ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-MO3BCO03

CONTROL SYSTEM DEVELOPMENT AT THE SOUTH AFRICAN ISOTOPE FACILITY (SAIF)

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Abstract

The first phase of the South African Isotope Facility (SAIF) at iThemba LABS is well into commissioning. The intention of SAIF is to free up our existing separated sector cyclotron (SSC) facility to do more physics research and to increase our radioisotope production and research capacity. An EPICS based control system, primarily utilising EtherCAT hardware, has been developed that spans the control of beamline equipment, target handling and bombardment facilities, radiation protection and safety systems. Various building and peripheral services like cooling water and gases, HVAC and UPS have also been integrated into the control system via Modbus TCP/IP and OPC UA to allow for seamless control and monitoring. An overview of the SAIF facility and the EPICS based control system is presented. The control strategies, hardware and various EPICS and web-based software and tools utilised are presented.

INTRODUCTION

iThemba Laboratory for Accelerator Based Sciences (iThemba LABS) is a multi-disciplinary research center offering accelerator facilities for various scientific research, training, radioisotope production for nuclear medicine, and accelerator mass spectrometry services. The K=200 separated sector cyclotron (SSC) facility has been in operation for more than 30 years. The facility operates two solid-pole injector cyclotrons, one for light ions and one for heavy ions and polarized protons, for the injection of beams into the K=200 SSC. The beamtime from the SSC facility is split between nuclear physics research and radioisotope production.

Existing Radioisotope Production

The routine production of short-lived radioisotopes utilising the SSC facility started in 1988 at the horizontal beam target station (HBTS aka Elephant). Towards the late 1990s, production methods for the long-lived radioisotopes ^{73}As, ^{68}Ge, ^{22}Na and ^{82}Sr were developed. In 1996 a second target station (Babe) was designed and built for production of semi-permanent targets including ^{18}F. Production of ^{18}F was later transferred to a dedicated Siemens 11 MeV cyclotron. In 2006, the vertical beam target station (VBTS) was commissioned to exploit high-intensity proton beams delivered by the upgraded SSC. Development focussed on the production of long-lived and high-value radioisotopes such as ^{68}Ge, ^{22}Na and ^{82}Sr in a tandem configuration. These upgrades and developments were all undertaken to increase radioisotope production in order to meet the high market demand.

South African Isotope Facility

Increased radioisotope production using the SSC facility would require additional allocated beam time. However, this would come at the expense of research and other programmes. The South African Isotope Facility (SAIF) was established to increase the beam time for radioisotope production and research, whilst simultaneously freeing up the SSC facility to do more physics research. SAIF will be realised in two functional phases: (i) a centre for the production of exotic isotopes and (ii) a centre for the production of exotic beams.

The first phase of SAIF is well into commissioning. A Cyclone® 70 (C70) particle accelerator system, comprising of a high-current 70 MeV H^- cyclotron and four attaching beamlines, has been procured from Ion Beam Applications (IBA) and installed [1]. Target bombardment and handling facilities and a number of beamline components have been designed and manufactured. Hardware and software for the control and monitoring of the manufactured systems, radiation protection, safety and various building and peripheral systems have been developed. The remainder of this paper addresses these SAIF control systems.

ARCHITECTURE

The SAIF control system is largely built on the EPICS framework and mostly utilises off-the-shelf Beckhoff EtherCAT I/O terminals and third party PLCs to interface with equipment[1] [2]. As shown in Fig. 1, the SAIF control system consists of 3 hierarchical layers communicating through the *Control Network* - a flat Gigabit Ethernet network using the TCP/IP protocol.

Network Two Ethernet networks exist at iThemba LABS: the *Campus Network* and the *Control Network*. The first one, as its name states, is deployed across the iThemba LABS campus and accesses the Internet; the second one is restricted to equipment control and does not access the Internet.

[1] This discussion excludes the Cyclone® 70's control system. This is a turnkey proprietary control system developed and installed by IBA. A brief overview of the C70's control system, with a mention of integration with EPICS, is given in the next section. Contact the manufacturer for a detailed and up-to-date specification.

