unusual for a \$1 billion facility, we point out that the ILL used 30 percent of its construction budget to develop new spectrometer components and build its initial complement of spectrometers.

A significant part of the R&D funding should be made available early in the project to assure that instrument designs have progressed to the point where the selection of moderators and other target characteristics can be made in a timely fashion.

The committee also notes that a research and development effort on liquid-methane moderators has the potential for significant improvement of the performance of instruments served by cold moderators.

The proposed laboratory space to support these instrument R&D activities by NSNS staff, initially at ANL and ultimately at ORNL, is not clearly delineated.

Although the project is clearly aware of the importance of communication across interfaces between instrument development and other parts of the project, the committee found several areas where these interfaces had not yet been adequately defined or where important decisions seemed not to have been made. Examples include:

- a. Timing of mechanical choppers with respect to the whole accelerator system (interface with linac and ring teams).
- b. The capacity of cranes (and doors) which may not be sufficient to accommodate the largest instrument components, some of which may weigh as much as 50 tons (interface with conventional facilities team).
- c. Instrument interlock/safety system (interface with accelerator/linac/ring/ES&H teams).
- d. The size of the chopper cavities (and their vertical access hatches) at the edge of the bulk shield (interface with target team).
- e. Provision for installation of and changing "in-pile" neutron-beam apertures, guide sections, multiple guides upstream of the neutron shutters (interface with target team).
- f. Exchange of instrument drawings/CAD files between ANL (which has prime responsibility for instrument design) and ORNL (which is accountable in the long term for all aspects of the facility). Apparently different CAD systems are in use and interoperability may be an issue.

- g. Acceptance testing (interface with target team).
- h. A library of moderator spectra and lineshapes for spectrometer simulations (interface with the target team).

Times for decisions on these interface issues must be included as milestones in the overall Project Management Plan.

While the instrument hall appears to be of sufficient size, the committee is concerned that office and lab space may have been seriously underestimated. While there is likely sufficient lab space for users actively engaged in experimentation at NSNS, there appears to be little provision for laboratories that might be used by NSNS staff scientists for crystal growth, wet chemistry, or other long-term lab projects. In addition, a cold room immediately adjacent to the experimental hall is essential for the support of neutron scattering experiments in biophysics/structural biology. Such facilities have proved necessary at the national laboratories, especially for the stabilization and handling of samples of supramolecular assemblies of biological macromolecules.

While sufficient user space for the storage of neutron-activated samples appears to be provided, there does not appear to be adequate space assigned for the storage of instrumentation unique to a particular set of users when they are not actively engaged in experimentation at the NSNS. In addition, space for development, off-line testing, and maintenance of ancillary equipment is not adequate.

Finally, the committee is concerned that office space for NSNS scientific staff and visitors may not be adequate. Since the committee was not able to determine how much of this type of space in the office building adjacent to the experimental hall would be used by accelerator or target personnel, we were unable to accurately assess the situation. Nevertheless, a rough calculation suggests that about 80 offices will be needed by personnel directly associated with the experimental program (scientists, postdoctoral researchers, technicians, user administration, visitors, et al.). This is to be compared with the 70 offices available, which must also, apparently, house some target personnel.

The committee encourages the NSNS project to use the recently completed Advanced Photon Source as a benchmark against which to judge the adequacy of the space provided for scientific activities.

3.6.3 Cost

The reference set of spectrometers was chosen in order to assess the likely cost of the instruments that will be available on day 1. The committee believes that the reference set of spectrometers has been chosen in a reasonable manner and that their costs have been well estimated

(the basis of the estimate including many vendor quotes, times and rates for design and engineering activities, etc.).

Our conclusion is that the budget requested for construction of 10 instruments on day 1 (\$45.9 million) is adequate and that sufficient contingency has been included.

The committee has not tried to estimate the cost to the project of ensuring that a complete suite of instruments (i.e., a total of 18 instrumented beam lines) is constructed in a timely manner after facility start-up (see recommendation #1 below). The cost to accomplish this will depend strongly on the method chosen to implement the recommendation and might be funded independently of the construction project.

As discussed elsewhere, the committee strongly recommends a substantial increase in the budget for instrumentation R&D, from less than \$10 million to about \$50 million. The committee is keenly aware that cost containment is very important for the NSNS project, and offers this recommendation with the caveat that it must be carefully weighed by the project in its cost-benefit analysis.

As discussed elsewhere, the committee recommends a relatively small addition of laboratory space, which likely adds about \$1 million to the conventional facility cost.

3.6.4 Schedule and Funding

The instrument-development timeline is feasible, but very tight, if 10 working instruments are to be available for the user community when the first neutrons are generated. The NSNS staff scientists who will design and construction design and build the instruments must be hired as soon as possible in order to coordinate with other subsystem teams and to have instruments ready for commissioning when the NSNS comes on line. Furthermore, because of the lack of investment in neutron scattering instrumentation over the past two decades in the United States, most of these new hires are likely to be inexperienced in neutron scattering and in managing an instrument design and construction program. Therefore, it will take them some time to come up to speed. The committee recommends that these new hires could profitably spend some portion of their initial time visiting other laboratories in the United States and Europe that have instrument suites at today's state-of-the-art.

As stated above, it is crucial that milestones and time lines for making instrument decisions be established quickly, and that these be consistent with the project decisions required for the target and moderators.

Although neutron spectrometers are not on the critical path of this project, it is wrong to believe that there is plenty of time to develop them. An aggressive schedule of R&D, hiring of new staff, and conceptual design is absolutely essential for the success of the NSNS project.

3.6.5 Management

Currently the instrumentation effort is handled by Kent Crawford at Argonne National Laboratory, who has done a remarkable job working on the NSNS part-time with extremely limited resources. In order to maintain the proposed schedule and to ensure that all of the new instrument design efforts will be as efficient as possible, it is essential to have a full-time project leader for the instrument activities very soon.

The CDR proposes three committees that will be responsible for instrument development. The Instrument Oversight Committee (IOC) will be responsible for representing the general user community in the choice and operation of the instruments. The Instrument Advisory Teams (IAT) will represent the user community of particular instruments or perhaps a class of instruments. This committee will include the NSNS scientist responsible for the construction of that instrument or instruments. The third type of committee is the Instrument Development Team, a group that gets external funding to build an instrument at the NSNS. There is time to refine this model based on the experience that will be gained by spectrometer construction at LANSCE, where outside teams are also heavily involved.

This Review Committee is, nevertheless, concerned that a committee structure may lead to instrument choices that are too conservative and too few instruments that stretch the state-of-the-art. The committee suggests that the final decisions regarding the initial instrument suite and all subsequent instrumentation projects should be made by the NSNS Director (assuming, as we believe imperative, that this individual has close ties to the neutron scattering community) with advice from the IOC. The committee notes that, while it is appropriate for the IOC to be nominated by the NSNS Steering Committee, this body should be chosen by and report to the NSNS project and not the NSNS steering committee.

Pending feedback from the LANSCE instrumentation project, the committee endorses the concept of Instrument Advisory Teams that involve the scientific community. However, we counsel caution in assuming that many instruments will be constructed by non-NSNS personnel. The committee believes that it is crucial for the project to develop and maintain a core competency (including engineering) and infrastructure at ORNL so that instrumentation of the additional beamlines can be developed in a timely fashion, allowing commissioning of one or two additional instruments each year after start-up.

3.6.6 Recommendations

1. *The NSNS project should expand the scope of the instrumentation activity to ensure that all beam lines are instrumented in a timely manner, following the construction of the initial suite of 10 spectrometers. This will require the creation of an instrument-development*

infrastructure within the project that should be preserved as a core competency at NSNS after the start of beam delivery in order to ensure that the facility retains international leadership.

- 2. A substantial increase in the R&D budget for instrumentation is needed. This will ensure that the NSNS develops the next generation of neutron instrumentation and does not simply install the present generation of instruments at a new spallation source.*
- 3. The needs of the neutron instrumentation must drive more of the decisions and performance specifications, including overall accelerator performance, target/moderator parameters, and features of the conventional facilities. This can best be accomplished by identifying, as soon as possible, the person who will manage, full-time, the development of experimental facilities.*

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3.7 CONTROLS

3.7.1 Summary

The Controls System Proposal is to base the system design on Experimental Physics and Industrial Control System (EPICS), which is used about 70 DOE laboratories and other sites. This system has been shown to work at Argonne National Laboratory's APS (Advanced Photon Source) and at the Thomas Jefferson National Accelerator Facility, which are accelerators with about four times the number of monitored and controlled variables as the NSNS will have, but with comparable overall configuration (linacs, rings, beam lines, and user facilities).

The EPICS architecture is a flat architecture with workstations and servers (e.g., modeling, archiving, etc.), a local area network (with connections to wide area networks as required), and IOCs (Input-Output Controllers) which are microcomputers. The IOCs are the interface to accelerator devices via VME crates, VXI crates, or PLCs (Programmable Logic Controllers) and other intelligent devices. Dumb devices are supported by cards in the VME or VXI crates or by vendor-proprietary interfaces to the PLCs.

