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LANSCE's INSTRUMENTATION AND CONTROLS SYSTEM MODERNIZATION PROJECT*

M. Pieck†, C.D. Hatch, H.A. Watkins, E.E. Westbrook
Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Abstract

The Los Alamos Neutron Science Center (LANSCE) continues to invest in the future of its facility. In 2022 and after an 11-year effort the original and reliable RICE (Remote Instrumentation and Control Equipment) system was decommissioned. It was replaced with a modern customized control system in small stages during each annual 4-month outage. Since 1972 when the first proton beam was delivered through the nearly-mile-long accelerator, the control system was in a continuous state of modification. Thus, an extensive amount of non-RICE equipment was added over the years to expand the capabilities of the facility. Some of that equipment is now up to ~40 years old. Hence, the effort to replace the lingering obsolete and end-of-life equipment must continue to ensure reliable beam operations enabling scientific success in LANSCE's five experimental areas. This paper discusses the scope of the designated Instrumentation and Controls Modernization project. We describe our technologies of choice and the remaining challenges we face before we can implement them. The boundary condition for the whole project, as usual, is that we must implement these changes on a running accelerator.

INTRODUCTION

For over 50 years Los Alamos Neutron Science Center, or LANSCE, has delivered one of the world's most intense proton beams through its nearly-kilometer-long accelerating structure. Since the first beam, the facility and its capabilities have continuously evolved. Proton beam is now delivered to five state-of-the-art experimental areas, a capability that makes the accelerator unique among its peers [1]. These distinct experimental areas are (year of starting officially operating - name of facility):

- 1977 - Weapons Neutron Research (WNR) Facility
- 1985 - Lujan Center (Neutron Scattering)
- 1997 - pRAD (Proton Radiography)
- 2004 - Isotope Production Facility (IPF)
- 2005 - Ultra Cold Neutron (UCN) Facility

With each new facility coming online [2], new beam lines were installed connecting the accelerator with the experimental areas requiring new instrumentation & controls equipment (ICE) interfacing with a variety of beam line devices. The ICE that was added was state-of-the-art of the time when it was designed & installed leaving the facility over the years with a wide variety of hardware form factors and software methodologies. Moreover, enhancements to the accelerator itself increased the ICE diversity even further, consequently escalating the challenge of LANSCE Control System (LCS) maintainability.

REPLACING 50-YEAR-OLD EQUIPMENT

With the LANSCE facility mission need constantly being extended, the longevity of the LCS became a major concern around the turn of the century. The original control system – RICE (Remote Instrumentation and Control Equipment) became a focal point of concern. However, the lack of funding and the absence of technical solutions for the time-sensitive measurements associated with the beam delivery location hampered any real modernization progress for the next ten years [3,4].

This changed between 2011 and 2022 when a relatively steady funding stream enabled a more concentrated effort with a focus on replacing/retiring RICE. Given its integral architecture, a project plan was put together to replace the functions that RICE performed one-by-one in a methodical manner. Given the project boundary condition that changes to the LCS only could be made during the annual 4-month outage, it took until 2022 when the last functionality was replaced and RICE was turned off [5, 6].

While the magnitude and complexity of this accomplishment is difficult to comprehend, the sheer number of computerized systems that were deployed to replace RICE provides a small taste. It included more than 40 data network switches, tens of thousands of meters of fiber optic cabling, redundant master timer systems, 105 distributed timing systems, 108 industrial control systems, 61 fast data acquisition systems, and 41 diagnostic systems [7].

CONTROL SYSTEM STANDARDS

One design objective for the RICE replacement was to choose hardware and software standards that would be applicable to most of our modernization efforts even beyond the RICE replacement, thus reversing years of increasing diversity and instead streamlining it with the intention to improve LCS's maintainability.

At the beginning of the RICE replacement project, an analysis of alternatives was conducted, and the decision was made to replace RICE with two types of systems: 1) National Instrument's (NI) cRIO automation controller and 2) a distinctive 2-form factor system (VPX/cPCI crate) both supporting distinct capabilities. NI cRIO systems are used for 1a) slow controls/monitoring, and 1b) interceptive beam diagnostics. VPX/cPCI systems are used for non-interceptive diagnostics such as beam position and phase monitors & timed data acquisition which captures waveforms with real-time customizable timing and beam

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† pieck@lanl.gov, LA-UR-23-24375

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species triggering. Those two systems have become a defacto standard in systemin the LCS and are being used for current and are under consideration for future upgrades.

