PLANS FOR A COLLABORATIVELY DEVELOPED DISTRIBUTED CONTROL SYSTEM FOR THE SPALLATION NEUTRON SOURCE[*]

W. R. DeVan, ORNL, Oak Ridge, TN; D. P. Gurd[#], LANL, Los Alamos, NM
J. Hammonds, ANL, Chicago, IL; S. A. Lewis, LBNL, Berkeley, CA
J. D. Smith, BNL, Upton, NY

Abstract

The Spallation Neutron Source (SNS) is an accelerator-based pulsed neutron source to be built in Oak Ridge, Tennessee [1]. The facility has five major sections - a "front end" consisting of a 65 kev H⁻ ion source followed by a 2.5 MeV RFQ; a 1 GeV linac; a storage ring; a 1MW spallation neutron target (upgradeable to 2 MW); the conventional facilities to support these machines and a suite of neutron scattering instruments to exploit them. These components will be designed and implemented by five collaborating institutions: Lawrence Berkeley National Laboratory (Front End), Los Alamos National Laboratory (Linac); Brookhaven National Laboratory (Storage Ring); Argonne National Laboratory (Instruments); and Oak Ridge National Laboratory (Neutron Source and Conventional Facilities). It is proposed to implement a fully integrated control system for all aspects of this complex. The system will be developed collaboratively, with some degree of local autonomy for distributed systems, but centralized accountability. Technical integration will be based upon the widely-used EPICS control system toolkit, and a complete set of hardware and software standards. The scope of the integrated control system includes site-wide timing and synchronization, networking and machine protection. This paper discusses the technical and organisational issues of planning a large control system to be developed collaboratively at five different institutions, the approaches being taken to address those issues, as well as some of the particular technical challenges for the SNS control system.

1 INTRODUCTION – WHAT IS SNS?

The Spallation Neutron Source (SNS) will be a 1 MW (upgradeable to 2 MW and eventually 4MW) accelerator-based facility that produces pulsed beams of neutrons by bombarding a liquid mercury target with intense beams of 1 GeV protons. It is being designed primarily to meet the needs of the neutron scattering community, with operations expected to begin in 2005. Some reference design parameters are given in Table 1.

(At the time of this conference, the original concept – a 1GeV linac followed by an accumulator ring – is under review. Alternative concepts, including less than full energy injection into a rapid cycling synchrotron, and/or starting at 2MW with a solid target, are under consideration. This paper assumes the original concept. Should a change take place the control system requirements and configuration would be unchanged except for details, and the issues of collaborative management discussed in this paper unaffected. The collaborative nature of the project and its siting at Oak Ridge are not under review.)

Table 1 – Design Parameters

REFERENCE DESIGN PARAMETER	INITIAL (1.0MW)	UPGRADE (2.0MW)
Pulse repetition rate	60 Hz	
Peak ion source H- current	35 mA	70 mA
Linac length	493 m	
Linac duty factor	6.2%	
Linac final beam energy	1.0 GeV	
Accumulator ring circumf.	220.7 m	
Ring orbit rotation time	841 ns	
Pulse length at ring injection	546 ns	
Kicker gap at ring injection	295 ns	
Ring filling fraction	65%	
Number of injected turns	1225	
Ring filling time	1.02 ms	
Protons per pulse on target	1.04×10^{14}	2.08×10^{14}
Protons per second on target	6.3×10^{15}	1.25×10^{16}
Time avg. beam current	1.0 mA	2.0 mA
Beam power on target	1.0 MW	2.0 MW

The SNS is a truly collaborative project, with the participating laboratories taking lead roles and responsibilities for specific sections of the complete facility. Laboratories were chosen on the basis of their expertise in particular technology areas. The lead laboratory for a given section is responsible for assembling all necessary resources to accomplish not only

the design but also the fabrication, testing, installation, and commissioning of its part of the SNS at the Oak Ridge site. Specific roles and responsibilities are as follows:

- ORNL is responsible for overall project management and co-ordination; for conventional facilities and construction; for maintaining and operating the SNS once completed; and for managing future upgrades.
- LBNL is responsible for the front end systems, including ion source and RFQ.
- LANL is responsible for the linac systems and has co-ordination responsibility for the controls design.
- BNL is responsible for the accumulator ring and associated transport lines.
- ORNL is responsible for the primary target system.
- ORNL and ANL are jointly responsible for the experimental systems (instruments, beamlines, choppers, etc.).