The EPICS workstations presently utilize Unix as the usual operating system, but Microsoft's Windows NT will almost certainly be supported by EPICS within the NSNS construction time frame.

Other systems included in the control system used by all the accelerators and beam delivery systems are the timing, fast protection, and beam permit systems.

3.7.2 Technical Scope

The scope proposed is complete and adequate. There is adequate R&D proposed to support the technical scope. This is due to the fact that EPICS is a proven toolkit for building a control system, and a number of important functions are available to NSNS through the EPICS collaboration. There are no areas of high technical risk in the proposal.

3.7.3 Cost

Controls Base Cost (No Contingency, No Escalation)

WBS 1.1.9:	Global System Development R&D	2,122 K\$
WBS 1.3.5:	Front End Control Systems	1,335 K\$
WBS 1.4.8:	Linac Control Systems	12,888 K\$
WBS 1.5.11:	Ring Control Systems	12,008 K\$
WBS 1.6.8:	Controls (Target Systems)	3,697 K\$
WBS 1.8.11:	Global Control Systems	18,902 K\$
Total		50,952 K\$

Engineering, Design, and Inspection (EDIA). The project has included software engineering costs under materials, and not in the normal EDIA totals. This makes the recovering of an EDIA total difficult. Software engineering is engineering, and such costs should be moved to the EDIA columns.

Adequate Resources. As is usual in control system reviews, one is always worried about the estimates for software. There is adequate software and database effort for the device-specific and IOC-level software (about four hours per control point, and 25,000 control points for the project; therefore 50 person-years). In terms of application software, the estimates show about 32 person-years of effort (in the linac, rings and global control systems), with an additional 27 person-years allocated in the preoperations budget in the controls and accelerator development groups. There is no entry for applications software in the front end controls budget (application software is being done under the R&D budget) and no entry for application software in the target systems control system (we have suggested the addition of 2 person-years for this WBS).

Design effort in the other global systems (timing, fast protection, and beam permit) for which controls is responsible is probably underestimated (See "Management Findings," below). We have chosen to increase estimates in these areas by 5, 5, and 3 person-years (at \$160k per person-year), respectively. This is based on experience with the design of the SLAC PEP-II timing system over the past three years, and with the design of the SLAC machine protection system (which was finished just before the design of PEP-II started).

Contingency. Lack of functional requirements for commissioning the NSNS (again, see "Management Findings") results in uncertainty about the amount of application software necessary. The committee has recommended increasing the contingency of WBS 1.4.8 (linac control systems) from an average 26 percent to a 50 percent figure that is equivalent to approximately 20 person-years. Similarly, the contingency of WBS 1.5.11.5 (ring applications software) should be raised from 30 percent to 50 percent, approximately 4 person-years; and that of WBS 1.8.11.9 (global systems)

software, covering system as well as application software, should be raised from 25 percent to 50 percent (5 person-years).

The committee has also recommended similar increases, from the original 25 percent to 50 percent, in the contingency for WBS 1.8.11.3 (Timing System), WBS 1.8.11.4 (Fast Protection System), and WBS 1.8.11.5 (Beam Permit System) for the same reason: lack of functional requirements. In these cases, the issues are more than just software. We believe that hardware and software engineering are underestimated, and have addressed that issue above, but the lack of functional requirements further increases the contingency estimate.

3.7.4 Schedule and Funding

The schedule and funding profiles look acceptable in general. Most of these purchases are standard items. The only concern here is that the linac Title II completion milestone is December 31, 1999. The design of the global systems (timing, fast protection and beam permit) must meet that schedule. See "Management Findings."

3.7.5 Management

The NSNS Controls effort is presently organized as a working group with one representative each from ORNL, LANL, LBNL, and BNL. This team has impressed the committee with respect to its software and systems engineering skills, its experience, and most of all, its teamwork. The committee is confident that, if the project can maintain this team and build on it as a foundation when the NSNS is approved, the control system will be well integrated and will meet its specifications.

Our main finding, as seen by other committees in this review, has to do with NSNS project management. The project-wide coordination and availability of NSNS accelerator personnel exhibited in this CDR is weak. This is most clearly seen in two areas: application software and global systems associated with controls.

The lack of functional requirements for application software necessary for commissioning demonstrates the need for more accelerator physics and commissioning input to the controls team. But there is not yet a core accelerator physics team, nor is there any team or individual responsible for how commissioning is to be done. Without the functional requirements input from such teams, the controls team has not developed a list of the applications software necessary, which, in our opinion, means that the contingency on the software for this project must be increased. (Details are described above.)

The second area where functional requirements are missing is the global systems associated with controls: timing, fast protection, and beam permit. In this case, the functional-requirements definition process requires input from the teams designing all the accelerator systems, the target, and

the instruments. Defining that input will require more than just coordination; it will require decisions. For example, there is some budget allocated in the rings for timing. Other laboratories have met such subsystem-specific requirements by putting the required functionality into the global timing system. A proposal has been made for a system-specific timing arrangement; this would require increased spares and maintenance resources during operation. So, definition of the functional requirements and system concept requires that a project decision be made in this matter.

The organization chart for this project does not match the WBS. Specifically, the budget for the controls system manager is found mainly in WBS 1.8 Conventional Facilities. Since power follows money, not lines on an organization chart, the Controls System Manager must be given the same budget authorization and control as the peers.

3.7.6 Recommendations

1. *NSNS Project Management needs to organize and manage working groups defining functional requirements and system interfaces for timing, fast protection, and beam permit systems. Organizations with input into these requirements include those developing the front end, linac, rings, target, Instruments, and controls. Similarly, NSNS Project Management needs to organize working groups to define the application software required for commissioning; this will require input from the accelerator development and commissioning groups (see Recommendation 2).*
2. *ORNL management needs to staff the accelerator development group, and also create and staff a commissioning group (with accelerator operations experience) to be responsible for commissioning the NSNS. The commissioning group will eventually become the NSNS operations group.*
3. *The controls system manager must be given the same budgetary control over his budget as the other system managers. The organization chart shown to us by the NSNS management indicates a controls manager who is a peer to the various accelerator system managers. However, as noted above, the WBS does not match the organization chart. Since power follows money, we recommend that WBS 1.1.9, 1.3.5, 1.4.8, 1.5.11, 1.6.8, 1.8.11 be assigned to the control system manager.*

3.8 CONVENTIONAL FACILITIES

3.8.1 Summary

The Committee had very useful meetings with the ORNL facilities staff. The staff described the buildings, as well as services that have been designed and costed at the conceptual level, to provide facilities and infrastructure for the accelerators and target areas.

The facilities and services seem to be adequate for the NSNS based upon the conceptual requirements for the proton source, linac, accumulator ring, target, research instruments, and support facilities. The costs are realistic for the conceptual design, although the design of the technical systems continues to evolve. During January 1997, a conventional facilities review was conducted; it served as the springboard for the current review. Substantial progress in the intervening time has been made in the design of the conventional facilities by the capable staff at ORNL. However, considerable work remains to be done in FY 1998 before preliminary design begins.

Four areas were identified that need additional evaluation or action for the success of the project. First, the conventional facilities team needs to get well-defined functional requirements, provided by the scientific teams. Until these requirements are fixed, the design will continue to fluctuate, which will affect design, costs, and schedule. Second, senior management attention must be focused on the project. It is recommended that locating key technical staff at ORNL, as well as hiring identified key project personnel now, would be major steps toward this goal. Third, the construction schedule as part of the overall project schedule should be reevaluated. It appears that with the considerable amount of work remaining to be done in conceptual design, coupled with the large increase in front-end construction activities, the proposed schedule may be overly optimistic. Fourth, it is recommended that the work breakdown structure (WBS) be reworked to match the physical elements of the design and the way in which actual work activities are conducted.

3.8.2 Technical Scope

The scope of the conventional facilities and services for the proposed NSNS consists of a newly developed site, various buildings housing technical components, electrical and mechanical systems, support buildings, and services. The buildings and services appear to match the currently identified technical needs of the proton source, linac, accumulator ring, target, and service systems. The committee notes that development of the final functional requirements for conventional facilities will be needed once the design requirements for the technical components and systems are defined.

Because of the importance attached to the technical and design requirements, the collection, documentation, and project approval of these requirements is quite important. Assembling the functional requirements, as collected by the facility engineers, provides confirmation to the scientists and

engineers in the technical system areas that the conventional facilities will meet their needs. This process completes the loop and helps to stabilize the information used as the basis of design.

At present, the requirements information is contained in the backup spreadsheets of the engineers and in tables in the CDR. The requirements information is scattered throughout the conventional-facilities CDR documentation and is hard to relate to the technical systems documentation. Consequently, it is recommended that the technical and conventional systems requirements be assembled in a Functional Requirements Document. This document is particularly important for this project in view of the wide distribution of participants in the proposed NSNS.

3.8.3 Cost

Overall, the base cost of \$332 million is more than adequate to support design/construction of conventional facilities for a 2 MW source based on the current input. However, the requirements must be formalized before any assurance can be given. Also, there are many areas that are substantially overestimated and based on conservative approaches.