AVAILABILITY, RELIABILITY, AND MAINTAINABILITY CHALLENGES

Despite recent modernization successes, LANSCE requires further significant ICE improvements to ensure that the facility remains a leader for the coming decades. While the RICE replacement eliminated 50-year-old equipment, a significant amount of ICE that is up to ~40 years old remains part of the current LCS. This poses a significant risk to beam availability & quality, equipment reliability that can cause beam downtime, and associated maintainability given the obsolesce of some of the equipment.

From the hardware perspective, the LCS still supports the following form factors: NIM-BIN, CAMAC, VME, VXI, and PLCs as well as our newer form factors like NI's cRIO, VPX, and cPCI. From the software perspective, the LCS supports the following real-time operating systems: RTEMS 4.x, VxWorks 5.x & 6.x, LinuxRT; other operating systems RHEL6, Solaris, Artix, Gentoo, RHEL7, Rocky 8, Windows; EPICS releases 3.14.x, 3.15.x and our own Data Access Release 3.15.x; programming languages; Java, Python, LabVIEW, and several scripting languages.

This collection of tools has created a hardware and software patchwork between the different technologies and methodologies. Moreover, the complexity has resulted in fragmented staff competency with, in many cases, only one subject matter expert for a particular system. Furthermore, our legacy domain knowledge has significantly deteriorated with recent retirements turning the maintenance of the older system into archaeology requiring reverse engineering, code analysis, and design recovery. Upgrades to the legacy software often led to code restructuring, addressing architectural issues, data migration & challenging integration efforts, resulting in significant time & cost commitment and negatively impacting our LCS staff from advancing and simplifying the LANSCE control system. Not to mention that our junior staff find it less than appealing to learn something about obsolete and past end-of-life equipment which makes hiring new talent and retaining existing ones a challenge of its own.

METHODICAL APPROACH TO MODERNIZATION

Given the complexity and size of our LCS (i.e.~165k process variables, ~100 managed network switches, ~1500 network addressable devices, ~930 operator screens, ~650 Input Output Controllers (IOC)) it has been historically difficult to assess our modernization needs. While we made improvements iteratively, given the current urgency of system problems or the availability of a certain amount of funding, a vision and long-term strategy had been absent.

Over the last ~5 years, we formulated a vision where maintainability and risk to operations became the dominant driver. As such our vision-based strategy is to reduce the variety of hardware and software tools which will help with the training requirements and spare inventory. It will also improve our ability to develop and maintain cutting-edge solutions using modern infrastructure, keep up with product lifecycle management, and leverage economies of scale for future upgrade purchases. among other things. From a hardware perspective, we will focus on future modernization efforts utilizing our NI cRIO and VPX/cPCI platforms where applicable. While the systems have their own life cycle challenges, we are aware of the upgrade path which should minimize labor requirements but still requires sufficient funding to keep up with the hardware technology maturation. In that context we are working closely with our industrial partners to develop life-cycle upgrade timetables for our equipment that will be added to our operations and maintenance request for our sponsors, so they are aware of our funding needs.

To prioritize our LCS modernization needs we are following our risk management plan including a risk register that is frequently being updated and used as our primary modernization prioritizing tool. Currently, we have over 70 major risks identified/described, each receiving a primary risk category (technical, funding, schedule, and/or scope), followed by a risk analysis based on a well-defined likelihood of occurrence & impact (mission impact of experimental facilities, beam downtime, and safety/environment/security) criteria. The top contenders in the risk register are then further evaluated by a risk response planning process in which the technical readiness level is determined, as well as the material cost and labor time requirements to develop and install/deploy a modernization solution associated with the risk.

APPROACH TO PROJECT EXECUTION

With this knowledge at hand, we then strategize over the sequence of modernization efforts considering their impact on each other followed by a funding source determination since many of our modernization efforts go beyond what our operations and maintenance budget can afford.

This usually leads at a high level to the following modernization project classification:

<u>Short-Term Projects (duration up to 1 year):</u>
Higher technical readiness level: material is at hand, has shorter lead times, and/or can be quickly purchased with available funds; lower to medium labor requirements; special funding may become available but is not continuous or guaranteed.

<u>Medium-Term Projects (duration 2 years):</u>
Medium to higher technical readiness level: shorter to medium lead times on material; longer sustained labor efforts that typically require some research and development; yearly reoccurring funding at different levels allowing for some planning security.

<u>Long-Term Projects (duration 3 years & beyond):</u>
Low to medium technical readiness levels: medium to longer lead times on material; longer labor efforts that often require more extensive research and development; may also addresses scope that has been pushed back due to lack of funding and/or priority; consistent funding allows for planning security permitting to increase staff levels.