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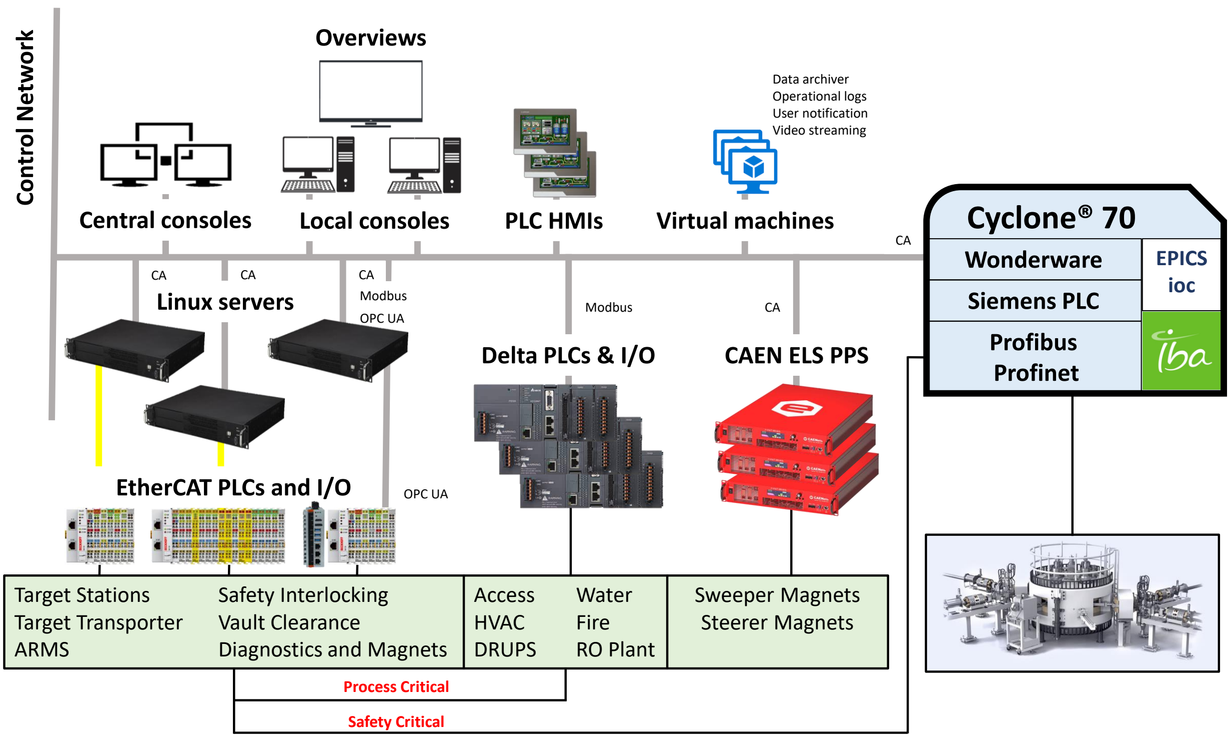

Figure 1: Overview of SAIF control system.

Equipment Interface

The SAIF control hardware comprises primarily of Beckhoff EtherCAT I/O terminals, Delta PLCs and I/O cards and a number of CAEN ELS power supplies [3, 4]. This hardware allows for the control and monitoring of the various equipment at SAIF. In a few instances, interface PCBs were developed to condition signals to suit the control system hardware. Figure 2 shows the SAIF power supply room, where most of the control electronics is installed.

Figure 2: SAIF power supply and electronics room.

Device Control

Device control is done through a number of EPICS iocs running on 19-inch rack mount servers running, predominantly, a *headless* Debian OS with the PREEMPT_RT patch applied. The IgH EtherCAT Master together with the Diamond Light Source (DLS) Controls Group EPICS support module for EtherCAT is used to communicate with EtherCAT field devices [5, 6].

Interfacing with the building and peripheral system PLCs is done over Modbus TCP/IP using the EPICS Modbus support module [7]. The CAEN ELS power supplies are controlled through the EPICS iocs embedded within the devices.

User Interaction

The "Pheobus" variant of Control System Studio (CS-Studio) is the primary toolset used for user input, monitoring and visualization [8]. This is supplemented by dashboards and overview screens developed in the React Automation Studio (RAS) progressive web app framework [9]. There are also a number of HMIs at the various building and peripheral system installation locations to allow for local control of the respective PLCs. Users can also interact with these HMIs through a VNC connection or directly with the PLC from Phoebus through a Modbus TCP/IP interface.

A number of additional tools for data archiving, operational logs, alarm and event notification and IP camera viewing are also provided to aid the SAIF control system users.

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CONTROL AND MONITORING OF SAIF SYSTEMS

This section describes the methods and strategies used to control and monitor the various systems at SAIF.