"Collaboration" is indeed the watchword of the SNS Project. This is true especially for the controls team, which is itself spread among the five collaborating laboratories. Even more than usual attention to organisation, integration and standardisation are required in this collaborative environment, and these are discussed in the sections that follow.

SNS is not the first collaborative effort of this nature. It is common in high energy physics for both the data acquisition and the detector "slow-controls" software to be developed collaboratively. In these cases the collaborators are generally more numerous and more geographically distributed. The difficulties are exacerbated, and yet these enterprises are generally successful. In data acquisition systems, however, a centralised team generally develops the real-time software. The peer relationship of the SNS control system collaborators is perhaps also an innovation.

2 ORGANIZATION

To facilitate the imposition of standards and overall system integration, the SNS has opted to unify the entire controls effort under one "level two" WBS element (Figure 1). This uncommon organization is a change from the original concept, in which the controls effort was distributed throughout the WBS structure, and was adopted at least in part in response to the recommendation of review committees.

The organization is a compromise, and was agreed to only after discussion among team leaders from all of the collaborating institutions. Potential disadvantages include:
- "Loss of ownership" of controls requirements by sub-project managers ("Not my problem");

- Difficulty in integration of controls activities into sub-project schedules;
- Disconnect between requirements changes effecting controls and resulting cost escalation of the controls element ("scope creep"); and
- A very complicated cost and schedule variance reporting system which must integrate the different systems in place at each collaborating laboratory.

Notwithstanding this impressive list of negatives, the integrated organization was preferred because of anticipated benefits in ease of integration and standards imposition, and the potential for resulting cost savings, during both construction and operation.

An attempt to mitigate the potential problems itemised above was made by organising the integrated controls effort to reflect the organization of the project as a whole, with a third level WBS element for each of the major distributed and subsystem-specific control systems. These distributed parts of the control system include I/O hardware, local databases, interlocks, automation and engineering screens, and subproject-specific high-level (physics) applications. The schedules for the distributed parts are integrated with the corresponding sub-project schedules, assuring requirements and schedule integration. Work at this level will be done at the collaborating laboratory, although common tasks, such as some device drivers, will be assigned wherever the appropriate resource is available.

"Global Systems" apply across the project. They include the network, timing system, equipment protection system and main control room, and are treated together as another level 3 WBS element. Work on these systems will be allocated among the collaborators. For example, the control system communication network will be implemented by the Oak Ridge members of the controls team.

All of the controls activity is co-ordinated by an "Integrated Controls Working Group," (ICWG) which includes each of the level 3 task leaders. This group meets weekly by telephone and regularly together, as well as using computer-based collaboration tools.