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No matter whether short-, medium-, or long-term projects – many of them occurring concurrently – they are all in need of labor resources coming from the same labor pool that is also overseeing the operations and maintenance of LANSCE's ICE. Hence, there is a constant struggle between acute tactical support vs visionary project activities. Under the current labor shortage, we are weighing our risks and deliberately omitting needed maintenance on our system to make strategic investments for our future.

Project planning complexity is added when we try to match our staff skill set and career growth opportunities with the skills needed to execute our projects. For our short-/medium-term projects we are utilizing our senior staff to support junior staff-led projects in case projects do not proceed as scheduled. For our long-term projects, we either grow or hire appropriate staff with the needed skill.

Project execution suffered in the past from the lack of leadership, accountability, and efficiency due to some degree of stove piping between the different teams involved, leaving us often with the feeling that more could have been accomplished. In response to this suboptimal approach, we are now assigning to each project a Person-In-Charge and supporting staff creating a mini project management environment. We also manage it accordingly in a graded fashion (based on complexity) with requirements & design reviews, as well as frequent status/progress reporting meetings during the planning and execution phase.

I&C MODERNIZATION PROJECT

Based on our methodical approach to modernization we have determined a preliminary scope for our long-term I&C Modernization Project. Given the budget cycles for projects of this size and expected cost, a start date of fiscal year 2025 (October 2024) may be the earliest we can expect. Therefore, the scope has been carefully chosen to ensure that it fits into the designated future time and doesn't interfere with any modernization projects until then. The scope is set to eliminate the remaining obsolete and past end-of-life equipment, some of which was custom-made. It further aims to streamline our hardware form factors and advance the majority of the LCS computerized equipment to the same up-2-date technology maturity level using our 2 hardware de-facto standards for most of our equipment. Completion of this project will position the group to focus the majority of our time going forward to being more innovative and forward-looking. Anticipated I&C Modernization project scope elements include:

CAMAC System

Extraction Line BPPMs: replacement using a VPX/cPCI for our proton storage ring Beam Position Monitors

NIM-BIN Systems

Absorber/ Collector: actuator module replacement. Possibly using NI cRIO/driver solution used for wire scanners, emittance and harp.

Beam Aperture & Beam Stop: functionality that requires R&D effort and determination of commercially off the shelf (COTS) available equipment.

Guard Ring Power Supplies: Requires redesign to be replaced using current COTS technology.

Jaw Control System: obsolete actuator-driven device which can be replaced with NI cRIO-based system that is being used for wire scanners, etc.

Beam Diffuser: a pRAD beamline actuator module replacement. Entire system redesign possibly using NI cRIO/driver solution used for wire scanners, etc.

VME Systems

Input Output Controller: providing RS232 communication to be replaced with serial servers and soft IOCs.

NI cRIO Systems

805 MHz Linac Wire Scanner: upgrading processor modules to newest module to avoid software /hardware maintainability issues.

Gate Enable Inhibit Count Down Controller: used for special time system configurations.

VPX/cPCI Systems

Field Programmable Gate Array (FPGA): upgrading technology to the newest hardware architecture to avoid software /hardware maintainability issues.

Custom/One-of-a-Kind Systems

Beam Line Actuator Interlock System: replacement with NI's cRIO digital/relay modules

Frame Capture System: like-for-like COTS is not available. Requires redesign using up-2-date technology.

Master Timer System: replacement of obsolete equipment requiring redesign of zero crossing module, upgrades to event generator and VME processor.

Fiber Media Converter: used to convert for timing, logic, serial, and analog signals between copper and fiber mediums are obsolete require replacement.

Distributed Accelerator Status Screens: replacement of obsolete video equipment requiring design.

Legacy Equipment Removal:

Site-wide removal of legacy/obsolete equipment and wiring. i.e RICE systems, coax/line driver card-based timing distribution.

Software Systems

EPICS 7: supervisory control system generation upgrade to the newest de-facto standard

EPICS Extensions: retiring of legacy applications (i.e. Data Watcher etc) and converting to accelerator community de-facto standards (i.e. Control System Studio (CSS) Alarm Handler, CSS Display Manager, EPICS Archive Appliance, …)

Relational Databases: expansion and improvements to existing system to utilize fully prescriptive and descriptive capabilities.

Documentation Systems: converting a collection of documentation systems to a minimum set providing version control, text searching for text and pdf files.

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