EDIA costs of approximately \$50 million are acceptable for typical projects of this size, yet they may be slightly high. Redundancy appears to exist between technical and management resources for ORNL, the architect/engineering (A/E), and the construction management (CM) organizations. Also, it is not possible to assess total resources because they are not loaded into an integrated cost/schedule program.

The contingency of \$51.3 million (18 percent) appears to be acceptable but may be somewhat low in certain high-risk areas for this stage of the project. The staff needs to complete an effective contingency analysis. A 1 percent change in contingency can mean up to \$10 million change in project costs.

3.8.4 Schedule and Funding

A schedule has been developed for initiating the project in FY 1999. All buildings, major components, and general testing activities appear to be included in the schedule, with site development beginning in January 2000 and construction completion in March 2004. Responsibilities for individual activities overlap in many cases and need to be segregated.

The critical path was developed from integrated planning and it is reflected in the schedule, but has not been verified. Durations and staffing should be verified and loaded to assess the true critical path. More thought should be given to how the construction work packages should be structured to assure proper integration with components provided by the other labs. The resources loaded against the schedule will help verify the realism of the activity durations.

Critical milestones can be identified in the schedule but are not addressed adequately in the Project Execution Plan.

3.8.5 Management

Systems engineers, under the guidance of an experienced manager of conventional facilities, have been responsible for developing the conceptual design. Both the engineers' work and the WBS have been organized by facility systems such as site, buildings, electrical power and communication systems, environmental control systems, mechanical/piping systems, etc., rather than by individual buildings.

This approach taken by the ORNL staff makes matching the conventional facilities to the technical systems (proton source, linac, ring, etc.) difficult. Furthermore, it is hard to schedule and monitor design status and construction progress for the technical facility enclosures. In light of these observations, the ORNL management is encouraged to reconsider their approach to the work by reconfiguring the WBS. In particular, it is recommended that the WBS be organized by physical facilities, such as linac, accumulator ring, etc.

3.8.6 Recommendations

- 1. The functional requirements identified by the scientific staff must be finalized forthwith. Until these requirements are fixed, the probability of design changes to the conventional facilities is high. Further, a "floating design" will continue to add time to the project and increase the total project cost.*
- 2. It is imperative that the key ORNL senior staff positions required for this project be filled now. The project will take on an identity that reflects the dedication, enthusiasm, and attitude of this team that needs to be established during the formative conceptual design stages. Additionally, key scientific liaison staff should be relocated to ORNL. Direction and management of this project at ORNL will be a challenge. Managing a project with collaborating teams located around the country will not be easy.*
- 3. Reevaluate the conventional facilities construction schedule and the overall project schedule. With the considerable conceptual work remaining before Title I design, coupled with the large staffing ramp-up in FY 1999, the required resources required in FY 2000 and 2001 are considerable. The task of managing a number of parallel activities appears to be risky.*
- 4. Reevaluate the WBS for conventional facilities. The committee recommends the WBS be reorganized to match the way contracts will be awarded and the actual physical work will be performed.*

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3.9 PRE-OPERATIONS

3.9.1 Summary

The committee's examination of pre-operational plans and cost estimates in the CDR raises some concern with regard to actual experience at other facilities. Experience has shown that actual commissioning takes longer and costs more than conceptual planning would indicate. Based on this experience, the committee believes the NSNS budget in FY 2004 to be low by perhaps as much as \$25 million.

3.9.2 Technical Scope

The commissioning process is phased over the life of the project such that plant subsystems are tested and operated sequentially in the direction of beam travel; i.e., the ion source, then the linac, the ring, etc. This approach will spread pre-operational activities over a few years, which is good. However, when all subsystems are operated together at the conclusion of facility construction, there will likely be a large number of "fixes" needed before acceptance tests can be performed.

3.9.3 Costs

There is \$74.7 million estimated for pre-operational activities on this \$1,096 million Total Estimated Cost (TEC) facility. When compared to other recent projects, the committee believes the pre-operational costs will likely be closer to 10 percent of the TEC, though this subjective estimate cannot be detailed.

3.9.4 Schedule and Funding

Time phasing of the pre-operational activities is reasonable, and the funding profile appears appropriate, subject to the committee's stated concerns regarding the sum.

3.9.5 Management

The project team proposed bringing ORNL operating staff on board early enough to be involved with fabrication and testing of facility components. To the extent possible, this staff should also have the opportunity to be involved in component design to help assure the resultant systems are easily operated and maintained.

3.9.6 Recommendation

The project team should examine recent experience with the commissioning and startup of DOE accelerator facilities to gain insight into the level of costs that should be anticipated for the NSNS, and based on that investigation, make appropriate adjustments in their cost estimate.

4. COST ESTIMATE

4.1 Summary

The Total Project Cost (TPC) estimated for the NSNS project by ORNL is \$1,266 million. The NSNS cost estimate without escalation in FY 1997 dollars is \$1,089 million and the DOE committee estimate is \$1,115 million—an increase of \$22 million. The major differences are in conventional construction (-\$20.5 million), Ring and Transfer Systems (-\$12.7 million), and Research and Development (+\$55.2 million), as shown in Appendix D1 and D2. The NSNS Cost Estimate System developed by ORNL successfully collects and displays all costs pertaining to the project. Each cost item has a WBS identification established in an Oracle database system with a World Wide Web interface.

The project estimated contingency is 20 percent (\$201 million) and the committee recommends 20 percent or \$207 million.

4.1 Summary - Cost Estimate

The Cost Estimate developed by ORNL successfully collects and accounts for all costs pertaining to the Research and Development, Line Item Project, Pre-Operation Costs and Prior Year Costs for NSNS. Each cost item has a WBS identification.

4.1 Summary - Contingency

The committee feels that the 20percent contingency on the remaining work is adequate at this stage of the project.

4.2 Methodology

Methodology - Cost Estimate

ORNL initiated an innovative approach for collecting estimated project costs from five DOE national laboratories. They developed a standardized Web data entry system that fed an Oracle database, which facilitated the consistency in the estimate and provided a robust mechanism for sorting costs to enable more prudence in management decision-making. Each cost item has a WBS identification. A variety of sources, including vendor quotes, standard tables, historical cost and expert opinion, were employed to estimate costs of the WBS 4-9 levels.

Methodology - Contingency

Contingency for the NSNS project is based on perceived technical risk associated with each WBS element. The resulting figures are shown at each WBS level in Appendix D, which gives the amount of contingency and estimated cost for each WBS Level 2 element and the corresponding DOE review committee evaluation.

The amount of project contingency is the sum of contingency estimates developed for lower-tier activities (WBS Level 3-5) by the appropriate laboratory team. The estimated composite contingency rate for the project by the ORNL team is approximately 19 percent (\$201 million) of base cost (not counting prior-year costs) at the conceptual design stage of the project. Individual WBS contingency rates vary from 10percent to 35 percent.

All allocations of NSNS project contingency to the prime contractor will be controlled by DOE through a change control process, but DOE will not control subsequent distributions by the prime contractors. The DOE acting project manager is planning to release 50 percent of the yearly contingency amount at the beginning of each fiscal year.

4.3 Evaluation

Evaluation - Cost

While ORNL's Oracle Data Base Cost Estimating system performed extremely well in support of the Conceptual Design Review, the approved project will entail additional requirements. Either a substantial upgrade of this system or another, more comprehensive system will be necessary in order to carry the analysis down to the lower WBS levels and enable sensitivity analysis with respect to changing parameters.

Cost estimate documentation is adequate for the level of detail of the Conceptual Design Review. While all backup documentation has yet to be delivered to ORNL, which will be the repository for the information, some of the voluminous information was reviewed and evaluated at the lowest levels for major portions of the NSNS system. It was found to adequately and fairly represent the estimated cost. A variety of sources, including vendor quotes, standard tables, historical analogous component cost, and expert opinion of person-hour build-up of costs, were employed to estimate costs to the WBS 4-9 levels. Costs were treated as FY 1997 then-year dollars, spread according to reasonable spending plans and escalated according to DOE inflation indices. Additional scrutiny and review is required by ORNL to properly translate the spending plan (Budget Outlay, or BO) into a required funding profile (Budget Authorization, or BA).

NSNS Project Cost appears to be reasonable for the scope of work defined and for the proposed schedule. Some specific areas bear close attention by DOE, ORNL, and the collaborating laboratories due to potential impacts from uncertainty and concern in schedule, components on the critical path, vendor production capability, and proper allocation of R&D funds. If the project can be completed in the proposed six years, the estimated cost appears to be reasonable. However, schedule slippage could increase the total cost by adding program management cost, extending preoperations cost, and availability of scientific expertise at the time of commissioning.

Some aspects of an Hg target are yet unproved—not "physics" challenges, but rather, engineering challenges pertaining to the material encapsulating the Hg, the effects of corrosion, and beam effects on the flowing Hg. The R&D program is to be completed within two months of starting the final target, which allows no room for error, this could affect schedule.