IBA Cyclone® 70 System

The Cyclone® 70 (C70) system, including the four attaching beam transport lines, is supplied together with a turnkey proprietary control system developed and installed by IBA. Figure 3 shows the C70 cyclotron. User interaction is through a Wonderware InTouch® client-server application. This enables users to communicate with the C70's control system PLC through a local Ethernet network. In addition to the Ethernet network, the PLC is also connected to a Profibus network for equipment control and a Profinet interface for safety critical signals. The PLC program was developed by IBA using the Siemens Totally Integrated Automation (TIA) Portal.

Figure 3: IBA Cyclone® 70 Cyclotron.

The C70 control system for SAIF includes an EPICS ioc developed by IBA. This allows for communication between the C70 and the SAIF control systems through the channel access (CA) protocol. This interface will be used to pass data to aid the radioisotope production process, to notify users and to be archived for maintenance and fault-finding purposes.

Target Bombardment and Handling Facilities

The target bombardment and handling facilities sit at the heart of the radioisotope production process at SAIF. These consist of two identical target stations located in two separate bombardment vaults and a target transport system to carry the targets to be bombarded to and from these target stations. The control of these systems is through EtherCAT I/O terminals and EPICS iocs.

The SAIF target station (shown in Fig. 4) was designed by iThemba LABS and manufactured by Thermodynamics Fluids (TF) Design Stellenbosch [10]. It was modelled on the existing horizontal beam target with a number of enhancements for improved performance and maintainability. The target station weighs close to 30 tons owing to the steel, borated wax and lead shielding required to contain the radiation emitted during the radioisotope production process. This shielding is opened and closed using a stepper motor with a potentiometer feedback. The station also includes a pneumatically controlled robotic arm to load and unload targets to and from the station and the transporter system and target helium and water-cooling systems.

The SAIF transporter system was built from the Telelift UniCar range of electric rails and trolleys [11]. The DC motor, gear rack and pick up brushes were stripped from the Telelift trolley (car) and built into a custom metal chassis more suited to a high radiation environment. The SAIF cars travel some 300 meters between bombardment vaults, storage and processing facilities. The control system routes cars between these locations, including with the use of track switches, and operates the end stations where the cars stop and are locked into alignment for robotic insertion and extraction of the payload.

Figure 4: SAIF SR target station and transporter in vault.

Beamline Diagnostics and Magnets

The beam transport lines supplied by IBA includes a number of magnets to adjust beam optics and collimators to remove stray particles that cannot be correctly focused on the target. However, the sweeper and last steering magnets and the target collimator on each beamline were designed and manufactured by iThemba LABS. The control systems for these magnets and collimator were developed using EtherCAT I/O terminals and a combination of TwinCAT PLCs and EPICS iocs.

The sweeper system "sweeps" the beam over the surface of the target in order to reduce local heat loading on the target as well as the Havar vacuum window located upstream of the target. The sweeper consists of two (X and Y) orthogonal air cooled AC magnets, with ferrite yokes, that produce a circular sweeping profile on the target. This requires control of the amplitudes and relative phases of the magnets is done through a TwinCAT PLC and interfaced via OPC UA [12].

The steerer is a window frame DC magnet that deflects the beam so that it is centred with respect to the collimator and target. The steerer contains two pairs of coils for simul-

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taneous control of the vertical and horizontal deflections. A set of CAEL ELS programmable supplies are used to control the coil currents.

The target collimator sits within the SAIF target station and is the last diagnostic tool before the beam hits the target. It is a four quadrant, water cooled, graphite block with an aperture concentric with the targets being bombarded in target station. The beam current measured on the four quadrants (left, right, top and bottom) of the collimator enables the C70 operator to centre the beam on the target. The collimator aperture is intentionally designed to be slightly smaller than the targets to prevent the beam from striking the target holder or any other unintended assemblies of the target station.

Radiation Protection and Safety

Radiation protection and safety, together with equipment and man-machine safety are of paramount importance in a radioisotope production facility like SAIF. This stems from the unique and potentially hazardous nature of the materials and processes involved and the stringent regulatory and compliance requirements. The Area Radiation and Monitoring System (ARMS), safety interlocking and vault clearance control systems address these requirements[2].

The ARMS system is made up of a number of Gamma and Neutron radiation probes and controllers. These measure the background radiation in the production areas and vaults and alert personnel of potential hazards. The radiation levels are read into the SAIF control system and used to enforce access control through the use of electronic signage and magnetic locks. Some examples of the SAIF ARMS hardware is shown in Fig. 5.