Money is allocated to the Level 2 controls task leader, and then, after consultation with the working group, sub-allocated among the laboratories according to agreed work packages. Some part of the controls allocation is withheld at Oak Ridge, which greatly facilitates reallocation as required. An intriguing and initially unappreciated benefit of this approach is flexibility to make purchases through the laboratory that can make the best deal, without moving money between laboratories and incurring additional taxes.
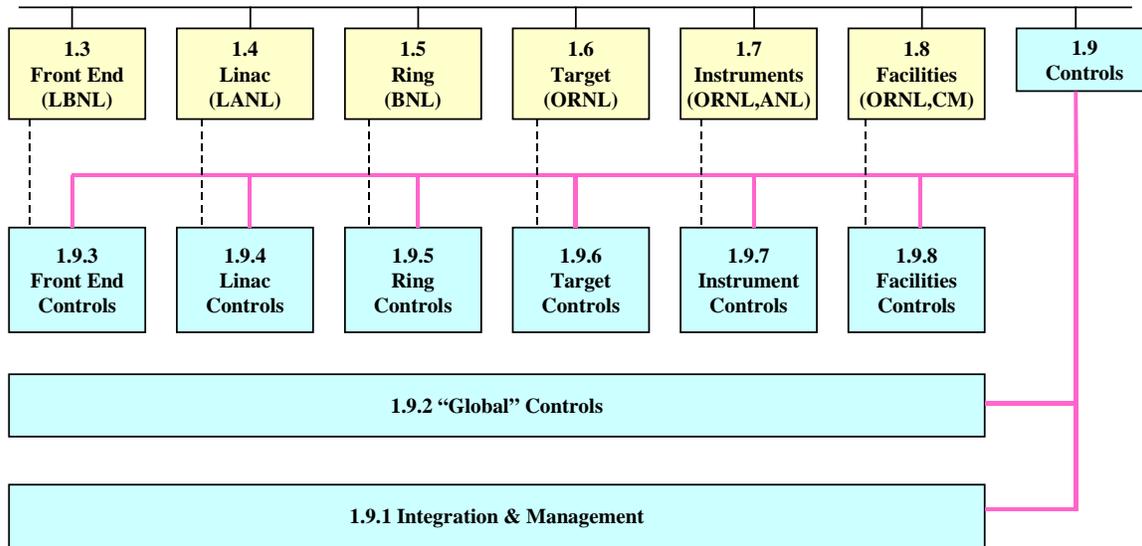
Figure 1. SNS Work Breakdown Structure Showing Controls WBS Level 3 Elements

3 INTEGRATION

3.1 Integration

The SNS control system will be completely integrated. That is, a single infrastructure and set of standards will be applied to all aspects of the facility. This approach is not entirely obvious. It is not the usual practice in accelerator laboratories to include target, experimental instruments or conventional facilities (power systems, plant cooling systems, HVAC, etc) in the accelerator control system infrastructure. It has, however, been a common experience that signals from these non-accelerator systems are found to be needed in the control room for purposes of correlation, and that ad-hoc integration is performed after operation begins. We plan to integrate these systems from the outset. EPICS (see section 4.1below) will serve as the integrating layer, making the specifics of local control systems transparent. Except for the imposition of standards, local process systems need not be conceptually different from familiar practice.

3.2 Interface

The "default" interface to the control system is defined to be at the input to a crate-based system (Figure 2). The transducer or measuring instrument itself belongs to the system it is in, as does the cabling from the instrument to the I/O module front panel. Standards will be established for the signals presented to these modules. This interface definition can be modified by negotiation on a case-by-case basis. Exceptions already established are in the beam instrumentation and low-level RF systems, where sophisticated and custom I/O modules will be developed

and packaged in specialised form-factors such as VXI. The interface is then at the crate backplane.

Notwithstanding the existence of this default interface, a series of detailed interface definition documents will be developed to delineate between subsystem and global functions, and to assure a seamless interface between parts of the control system executed by different institutions.
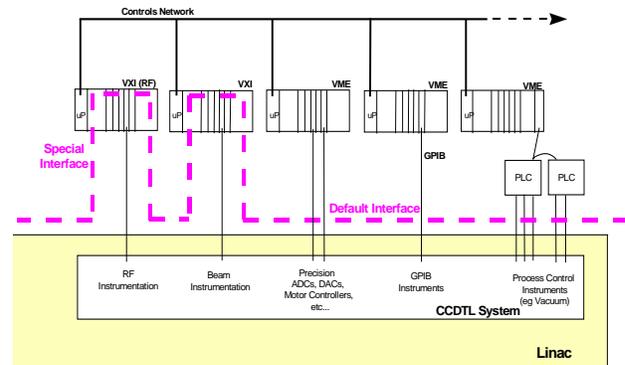

Figure 2 – Interface to SNS Control System

3.3 Project Database

SNS intends to follow the recent successful examples at BESSY and KEKB of a comprehensive project-wide relational database from which (among other things) the EPICS distributed database can be automatically produced. Oracle will be used for this purpose. Following the BESSY example, project engineers will be responsible for maintaining the data for their own subsystems.