While a 100 K moderator (reduces the effective 'temperature' of the spallation neutrons by 100 Kelvin) has not been built either, other proven moderators could fill that void if needed, thereby avoiding schedule delays.

Clarification and more detail must be provided by ORNL to give reasonable assurance that conventional facilities will not take an additional year or two to complete.

There is a production capability uncertainty with respect to klystrons. Los Alamos National Laboratory's submission is predicated on running two shifts for two years to meet delivery schedules. This production capacity has not necessarily been sufficiently demonstrated in this review. Further detailed explanation is required.

The last major area of cost impact is the allocation (or amount) of R&D funding. To mitigate some of the mercury-target concerns, a redistribution of R&D funding may be required. While estimated costs appear to be adequate for a six year schedule, there is ample concern that it may be inadequate to compensate for a significant schedule slippage.

Beyond the scope of this CDR, the user community has a keen interest in what would be a pre-planned product improvement (P3I) program to fund the development of more state-of-the-art experimental instrumentation and the 2 MW upgrade.

ORNL has recently negotiated a special overhead casual/benefit rate of 28.17 percent for the NSNS project versus a 39.8 percent for ORNL. If a pending space charge-back system is implemented, the NSNS rate will be 21.6 percent. Similar casual/benefit overhead rates are to be negotiated with the participating laboratories. The major categories of the NSNS cost are shown in Table 4.1, and the overhead costs as percentages of base cost for the five laboratories are shown in Table 4.2.

TABLE 4.1

NSNS Major Categories of Cost

	<u>Operating Expense</u>	<u>Line Item</u>	<u>Total</u>
Material Direct	25	362	387
Install Direct	0		105
105			
EDIA Direct	52	<u>205</u>	<u>257</u>
Subtotal Direct	77	672	749
Indirect Subtotal	0	49	49
Overhead Subtotal	15	<u>64</u>	<u>79</u>
Subtotal Overhead	15	113	128
and Indirect			
Overhead as a percent of direct $128M/745M = 17$ percent			
Tax	2	30	32
Contingency	18	159	177
Escalation	<u>17</u>	<u>121</u>	<u>138</u>
TPC	129	1,096 TEC	1,225 TPC

TABLE 4.2
NSNS FY 97 Costs Without Contingency or Escalation in \$M

<u>Participant</u>	<u>Base Cost</u>	<u>Overhead</u>	<u>Overhead percent</u>
ORNL	127	26	20
ANL	39	5	12
BNL	111	12	11
LANL	158	19	12
LBNL	17	4	25
AE	24	1	4
Constr1			
Manager	129	5	4
FPSC	226	8	3

<u>Participant</u>	<u>Base Cost</u>	<u>Overhead</u>	<u>Overhead percent</u>
ORNL	482	38	8
ANL	39	5	12
BNL	111	12	11
LANL	158	19	12
LBNL	17	4	25
AE	24	1	4

The method of applying some of the CM indirects and sales tax in the cost estimate was faulty. The CM indirects (for shipping and dunnage, renting heavy equipment, small tool allowance, etc.) should not have been applied to the costs for "in-house" labor such as computer programming, assembly technicians, etc. at participant laboratories. In addition, Tennessee sales tax of 8.25 percent was incorrectly applied to all material and non-EDIA labor costs planned to be incurred at the four out-of-state labs.

Evaluation - Contingency

The committee feels that the 20 percent contingency on the remaining work is adequate at this stage of the projects. The proposed 50 percent allocation of yearly contingency to the laboratory at the beginning of each fiscal year is also supported by the committee.

4.4. Recommendations

Recommendations - Cost

1. *Evaluate the cost estimate based on comments contained in previous sections of this report and Appendix D.*
2. *Evaluate and negotiate special overhead rates with the participant laboratories, and tax rates with local county and state, and ensure their proper application in the cost estimate.*
3. *Subtract "in-house" labor from the CM indirect-labor pool in the cost estimate.*
4. *Complete selection process for a cost/schedule performance measurement system (earned value) and implement it when project construction funds are released (FY 1999).*
5. *Review construction cost estimate to assure current Davis Bacon craft labor wage rates are being used.*

Recommendation - Contingency

The allocation of contingency and corresponding change control produce should be spelled out in the Project Execution Plan.

5. SCHEDULE AND FUNDING

5.1 Summary

The Total Project Cost (TPC) in the CDR for the NSNS is \$1,266 million. This is comprised of \$1,096 of Line Item funds (TEC) and \$170 million of R&D and Pre-Operations. The funding profile (Appendix E1) shows a substantial increase in budget authority (BA), from \$23 million in FY 1998; to \$178 million in FY 1999; to \$302 million in FY 2000. The peak BA of \$319 million occurs in FY 2001.

A summary six-year construction project schedule (Appendix E2) was presented that provides for a FY 1999 start, with completion at the end of FY 2004. Installation of the Target Systems is completed in April 2004, with initial commissioning of the Experiment Systems finished by the end of FY 2004.

An integrated project schedule covering R&D, design, construction, installation, and commissioning has been generated from basic information provided by each of the participant laboratories. The data (about 2,050 specific task activities staff at levels 3 and 4) was entered by ORNL project office staff into a schedule database (Microsoft Project) and activity logic ties were established with the aid of laboratory teams.

A Critical Path Schedule (Appendix E3) has been generated which shows the critical path running through design, fabrication, and installation of the linac and then through ring, HEFT, and target commissioning. The currently identified critical path milestones are:

Start Title I	October 1998
Start Title II	March 1999
Start construction	January 2000
Start technical equipment installation	December 2000
Construction complete	September 2004
Project completion	September 2004

There are four DOE critical decision points and schedule items associated with regulatory review and certification. Delays in passing these decision points have the potential to cause significant delays in the project schedule and result in significant project cost increases. Similarly, NEPA and environmental permitting activities are scheduled to take place very early in the project, and it is clear that success in meeting regulatory requirements and securing permits is essential to maintaining a credible schedule.

5.2 Assumptions

1. The line-item project start is in FY 1999.
2. The line-item project is six years long, with completion at the end of FY 2004.
3. No R&D task would be scheduled as part of the project critical path.
4. The FY 1998 budget of \$23 million will be available for R&D and advanced conceptual design work.
5. The Environmental Impact Statement Record of Decision will be completed in an appropriate time to allow site preparation to begin in the second quarter of FY 2000.

5.3 Evaluation

The Project has made a good start on developing an integrated schedule; the existing document provided a good basis for this CDR review. However, concerns about overly aggressive schedules have been noted in both the linac and the conventional-facilities sections of this report. ORNL project staff should closely revisit the scope of work and schedule data for these sub-projects with the senior team leaders to ensure that schedules are achievable. In addition, this detailed schedule review should result in a revised funding profile.

Project staff are aware of the need to continue development of detailed schedules. Careful integration of these schedules into one resource-loaded document is of critical importance on this project due to the special challenges presented by hardware interfaces controlled by design teams located in different parts of the country.

While a critical path schedule has been produced, a more significant group of critical project milestones, as well as a set of meaningful Level 3 and 4 interim milestones for each system, should be identified to aid in measurement of progress. As a general rule, activity completions are more meaningful project milestones than are activity starts.

Project staff have made an early start on evaluation of a cost/schedule earned-value measurement system for use during the construction project. This effort should continue to fruition so that a system is ready when the project is initiated with construction funds.

The core members of a project controls team are in place. They clearly possess an impressive set of database and system-software skills and have demonstrated mastery of the existing project management systems.

5.4 Recommendations

1. *Evaluate and revise schedules based on comments contained in other sections of this report to ensure that schedule goals are achievable.*
2. *Develop a funding profile based on the revised schedule.*
3. *Identify the critical path Level 3 and 4 milestones.*
4. *Develop a resource-loaded integrated project schedule.*

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6. MANAGEMENT

6.1 Summary

The NSNS construction project will involve an integrated team of DOE national laboratories: Oak Ridge, Brookhaven, Lawrence Berkeley, Argonne, and Los Alamos. Memoranda of Understanding are in preparation between ORNL, the lead laboratory, and the other four laboratories. These MOUs will mutually establish technical scope, cost, schedule, and performance goals and commitments. In this arrangement, each laboratory will execute its scope as set forth in the MOU according to schedule and within planned resources. There will be regular meetings among the parties for technical, cost, schedule, and progress reviews.

Oak Ridge National Laboratory has done a good job in pulling this partnership together in sometimes trying circumstances. This model, using the best talent and resources in the DOE laboratory system to execute a major project, is an example of how these projects can be better conceptualized and executed in the future. It will keep the skill set throughout the system strong, and allow the host institution to focus on the core mission of the facility.

Documents

1. A letter from the directors of the five laboratories to the Secretary of Energy supporting the scientific justification of the NSNS, describing the teaming arrangement, and asking for the support of the Department of Energy for this management model. (Appendix F)
2. A letter in response from Martha A. Krebs, Director, DOE Office of Energy Research (at the direction of the Secretary of Energy) expressing support for the teaming concept and encouraging the team to proceed. (Appendix F)
3. Drafts of the four MOUs and their addenda.