The safety interlocking system is implemented through a number of hard and soft interlocks. Hard interlocks are safety critical signals, such as emergency stops or door limit switches, that are routed directly into the C70's safety interlocking system to stop production without software input. Soft interlocks at SAIF are comprised of a number of safety equations that aggregate building and peripheral services, equipment and operational statuses to define safe/unsafe operational states.

The vault clearance system implements a specific, predefined and agreed upon, sequence of steps that a SAIF user must follow to clear a given production area or vault of personnel. This is done through a series of push buttons, limit switches, lights and sirens.

Building and Peripheral Systems

A number of turnkey building and peripheral systems were designed and built to allow SAIF to operate efficiently. These included an access control system, a compressed air plant, a chiller plant and supporting water cooling loops (shown

[2] Equipment, man-machine and radiation safety is addressed holistically through ergonomics and safe design, training and education, emergency protocols, labels, signage and barriers, personal protective equipment (PPE) and regular maintenance and inspections amongst other interventions.

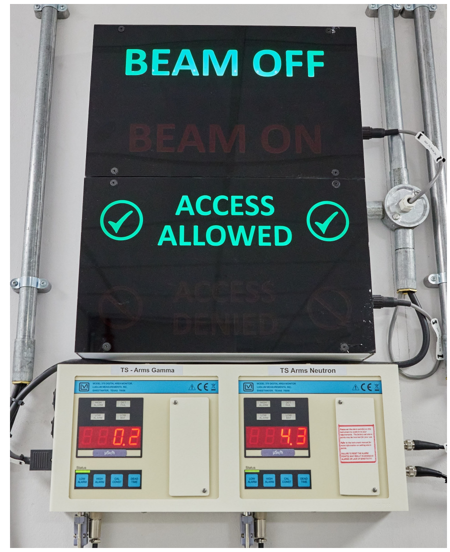

Figure 5: Electronic signage and radiation controllers as part of ARMS system.

in Fig. 6), overhead crane and lift systems, a diesel rotary uninterruptible power supply (DRUPS) system (shown in Fig. 7), a fire detection system, a heating, ventilation, and air conditioning (HVAC) system, a reverse osmosis (RO) plant, target water and helium cooling systems and waste management and storage facilities.

Figure 6: Chilled water plant.

The various equipment and mechanical plants/systems were developed and installed by an array of subcontractors. The development of the control system PLCs, programs and integration was primarily done by the controls team from TF Design. The Delta AS series of PLCs were used with development done in the Delta DIAStudio suite. Each remote equipment location was connected to the *Control Network* via optical fiber and several network switches. A Modbus TCP/IP link was provided for integration with EPICS and several independent sensors were also installed for process and safety critical parameters to be read directly by the SAIF control system via EtherCAT I/O terminals.

ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-M03BC003

Figure 7: Diesel rotary uninterruptible power supply (DRUPS) installation.

Tools and Other

A number of tools are also used or have been developed to aid the SAIF control system users. These include:

Data Archiving EPICS pv data, including data received from the C70 and the building and peripheral systems, is archived using the EPICS Archiver Appliance [13]. The archiver appliance was customised for a site specific build including the use of policies to support different configurations.

Operational Logs Equipment and operational logs are logged to a MongoDB replica set (a group of mongod processes that maintain the same data set for redundancy and high availability) [14]. The logs can be viewed on a web front end and is displayed in Phoebus using the Web Browser widget.

User Notification A user notification system has been developed to notify users of EPICS alarms and other events via Signal. Signal is an encrypted messaging service with an Android and iOS app [15]. Users are informed of alarm (MINOR/MAJOR) changes and can query other pv info like value, severity and timestamp.

Video Streaming A number of cameras have been installed across the SAIF facility for operational purposes. These cameras enable the SAIF control system users to view the target bombardment and handling facilities remotely during production. The cameras are connected to Extended Video Recorders (XVR) and Network Video Recorders (NVR) for remote viewing using the Real Time Streaming Protocol (RTSP). A tool is in development to stream this video directly to a web browser.

STATUS AND OUTLOOK

The control system development at SAIF is at a mature stage. With the facility coming online, the core equipment interface and device control layers' hardware and software have been installed and commissioned. Although we expect most of the development going forward to be on the user interaction layer, updates and changes to the lower layers may be necessary as we start radioisotope production and require revisions. As with all technology-centric systems, the SAIF control system hardware and software is continuously impacted by technological advancements and will require ongoing development and maintenance.

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