The database will be based upon a consistent, hierarchical, plant-wide naming convention that has been in place for over a year. From the point of view of the operators or of the control system, the naming convention

provides standard names for devices and signals. These names should also be used for all aspects of the project, such as models, mechanical drawings, equipment databases, cable plant databases, etc.

As now defined, the complete formal signal names may in some cases exceed the present string length limitation in EPICS. Because we do not believe that a software limitation should constrain names developed for operational convenience, this constraint will be removed from EPICS.

3.4 Application Development Environment

The SNS controls team has installed and is now operating a distributed Concurrent Version System (CVS) at Oak Ridge. This system assures a uniform software development environment for all five laboratories, as well as release control through the overlapping phases of software development, integration and operation.

Running on that system will be an Application Development Environment (ADE) developed together with the controls groups at the APS at Argonne and BESSY in Berlin, and benefiting from experience at TJNAF in Virginia. The ADE defines the file structures and procedures for software development and integration for all of the SNS laboratories. APS will adopt the same environment.

4 STANDARDS

4.1 EPICS

The recognised need for an open system standard, and the general acceptance and track record of EPICS in the accelerator community (and beyond [2]), resulted in an early and easy agreement to use the EPICS toolkit [3] as the basis for the SNS control system. This decision was reached with strong support from project management, review committees and all participating laboratories, including those having little or no EPICS experience. It represents an important first step in the attainment of an integrated control system, and was reached early enough to allow time to prepare standards and examine remaining integration issues.

Because neither ORNL nor BNL had experience with EPICS, an early activity was to do on site training at these laboratories. Local test stations were then set up, and at this time there are active groups implementing EPICS applications at all five collaborating laboratories.

4.2 Software Standards

The selection of EPICS is far from a complete definition of required software. Within the EPICS toolkit there are a number of choices to be made, and EPICS in any case does not include any of the high-level applications required for accelerator commissioning and operation. In the interest of uniform software development across the

collaboration, the ICWG has undertaken to make a number of these choices before the end of the year, although in many cases it is neither necessary nor desirable to do so prematurely.

- Operator Interface. There are two EPICS tools for screen development and display – MEDM and EDD/DM. MEDM comes in two flavors – European and American. The community is developing new tools, based, for example, on JAVA. Commercial tools are also available. SNS is currently experimenting with both flavors of MEDM and with JAVA. A common approach will be selected.
- Archiver. Several EPICS Archivers have been developed. A new archiver is currently under operational test for LEDA. If satisfactory, this will form the basis of the SNS data archiver.
- Alarm Manager. This is a case where the EPICS community all uses the same tool. SNS will do the same.
- Database Configuration. Several tools are available for building the EPICS active distributed configuration database. As mentioned already, SNS expects to follow the model of both BESSY and KEKB, using the graphical tool "Capfast" to design database templates, and then to populate and instantiate the database from an Oracle-based project-wide configuration database.
- Applications. EPICS has been interfaced to a number of commercial mathematical packages, such as Mathematica, MatLab, PVWave and IDL. SDDS, a specialised package for accelerator physics, is in use at the APS. SAD, a combined physics modelling and mathematical package, is being used with EPICS to commission KEKB. SNS will use a subset of these tools, and is also experimenting with the "Unified Accelerator Library" now in use at RHIC.
- Client and Development Systems. Developments to date have been done under Solaris, however the collaboration anticipates adopting LINUX in the near future.

4.3 Hardware Standards

In addition to an attempt to use common software, SNS will try to standardise hardware choices in the distributed systems to the extent that that is reasonable. Given the duration of the project, we recognise that time-phased standards may in some cases be more cost effective. Candidates for standardisation include: distributed processors, preferred I/O modules, fieldbuses, interface standards, PLCs, isolation standards and a uniform device and signal naming standard.

- I/O Controllers (IOCs). Most implementations of EPICS use VME or VXI crates to house I/O processors and modules. LEDA has experimented successfully with PC-based IOCs, which are much cheaper to field. Newer backplane systems are now

available. SNS expects to use a traditional approach, although PC-based IOCs are also likely.