6.2 Management Organization

The philosophy for integrating the work of the five laboratories is based on the following few principles (from the Project Execution Plan or PEP, p. C-2):

1. Ensure that laboratories clearly understand their scope of work and what is expected, and have a clear commitment to deliver it.
2. Clearly establish effective project requirements and baseline technical information.

3. Establish useful communication mechanisms and modify them as better methods are identified.
4. Avoid interference with existing, proven, effective methods as much as possible.
5. Delegate responsibility for appropriate activities to each laboratory.

See also Appendix F, "Project Execution Plan."

6.3 Management Controls

The MOUs are the mechanism for implementing this philosophy. The purpose of the MOUs is to establish the work scope, guidelines, commitment of resources and personnel, overhead charges, and agreements to accomplish the work. In general, the planning and directions for the NSNS project are established by the collaboration as a whole.

The committee posed the question: How is ORNL, the responsible laboratory, going to manage the project under this MOU arrangement?

The ORNL response: Through the communications processes, and the regular progress meetings, adjustments will be made as required to maintain project performance. If there is a major problem at one of the laboratories, the NSNS Project Director has the authority to remove work from the problematic laboratory and place it at another laboratory within the team; another national laboratory (e.g., SLAC, FNAL, or TJNAF); or with a commercial firm. Such action should be at the request of ER-10, since this program office will have the best reading of whether improved system coordination will be an overall help.

6.4 Evaluations and Recommendations

6.4.1 Laboratory Team Management Evaluation

The committee generally feels that the MOU arrangements, while clearly defining the role, responsibilities, and commitments of each team member and the team collectively, do not take adequate advantage of the infrastructure now in place to manage the performance of work within the DOE national laboratory system. Without overt support and authority from the Secretary of Energy down through the program offices of the Assistant Secretaries and the Director of the Office Energy Research, ORNL will have a difficult time maintaining the discipline required in this complex arrangement.

Recommendations

1. *The Secretary and the participating Secretarial officers need to declare their support and expectations for the DOE infrastructure at Headquarters, the Field Offices, and within the Laboratories to facilitate the successful completion of this project as a Strategic System Acquisition (SSA). The rigorous performance, cost, schedule and reporting requirements of the SSA must be supported with clear expectations and support throughout the system. In a more general sense, it is important that DOE support this arrangement as a model for future projects, and provide creative management and administrative processes to help it along and prepare the way for others to follow.*
2. *In order to support the collaborative effort, the project and the DOE should consider adding an NSNS performance measurement factor among each participating laboratory's contract performance measures. Contractual impact would clearly enlist HQ and the field in assisting the project to insure progress and quality, and would keep the project at a high priority with laboratory management (even though some labs have a relatively small element of the project, all would have to treat it as a SSA.). It would solidify the allegiance of the laboratory directors to the project as a whole, since their performance score would be determined by the ORNL and DOE NSNS Project managers. This arrangement will also assure that the laboratories are given proper credit for successful performance.*
3. *ER-1, DP-1, and the OR Manager should coordinate the DOE system of headquarters, field offices, and laboratories with regard to NSNS priorities, commitments, and performance of each of the labs and the labs collectively. Again, it is important that the DOE take an active and supportive role in facilitating these partnerships.*

6.4.2 ORNL NSNS Management Team Leadership

Evaluation

The ORNL has proposed a management structure wherein the person ultimately responsible for delivering this project, or PUR (see page C-8) would report through an Associate Laboratory Director (ALD) for the NSNS, and be called the Project Director. The rationale is that the ALD would provide support and interface to elements of the lab, DOE, and other external entities as needed, and that the PUR could then concentrate exclusively on project issues. Given the complexities and size of this project, this does not seem to be an adequate rank for the PUR.

Recommendations

1. *The PUR has a very difficult task in managing not only activities within the lab, but also projecting influence and authority to the other team laboratories. The PUR should have as high a status within ORNL as practicable. This will facilitate interaction with the senior management team of the lab by making the PUR part of that group; let the PUR interact day-to-day with the heads of finance, engineering, facilities, etc. on a peer basis; and make the PUR the peer of those at various team laboratories who have responsibility for NSNS activities. For these reasons, the PUR should be at the ALD level, rather than having an ALD between the PUR and the laboratory's authority and resource base. The committee would suggest that the Project Director be more responsible for day-to-day running of the project. The committee suggests that the responsibilities now ascribed to the ALD in the ORNL mode should be retained by that ALD, since this kind of interaction is at the heart of sound project execution. Some responsibilities can be delegated to subordinates as needed. The ALD for NSNS must also have responsibility for consolidating and perpetuating community support for the continued budget to successfully compete the project.*
2. *It is critical that the permanent leadership for the NSNS project be named as soon as possible. The leaders must be in place early enough to put their personal stamp on the technical strategy, the cost estimates, and management philosophy, and to generate the kind of personal commitment to the project and its execution which is required for success. The right people will add greatly to the project scientifically, technically, and in management, and must be able to influence the project in the design and planning phases. It will also be a mark of ORNL's ability to execute this project that key scientific, technical, and management leadership, committed to making the NSNS succeed, can be successfully recruited to ORNL before the project is funded by Congress.*
3. *The successful development of the NSNS as a science facility will require that the neutron scattering community develop a cohesiveness and sense of community which has not been a strong part of their history. This tremendous investment in neutron science will carry the community into a new era, and will require them to work together in new ways to support this investment and grow the user community that will benefit from it. The ORNL ALD for NSNS must provide leadership in making this happen.*
4. *We recommend that the Director of ORNL and the Project Management seek to secure the genuine commitment of the Director of each participating laboratory to support the NSNS as a high-priority mission of his own laboratory.*
5. *The Committee urges the management of the project and the ORNL to seek ways of incorporating the Senior Team Leaders from the outside laboratories (e.g., Bill Weng from BNL) directly into the project management structure in such a way that they participate in the*

decision-making process for the whole project and therefore share in its success. Although this may be difficult, it is important to maintaining a sense of responsibility for building to the baseline estimates.

- 6. In each of the technical review groups, there has been a call for ORNL to take charge of the project--regardless of which laboratory is the lead laboratory for a particular system--to make key decisions, take ownership of the facility as a whole, and provide critical interface decisions and guidance. Therefore, in addition to management leadership, it is important that the ORNL NSNS project team develop, as quickly as practicable, technical leadership and capabilities in the areas important to the project execution and the eventual operation and further development of the NSNS. This would include, for example, accelerator physics and engineering, instrumentation, neutron science, etc. Such early ownership will provide ORNL with the capability to influence the design and execution in a manner consistent with their responsibility and accountability for the success of the construction project and the successful operation as a scientific facility. A comprehensive set of functional requirements is needed to allow the system integration that is now missing in the CDR, and should be pulled together by the ORNL team.*
- 7. There is not enough top level technical integration to force performance/cost tradeoffs of individual machines. Each design group seems to be specifying performance requirements for other machines in such a way as to make their own design and performance requirements less demanding. ES&H requirements have not been cost/benefit tested. The ORNL NSNS Project Office needs to put pressure on the linac, front-end, transfer lines, rings, and ES&H groups to perform cost savings and performance trade-off studies and subsequent refinements to their designs.*
- 8. The project schedule is weak at this point, and in many cases does not appear realistic. There has not been a rigorous top-down systems analysis to tie the elements of the project together.*

FY 1998 Priorities

- ORNL must recruit the necessary scientific, technical and management leadership to the project. The ORNL project team must take charge of all elements of the project.*
- They must be a full system/value analysis of the project, with all the necessary cost/performance trades analyzed and design refinements identified.*
- R&D to accelerate the schedule and support technical, cost, and schedule decisions for the project must be carried out.*

6.4.3 DOE and ORO Project Office Draft Project Execution Plan (PEP)

Material Presented:

Draft Project Execution Plan (PEP)
MOUs and addenda
Work Breakdown Structure
Systems Diagram/ Interface Drawings at Level 3
Change Control Description

Evaluations

The PEP is adequate for a project at this stage. It is important that adequate ORO Project staff be situated together with the ORNL Project Office, in accordance with staff level plans presented (three in FY 1998, five in FY 1999, and seven in FY 2000).

Recommendations

1. *The intent with respect to appropriate use of Budget Authority is good; but possible confusion regarding contingency allocation needs to be clarified. Allocating at a proportionate rate is not consistent with how contingency has historically been used.*
2. *A permanent DOE Project Manager should be appointed as soon as practicable.*
3. *Three permanent DOE/ORO project office positions will be required in FY 1998 if NSNS is included in the FY 1999 budget.*

6.4.4 Other Issues

1. **Finding:** BNL identified a problem in obtaining adequate staff if the project slips out of the FY 1999-2000 window. Currently, it is intended that the people will come from other projects that are ramping down.

Recommendation: *All participant laboratories should pursue options to maintain or add qualified staff when needed by the project. Other factors which could be affected by project start and duration and other aspects of the schedule need to be properly understood and accommodated.*

2. **Finding:** The linac management group at LANL has identified part-time staff in almost all categories.