- I/O Processors. It is probably unwise to settle on one processor at this time – the market changes rapidly. Early IOCs will use the PowerPC, already applied in the EPICS community. We are using these in test stand applications at BNL.
- PLCs. Because of the inclusion of conventional facilities, there will be many PLC-based systems interfaced to EPICS. Although we recognise that compromises are inevitable, SNS intends to identify preferred PLC manufacturers, models, programming languages and interface mechanisms. Tests are taking place at BNL, LBNL, and ORNL.
- Fieldbuses. A number of multidrop systems have been used with EPICS for interfacing power supplies, vacuum equipment, etc. These include Canbus (BESSY), Bitnet (APS), Arcnet (KEKB) and others. SNS is currently evaluating these and other possibilities (DeviceNet, ControlNet, G3, etc) for appropriate applications. SNS will attempt to standardise on all vacuum and power supply equipment (pumps, gauges, etc) which will facilitate the controls task. The LBNL front end test stand is experimenting with some of these.

5 GLOBAL SYSTEMS

Work on the "global systems" will be distributed among the collaborating laboratories, based upon expertise and available resources.

5.1 Timing System

The most interesting and time-critical technical issue facing the SNS controls team has to do with timing and synchronization. The entire accelerator chain, including accelerating structures, choppers and bunchers, injection and extraction kickers and data acquisition systems must be synchronized with each other and with a large number of independently-phased neutron choppers. These choppers, a key element in all of the neutron scattering experiments, are rapidly rotating (thousands of rpm) slotted flywheels, which are used to select neutrons of a specific energy from the spectrum emitted by the target. Where there is a single chopper, protons can be extracted based upon a signal from that chopper. Where there are several choppers, the question becomes: "who is the boss?". The solution to this issue affects both the rf low-level and power systems, as well as the timing and synchronization system.

This system will be modelled upon systems with similar requirements at RHIC, PSR, ISIS or the IPNS.

5.2 Equipment Protection Systems

Equipment Protection systems include:

- a hardware-based "fast protect" system which turns off the injector and dumps any beam in the machine within 10usecs of sensing an anomalous condition (typically high radiation);
- a hardware-based "beam pulse enable system" which permits injection pulse-by-pulse provided that all systems, including kickers, are ready; and
- A software-based "run permit" system which compares the accelerator state with the operator-selected running mode before permitting beam injection.

These systems are all independent of the personnel safety systems, which are both physically and organisationally separate from the control system.

5.3 Network

A preliminary SNS control system network design is based upon 100 Mbit switched Ethernet with a Gigabit switched Ethernet backbone.

5.4 Control Room

All systems – accelerators, target and conventional facilities --will be operated and monitored from a single control room, although there will be local control rooms available for commissioning and troubleshooting. It is anticipated that the main control room will be modelled after the APS main control room, which features a functional round console arrangement.

6 CONCLUSIONS

A collaboration of five national laboratories is proposing to construct a 1 MW (upgradable) accelerator-based pulsed spallation neutron source (SNS) in Oak Ridge, Tennessee. To facilitate integration and standardization, the control system is treated as a peer to the other major project subsystems (linac, ring, target etc). The control system will be integrated over the entire facility, including the conventional facilities, and will be based upon the widely used EPICS toolkit.

7 REFERENCES

1. Alonso, these proceedings
2. In the past year, for example, a number of new facilities have come on line using EPICS. These include, among others: LEDA – the Low Energy Demonstration Accelerator at Los Alamos, NM; NSTX – the National Sperical Toroid Experiment at Princeton, NJ; ISAC – a radioactive beam facility at TRIUMF, Vancouver, Canada; The Swiss Light Source (SLS) Test Stand at the Paul Scherrer Institute in Villigen, Switzerland; and the Gemini North Observatory on Mauna Kea, Hawaii.
3. http://epics.aps.anl.gov/asd/controls/epics/EpicsDocumentation/ WWWPages/EpicsFrames.html