Recommendation: *NSNS will be a full time activity which will require full time attention of any individuals directing the work. Only employees assigned full time to NSNS should be in the top management team.*

3. **Finding:** The construction schedule requires freezing the RF systems design by December 1999. This is a short time considering that tube and power supply development is required.

Recommendation: *More preconstruction operating dollars should be provided starting next year to buy a second klystron and power supply to test options. Funding should be added for a CCDTL structure to be tested at full power.*

Intentionally Blank

7. ENVIRONMENT AND SAFETY

7.1 Summary

The NSNS project is committed to a proactive ES&H program on the design, construction, and operation of the NSNS. This new project offers an excellent opportunity for NSNS and the Department of Energy to initiate a new accelerator research program that starts clean and stays clean, and that integrates ES&H with accelerator design and operations in a cost-effective manner.

The project has used matrixed ORNL staff and has planned appropriately for facility ES&H staff to transition from construction to operation. The project would benefit during the design stage by identifying and establishing a multi-lab ES&H integration management team and a dedicated staff for ES&H who would be responsible for integrating ES&H with all aspects of facility design, on a systemwide basis as well as component by component. Recommendations on this are included in the "Environment" section below.

The NSNS project has committed to a conservative approach to safety and environmental protection that needs to be implemented in a cost-effective manner. The facility design would be enhanced by a cost-benefit approach to integrating ES&H with accelerator design. This should be accomplished by the dedicated ES&H team.

Early planning for waste minimization, pollution prevention, and the reuse of recycled materials is appropriate and should result in cost savings.

The primary recommendations are made on integrating ES&H with facility design, implementing ES&H in a cost-effective manner, establishing a dedicated ES&H management and staff team, and revisiting the hazard classification for the target.

7.2 Environment

7.2.1 Overview

An Environmental Impact Statement (EIS) is being prepared on the potential impacts associated with the proposed NSNS project.

The NSNS solid target feasibility study provides a basis for a backup target, should an unexpected difficulty occur in the development of the reference mercury target.

The NSNS project management organization structure generally defines accelerator project roles and responsibilities.

The project prepared the ES&H portions of the CDR using ORNL matrix staff as needed.

7.2.2 Evaluation

The EIS is being prepared at an appropriately early stage in the project. Its cost and schedule are reasonable, but may be affected by design decisions in the project.

The CDR describes a solid target as a basis for a backup design, should an unexpected difficulty occur in the reference mercury target development. Using different materials, the backup solid target has the potential for creating different environmental impacts, especially regarding waste generation. The potential impacts of using a solid target need to be bounded for use in the NSNS EIS. ORNL ES&H staff must be informed of the viability of this option and the potential for including this information in the NSNS EIS.

The project has prepared the ES&H portions of the CDR using ORNL matrix staff as needed. The NSNS project management organizational structure does not identify a dedicated ES&H organization and manager.

7.2.3 Recommendations

1. *NSNS project should decide whether the solid target should remain as a viable backup to the liquid mercury target. This decision could affect the preparation of the EIS, and this should be made as soon as possible.*
2. *The NSNS project should consider establishing a multi-laboratory ES&H management team to integrate ES&H with all aspects of NSNS facility design. This applies to both environment and safety.*

7.3 Safety

7.3.1 Overview

Discussions on the hazard categorization of the proposed NSNS facility indicate that there is some discrepancy in the proposed classification of the facility. Information presented to the ES&H review team indicated ORNL is now considering a Category 2 designation. A designation of Category 2 rather than Category 3 could result in higher design and operational costs. A more detailed evaluation is now required to determine the correct facility hazard classification.

DOE Order 5480.23, which provides guidance for the preparation of PSARs requires completion and approval of the PSAR before purchase of any materials for a project. Currently, the schedule shows the PSAR being completed in June 2000. This has the potential to adversely impact the project's ability to purchase materials, which is supposed to begin in October 2000.

Calculations of shielding requirement activation and spallation product yields have been made which depend upon cross-section values, some of which were measured in the 1940's, particularly those for mercury. Furthermore, very little nuclear data for reactions at energies above 20 MeV has been validated.

Reliable functioning of the NSNS Project Personnel Protection System is a vital element of the facility's safety program. Use of Programmable Logic Controllers (PLCs) in PPSs has succeeded at other facilities, e.g., the Advanced Photon Source, the Thomas Jefferson National Accelerator Laboratory, and the Stanford Linear Accelerator Center.

The project has committed to a conservative approach to worker protection and compliance with federal ES&H requirements.

7.3.2 Evaluation

The CDR reported a facility hazard classification of nuclear Category 3 per STD-1027 methods for the quantity of radioactive materials that would be present. This level appeared to be appropriate for the mercury target and experimental room. ORNL stated at the review, however, that an initial designation of Category 2 would be consistent with the STD-1027 guidance, based on a new calculation of the radioactive spallation product inventory that would be generated in the mercury target. Full consideration of the fission product production/removal process will likely result in a return to Category 3 nuclear material levels. A facility designation as Category 3 will result in lower costs for the SAR and other safety documentation, operations, and maintenance, as well as a lower Price Anderson Amendment Act (PAAA) level of attention.

Currently, the project schedule shows the PSAR being completed in June 2000. It is unclear if this includes time for review and approval. Procurement is currently planned for October 2000 and is contingent on PSAR approval. This element could become a critical path item if it were not completed on time.

Numerous calculations of shielding requirements, activation, and spallation product yields have been made which depend upon cross-section values, some of which were measured in the 1940's, particularly those for mercury. Furthermore, very little nuclear data for reactions at energies above 20 MeV has been validated. The effects of the cross-section uncertainties upon NSNS design

calculations is unknown. It is necessary to complete a study of sensitivity of calculations to cross-section uncertainties as soon as possible, and establish a prioritized list of nuclear cross-section measurements needed to complete the design of NSNS.

Developers of the PPS have made excellent progress with their system concepts, but would benefit from formal consultation with PPS specialists at other facilities.

A beam loss criterion intended to maximize the possibility for hands-on maintenance was established without having completed a cost-benefit As Low As Reasonably Achievable (ALARA) study. This criterion may be inappropriately driving raising facility costs. The conservatism in this approach should be revisited for its appropriateness and necessity.

7.3.3 Recommendations

1. *Consider performing a more complete hazard classification evaluation of the spallation products in the mercury target to determine if analysis, by itself, can demonstrate justify a Category 3 designation. If analysis alone is unable to show justify Category 3, then consider the cost-benefit of employing a mercury purification system to maintain a Category 3 designation.*
2. *Calculational uncertainties resulting from nuclear data deficiencies should be resolved as soon as possible.*
3. *An advisory team of subject matter experts should be formed to assist the NSNS project in development of its Personnel Protection System (PPS).*
4. *The NSNS project should consider performing a cost-benefit ALARA study on the beam loss criterion before finalizing facility design.*

Appendix A

memorandum

DATE: FEB 06 1997

REPLY TO: Energy Research
ATTN OF:

SUBJECT: Review of the Conceptual Design Report for the National Spallation Neutron Source

TO: Daniel R. Lehman, Director, Construction Management Support Division, Energy Research

The purpose of this memorandum is to request that you organize and lead the review of the Conceptual Design Report for the National Spallation Neutron Source at Oak Ridge, Tennessee.

The Office of Basic Energy Sciences within the Office of Energy Research has responsibility for the possible construction and operation of the National Spallation Neutron Source, which is to be the premier national user facility providing intense neutron beams for the study of materials, bio-molecular structures, magnets, superconductors, polymers, etc. The National Spallation Neutron Source will likely include a proton linac, a storage ring, a spallation-target, a neutron scattering guide hall and various instruments to utilize these intense neutron beams.

The Office of Basic Energy Sciences/Office of Energy Research has supported the development of the Conceptual Design for the National Spallation Neutron Source in fiscal year 1996 and fiscal year 1997, and needs to have the Conceptual Design Report reviewed in detail this summer with regard to the accuracy of its cost estimate, the schedule to accomplish the construction, and the feasibility of its technical scope.

Because of the size of the potential investment in the National Spallation Neutron Source project, its importance to the Department of Energy laboratories, its impact on the United States neutron sciences research programs, and its importance to United States participation in future international science projects, the Office of Energy Research will need to be able to substantiate to Congress and to elements of the administration that its investment in the National Spallation Neutron Source project is reasonable and likely to achieve the expected results within the planned cost and schedule.

Therefore, I request that you assemble a committee of experts, charged as follows.

The National Spallation Neutron Source Conceptual Design Report Review Committee should assess the technical feasibility and expected performance of the designs proposed for the National Spallation Neutron Source. The committee should carefully review the cost estimates, understand in detail the basis for the estimates, identify uncertainties, and judge the overall validity of the estimates. Cost optimization should also be considered. The realism of the plans for meeting the required schedule should be carefully evaluated on the basis of the expected funding profile. The manner in which this work will be accomplished, including how it will be managed, should be reviewed and assessed. In summary, the committee is to review and assess the technical feasibility of achieving the proposed technical goals for the National Spallation Neutron Source, and the credibility of the associated cost and schedule estimates, and the adequacy of present and planned management arrangements to accomplish the scope of work.

You should ensure that your review committee will receive the necessary documentation from the National Spallation Neutron Source Conceptual Design Team in a timely manner. Your review of the National Spallation Neutron Source Conceptual Design Team should take place during June 1997.

By copy of this memorandum, the Office of Basic Energy Sciences and the Office of Resource Management are directed to support you in whatever ways that are required to make this a successful endeavor.

James F. Decker
Deputy Director
Office of Energy Research

cc:

Martha Krebs, Energy Research
John Rodney Clark, Energy Research
Patricia M. Dehmer, Energy Research
Iran L. Thomas, Energy Research
William T. Oosterhuis, Energy Research
Bill Appleton, Oak Ridge National Laboratory

Appendix B

**DOE NATIONAL SPALLATION NEUTRON SOURCE (NSNS)
REVIEW COMMITTEE**

June 23-27, 1997

Review Chairman - Daniel Lehman

Observers

Pat Dehmer (DOE/BES)

Iran Thomas (DOE/BES)

Walter Polansky (DOE/HQ)

ICE

Juan Castro (DOE/FM)

Burns & Roe (2-3 Consultants)

Report Coordinator

Bill Oosterhuis (DOE/BES)

(LBNL) Editing Support

Support (DOE)

Christie Ashton (DOE)

Mary Stowers (DOE)

Karen Lee (ORNL)

Legend

C-Chairperson

SC-Subcommittee

[] - Part-time
Subcommittee
Member

SC 1

Accelerator Physics

(C) Steve Peggs (BNL)

Rick Baartman (TRIUMF)

Nikolai Mokhov (FNAL)

Jean Delayen (CEBAF)

SC 2

Project Management

WBS 1.2

Pre Operations

WBS 1.9

(C) Ed Temple (ANL)

Mike Knotek (PNNL)

David Wilfert (DOE/ORO)

Larry Kelly (DOE/ORO)

John Rees (SLAC)

[Jim Carney (DOE/HQ)]

SC 3

Front End

WBS 1.3

(C) Gerald McMichael (ANL)

Chuck Schmidt (FNAL)

Jim Alessi (BNL)

SC 4

Linac System

WBS 1.4

(C) Roy Cutler (Cornell)

Matthew Allen (SLAC)

Dixon Bogert (FNAL)

Jerry Watson (INC.)

Jock Fugitt (TJNF)

Rusty Humphrey (SLAC)

Bill Brewster (DOE/ORO)

Bob Kustom (ANL)

SC 5

Ring System

WBS 1.5

(C) Dave Finley (Fermilab)

Rod Gerig (ANL)

Rudy Damm (ANL)

Mike Craddock (TRIUMF)

Dave Sutter (DOE/HEP)

Dan Wolff (FNAL)

Richard York (Michigan State)

SC 6

**Neutron Source System
& Targets**

WBS 1.6

(C) Gunter Bauer (PSI)

Gary Russell (LANL)

Mike Cappiello (LANL)

Mike Todosow (BNL)

Jack Carpenter (ANL)

SC 7

**Experiment System
& Instruments**

WBS 1.7

(C) Roger Pynn (LANL)

Jim Jorgensen (ANL)

Larry Passell (BNL)

Sunny Sinha (ANL)

Dan Neumann (NIST)

Kent Blasie (U Penn.)

Rob Robinson (LANL)

SC 8

Conventional Facilities

WBS 1.8

(C) Jim McClusky (PNNL)

Tom Pawlak (FNAL)

Dale Flowers (PNNL)

Rudy Etheridge (ANL-retired)

Jim Sanford (BNL-retired)

Harry Peters (DOE/ORO)

[Dixon Bogert (FNAL)]

[Jim Carney (DOE/HQ)]

SC 9

Environmental & Safety

(C) Clarence Hickey (DOE/HQ)

Bill Taber (RF WESTON, INC)

Sat Goel (DOE/HQ)

Al Evans (DOE/HQ)

SC 10

Cost & Schedule

(C) Jim Krupnick (LBNL)

Jim Carney (DOE/HQ)

Wilson Carnes (DOE/ORO)

DOE Committee Total-60

(Excludes Observers & ICE)

Appendix C

**DOE Review of the
National Spallation Neutron Source Project
(Technical/cost/schedule/management)
June 23-27, 1997
Pollard Auditorium
Oak Ridge, TN**

PLENARY SESSION AGENDA

Monday, June 23, 1997

8:00 am	DOE Executive Session	
9:00	Welcome and Introductions	B. R. Appleton (ORNL)
9:15	DOE-ORO Welcome	J. C. Hall (ORO)
9:30	Opening Remarks	W. F. Ballhaus (LMC)
9:45	Vision, Overview, and Management Structure	B. R. Appleton (ORNL)
10:30	Instrumentation and User Interactions	H. A. Mook (ORNL)
11:00	Overview of Conceptual Design, Alternatives, and Upgrade Paths	J. R. Alonso (ORNL)
11:30	Overview of Costs and Schedules, and Work Plan	J. E. Cleaves (ORNL)
12:00	LUNCH	
1:00	Overview of Front End Systems	R. A. Gough (LBNL)
1:30	Overview of Linac Systems	A. J. Jason (LANL)
2:00	Overview of Transport and Ring Systems	W. T. Weng (BNL)
2:30	Overview of Target Systems	T. A. Gabriel (ORNL)
3:00	BREAK and Schedule Contingency	
3:30	DOE-ORO Management and EIS Activities	D. K. Wilfert (ORO)
4:00	Overview of Conventional Facilities	J. E. Cleaves (ORNL)
4:30	Pre-Operations, Commissioning, and Operations Plans	J. R. Alonso (ORNL)
5:00	DOE Executive Session	
7:00	Buses leave Garden Plaza for dinner	
7:45	Dinner - Club LeConte	

**DOE Review of the
National Spallation Neutron Source Project
(Technical/Cost/Schedule/Management)
Preliminary Agenda**

Monday, June 23, 1997

8:00 a.m.	DOE Executive Session - Pollard Auditorium
9:00 a.m.	Plenary Presentations
12:00 noon	Working Lunch
1:00 p.m.	Plenary Presentations
5:15 p.m.	DOE Executive Session - Pollard Auditorium
6:15 p.m.	Adjourn

Each of the subcommittee presentations/discussions are to provide an overview of the technical scope, and detailed presentations on cost, schedule, and management.

Tuesday, June 24, 1997

8:30 a.m.	Subcommittee Presentations/Discussions
12:00 noon	Working Lunch
1:00 p.m.	Subcommittee Presentations/Discussions
4:00 p.m.	Subcommittee Executive Session
5:00 p.m.	DOE Full Committee Executive Session - Pollard Auditorium

Wednesday, June 25, 1997

8:30 a.m.	Subcommittee Presentations/Discussions
12:00 noon	Working Lunch
1:00 p.m.	Subcommittee Presentations/Discussions
4:00 p.m.	DOE Subcommittee Executive Session
5:00 p.m.	DOE Full Committee Executive Session - Pollard Auditorium

Thursday, June 26, 1997

8:30 a.m.	Subcommittee Working Sessions - report writing
12:00 noon	Working Lunch
1:00 p.m.	Subcommittee Working Session - report writing
3:00 p.m.	DOE Full Committee Executive Session - Pollard Auditorium

Friday, June 27, 1997

8:30 a.m.	Subcommittee Working Sessions
11:00 a.m.	Full Subcommittee Chairperson Mtg. - dry run - Pollard Auditorium
12:00 noon	Working Lunch
1:00 p.m.	Continue Full Subcommittee Chairperson Meeting - Pollard Auditorium
3:00 p.m.	DOE Summary and Close-out - Pollard Auditorium
5:00 p.m.	Adjourn

Appendix D

Appendix D1

TIMATE FY 1997 Dollar in Thousands) COMPARISON TABLE										
WB	System or Item	NSNS ESTIMATE			Total k\$	DOE ESTIMATE			Total k\$	Variance
		Base Cost k\$	Cntngncy %	k\$		Base Cost k\$	Cntngncy %	k\$		k\$
1.0	NSNS (As-Spent k\$)	1,026,094	20	200,519	1,226,613	1,041,894	20	206,968	1,248,863	22,249
	Escalation	115,567		22,584	138,151	115,256		22,895	138,151	
1.0	NSNS (FY97 k\$)	910,527	20	177,935	1,088,462	926,639	20	184,073	1,110,712	22,249
1.1	Research and Development	43,332	19	8,131	51,463	89,893	19	16,821	106,715	55,252
1.2	Project Support	41,897	15	6,480	48,377	41,897	16	6,870	48,767	390
1.3	Accelerator Front End Systems	15,645	27	4,180	19,825	15,645	27	4,180	19,825	(0)
1.4	Linac Systems	240,853	19	46,589	287,442	240,853	19	46,666	287,520	78
1.5	Ring and Transfer Line System	119,962	21	24,984	144,945	110,132	20	22,118	132,250	(12,696)
1.6	Target Systems	74,622	23	17,531	92,153	73,331	25	18,495	91,826	(327)
1.7	Experiment Systems	42,093	20	8,417	50,510	42,093	20	8,417	50,510	
1.8	Conventional Facilities	280,391	18	51,277	331,669	261,062	19	50,160	311,221	(20,447)
1.9	Operation	51,732	20	10,346	62,078	51,732	20	10,346	62,078	

Major Variance Comments

1.1 Research & Development Total Variance = +\$55.2M

1.1.2 Linac Development +\$7.2M

More early work on rf structure and rf amplifier design is required.

1.1.5/6/7 Mercury Target Systems +\$1.3M

Perform beam Corrosion and enhance thermal shock tests and participate in international '100k' moderators; some duplication of efforts.

1.1.8 Beam Tube, Guide, and Instrument Development +\$46.9M

Hire 10 instrument scientists early; develop, document, and distribute sophisticated design tools.

1.5 Ring and Transfer Line Systems Total Variance = -\$12.7M

EDI is too high; details do not support estimate; some material and travel costs are too high.

1.8 Conventional Facilities Total Variance = -\$20.5M

1.8.2 Land Improvements and Construction Support -\$18.9M

Overdesign; Unit costs too high; redundancy within estimate.

Appendix E

Funding Profile

NSNS

Budget Authority (BA) in Millions of Dollars - As Spent

	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	Total
TEC				150	287	308	211	97	44	1,096
R&D										
OPEX				25	14	9	5	2		54
Capital				2						2
Pre-Ops				1	1	2	6	16	50	75
Prior Years	8	8	23							39
Total	8	8	23	178	302	319	222	115	94	1,266

Costs (BO) in Millions of Dollars - As Spent

	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	Total
TEC				63	254	344	250	141	44	1,096
R&D										
OPEX				25	14	9	5	2		54
Capital				2						2
Pre-Ops				1	1	2	6	16	50	75
Prior Years	8	8	23							39
Total	8	8	23	91	269	355	261	159	94	1,266

National Spallation Neutron Source Project Schedule (FY)

NSNS

National Spallation Neutron Source Critical Path Schedule

Appendix F

OAK RIDGE NATIONAL LABORATORY
MANAGED BY LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
FOR THE U.S. DEPARTMENT OF ENERGY

ALVIN W. TRIVELPIECE
DIRECTOR, OAK RIDGE NATIONAL LABORATORY
PRESIDENT, LOCKHEED MARTIN ENERGY RESEARCH CORPORATION

POST OFFICE BOX 2008
OAK RIDGE, TN 37831-6255
PHONE: (423) 876-2900
FAX: (423) 841-6967
INTERNET: AVT@ORNL.GOV

April 28, 1997

The Honorable Federico Peña
Secretary of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585

Dear Secretary Peña:

As you know, the scientific justification and need for a new neutron source and upgrades to existing neutron sources has been thoroughly established in numerous studies by the National Research Council (NRC) and the Department of Energy (DOE) dating from the early 1970s; the last two occurring as recently as 1993 and 1996. In response to this need, the DOE and Congress have directed \$8 million in FY 1996 and \$8 million in FY 1997 to initiate the R&D and conceptual design for the National Spallation Neutron Source.

To accomplish this task, the National Spallation Neutron Source (NSNS) collaboration has been established to complete a Conceptual Design Report (CDR) for the DOE. The NSNS is a truly collaborative project involving five DOE National Laboratories (Argonne, Brookhaven, Los Alamos, Lawrence Berkeley, and Oak Ridge National Laboratories) assembled to select a single combination of technologies that best meets the requirements set down by the scientific user community, to perform a detailed technical design, and to establish the cost and schedule required to complete this source. An external committee of 50-60 experts from the scientific and business community will be assembled by the DOE Office of Energy Research June 23-27, 1997, for a full validation of NSNS "to review and assess the technical feasibility of achieving the proposed NSNS design and goals; the credibility of the associated cost and schedule estimate; and the adequacy of present and planned management arrangements to accomplish the scope of work."

We believe this multilaboratory approach is an appropriate way to focus the combined expertise of the DOE National Laboratories on the conceptual design of the NSNS. It avoids costly duplication of effort, accesses the best available expertise in the DOE laboratories, and leverages valuable DOE manpower and resources. As participating laboratories, we strongly endorse the collaborative design approach for the NSNS.

Sincerely,

Alvin W. Trivelpiece

Dean E. Eastman
Argonne National Laboratory

Siegfried S. Hecker
Los Alamos National Laboratory

Sincerely,

Nicholas P. Samios
Brookhaven National Laboratory

Charles V. Shank
Lawrence Berkeley National Laboratory

Department of Energy

Washington, DC 20585

June 9, 1997

Dr. Alvin W. Trivelpiece
Director
Oak Ridge National Laboratory
Bethel Valley Road
Oak Ridge, Tennessee 37831

Dear Dr. Trivelpiece

Secretary Peña has asked me to respond to your letter of April 28, 1997, in which you discuss the many merits of and collectively endorse the multilaboratory collaborative design approach of the National Spallation Neutron Source (NSNS). I am very pleased to respond on his behalf and to have this opportunity to thank you for your support of and participation in this major effort.

I have made neutron science my highest priority. For more than a decade advisory committees of the National Research Council and the Department of Energy (DOE) have documented the critical national need for a new neutron source. The time for that new source — the National Spallation Neutron Source — is now. The NSNS interlaboratory collaboration involving five laboratories — Argonne National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, and Oak Ridge National Laboratory — is a unique effort for a project of this magnitude. I am pleased that the laboratories have worked together seamlessly and have thus drawn upon the best talent of the Nation. I commend you for vigorously and aggressively including the scientific-user community in your planning and for having all aspects of the project reviewed by external consultants from the United States, Europe, and Japan at several stages in the project life. The Conceptual Design Report (CDR) review later this month will bring together yet another group of 50-60 experts from the scientific and business communities for a full validation of the NSNS.

I am committed to the concept of an Integrated Laboratory System, which will use the best talent from across the Nation, enable efficient use of our investments, develop critical mass for difficult tasks and enable individual laboratories to

maintain strength and expertise in their own core competencies. The multilaboratory approach to the design and construction of the NSNS is our best example of the Integrated Laboratory System. I look forward to receiving the results of the CDR review and to moving on to the full construction phase of the project.

Sincerely,

A handwritten signature in cursive script that reads "Martha".

Martha A. Krebs
Director
Office of Energy Research

NSNS Project Management: Design and Construction

NSNS Project Management: CDR

Appendix G

GLOSSARY

2-D	two dimensional	LBNL	Lawrence Berkeley National Laboratory
A	Amperes		
Å	Angstroms (= 10 ⁻¹⁰ meter)	linac	linear accelerator
AGS	Alternating Gradient Synchrotron	LHC	Large Hadron Collider
ALARA	as low as reasonably achievable	mA	milliamperes
ANL	Argonne National Laboratory	MEBT	medium energy beam transport system
A/E	architect/engineer		
BNL	Brookhaven National Laboratory	MeV	million electron volts
CAD	Computer-Aided Design	Mhz	megahertz
CCDTL	coupled cavity drift tube linac	mrاد	milliradians
CCL	coupled cavity linac	ms	millisecond
CDR	Conceptual Design Report	MTBF	Mean time between failures
CM	Construction Manager	MTTR	Mean time to repair/mean time to restore
DTL	Drift Tube Linac		
EDIA	Engineering, Design, and Inspection	MW	megawatt
EIS	Environmental Impact Statement	NEPA	National Environmental Protection Act
EPICS	Experimental Physics & Industrial Control System	ns	nanoscale
ESS	European Spallation Source	NSNS	National Spallation Neutron Source
ES&H	Environmental Safety & Health		
FODO	Focus/defocus	ORNL	Oak Ridge National Laboratory
FOFODO	Focus/focus/defocus/defocus		
GeV	gigaelectron volts (= 10 ⁹ eV)	PEP	Project Execution Plan
HEBT	High Energy Beam Transport System	PSAR	Preliminary Safety Analysis Report
Hz	Hertz (frequency per second)	PSR	Proton Storage Ring (at LANSCE)
H ⁻	hydrogen minus ions		
GBT	Insulated gate bipolar transistor	RF	radio frequency
IOC	Instrument Oversight Committee	RFQ	Radio Frequency Quadrupole Accelerator
IOC	Input-Output Controllers		
IPNS	Intense Pulsed Neutron Source	RHIC	Relativistic Heavy Ion Collider
SIS	160 kW Spallation Neutron Source in the UK	RTBT	Ring to Target Beam Transport Line
SR	Accelerator at CERN Laboratory		
IO	input/output	SAR	Safety Analysis Report
LEK	Japanese Accelerator Laboratory	SSC	Superconducting Supercollider
J	kilojoules		
W	kilowatt	usec	microseconds
ANL	Los Alamos National Laboratory	VME	Versa Module European (type of bus)
LANSCE	Los Alamos Neutron Science Center	VXI	Extension of VME
		WBS	Work Breakdown Structure