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PERSONNEL SAFETY SYSTEMS FOR ESS BEAM ON DUMP AND BEAM ON TARGET OPERATIONS

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Abstract

The European Spallation Source (ESS) is a Pan-European project with 13 European nations as members, including the host nations Sweden and Denmark. ESS has been through staged installation and commissioning of the facility over the past few years. Along with the facility evolution, several Personnel Safety Systems, as key contributor to the overall personnel safety, have been developed and commissioned to support safe operation of e.g. test stand for cryomodules Site Acceptance Test, test stand for Ion Source and Low Energy Beam Transport, and trial operation of the Normal Conducting Linac. As ESS is preparing for Beam on Dump (BoD) and Beam on Target (BoT) operations in coming years, PSS development is ongoing to enable safe commissioning and operation of the Linear Accelerator, Target Station, Bunker and day-one Neutron Instruments. Personnel Safety Systems at ESS (ESS PSS) is an integrated system that is composed of several PSS systems across the facility. Following the experience gained from the earlier PSS built at ESS, modularized solutions have been adopted for ESS PSS that can adapt the evolving needs of the facility from BoD and BoT operations to installing new Neutron Instruments during facility steady-state operation. This paper provides an overview of the ESS PSS, and its commissioning plan to support BoD and BoT operations.

INTRODUCTION

The European Spallation Source (ESS) represents a leap in the world of scientific research. Located in Lund, Sweden, ESS is a state-of-the-art facility under construction to address some of the most profound questions in the realm of materials science, chemistry, biology, and physics. Central to its mission is the utilization of neutrons produced through a process called spallation. This facility will boast the capability to accelerate protons to high energies, causing them to collide with a heavy metal target. This collision results in the release of neutrons, which are then harnessed to study the atomic and molecular structures of materials, providing insights into their fundamental properties and behaviours [1].

The operation of ESS is accompanied by the need to address a range of potential hazards that arise in a facility of this magnitude and complexity. These hazards can broadly be categorized as radiation, chemical, cryogenic, electrical, explosion, fire, laser, vacuum-related hazard, etc. Addressing these hazards effectively is paramount to ensuring the continued success of ESS in advancing scientific knowledge while maintaining a safe and secure research environment. This paper delves into the *Personnel Safety Systems* at ESS, which plays a pivotal role in mitigating a designated number of hazards and safeguarding the individuals and infrastructure at ESS.

PERSONNEL SAFETY SYSTEMS

At ESS, during the operation of proton accelerator and producing neutrons to be used at experimental stations, radiation is generated. This radiation includes neutron radiation, gamma radiation, fats neutrons, activation products, etc. The immediate radiation produced from these interactions is referred to as prompt radiation. ESS employs systems and administrative procedures to ensure the safety of personnel in the presence of prompt radiation. In this regard, one of the key systems is Personnel Safety Systems (PSS) that primarily encompasses a safety interlock system designed to protect personnel from prompt radiation. The PSS ensures that sources of prompt radiation, such as proton beam or Radio Frequency (RF)-powered cavities are switched off to protect personnel in beam enclosures (e.g. accelerator tunnel, experimental stations, etc.) from exposure to prompt radiation, prevent entry to beam enclosures while prompt radiation sources are energized, and switch them off when designated pre-defined access functions are violated.

The PSS at ESS is not confined solely to mitigating prompt ionizing radiation hazards but its function can be extended to mitigating a number of conventional hazards such as electrical and vacuum-related hazards. Moreover, where required, PSS contributes to access management to radiation areas in conjunction with ESS physical access control system.

Methodology

The development of the PSS embodies a structured approach, guided by two foundational references: the ESS Handbook for Engineering Management and the Functional Safety Standard IEC 61511 [2]. The ESS Handbook for Engineering Management outlines the overarching principles that govern engineering practices at ESS. Within this framework, the development of the PSS is systematically planned and executed.

Complementing the ESS Handbook for Engineering Management, the Functional Safety Standard IEC 61511 provides a globally recognized framework for achieving functional safety in process industries. ESS draws upon the principles and best practices outlined in this standard to de-

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sign, implement, and maintain the PSS. IEC 61511 offers a structured approach to risk assessment, safety instrumented systems (SIS) design, and lifecycle management.

PSS Design Principles

In order to ensure the development of a robust and adaptable PSS, two fundamental elements have been considered in the design process of PSS; standardization and scalability.

In order to ensure consistent designs, proven methods and components, reducing the risk of errors and system failures, and cost savings for the project in short and long runs, standardization is implemented as much as reasonably practical in the chosen technology (hardware and software), user interfaces (trapped key interlock systems, and Graphical User Interfaces), system documentation, system verification, etc.

Moreover, given the staged commissioning of facilities like ESS, and their evolving needs over time, PSS design considers scalability in order to accommodate upgrades and expansions. In this respect, PSS design accommodates a) planned upgrades, e.g. support additional RF systems in Accelerator, or additional planned experimental stations, and b) predictable upgrades, e.g. the PSS architecture to support additional neutron instrument beyond the planned 16 instruments.

PSS Architecture

The core of our PSS is a Siemens Programmable Logic Controller (PLC)-based system, a commonly-used and proven technology for its reliability and versatility in safety interlock systems.

Within ESS, each individual PSS, e.g. the PSS for the accelerator, operates with its dedicated PLC, which is connected to field devices and the Equipment Under Control (EUC) through remote input/output modules. These modules facilitate communication with the system PLC via PROFIsafe protocol, ensuring efficient and secure data ex-change. Figure 1 details the architecture of Accelerator PSS.

The other PSS at ESS, e.g. the PSS for neutron instruments or target station, need to have an interface with Accelerator PSS in order to request switching off the proton beam generation in certain hazardous scenarios. In order to ensure a robust and reliable interlink between different PSS, a centralized system called Nexus PSS, which interfaces all other PSS systems, is designed. See Fig. 2. The Nexus PSS stretches across the facility over a fiber ring, and interfaces each PSS through hardwired connection. Figure 3 details the concept of this hardwired connection.

ESS BEAM COMMSSIONING PLAN & PSS

The commissioning of a complex research facility like ESS is a meticulously planned and phased process, designed to ensure the safety, reliability, and functionality of its complex systems. Upon successful conclusion of the beam commissioning in the normal conduction section of the ESS linac in 2023, which was enabled by PSS1, the preparations (manufacturing, installation, local and integrated hardware testing, etc.) for the upcoming beam commissioning stages and their required PSS are currently in progress.

Beam on Dump Commissioning

The next stage of beam commissioning at ESS is to send the proton beam to the tuning beam dump installed at the end of the accelerator tunnel. For this stage of beam com-

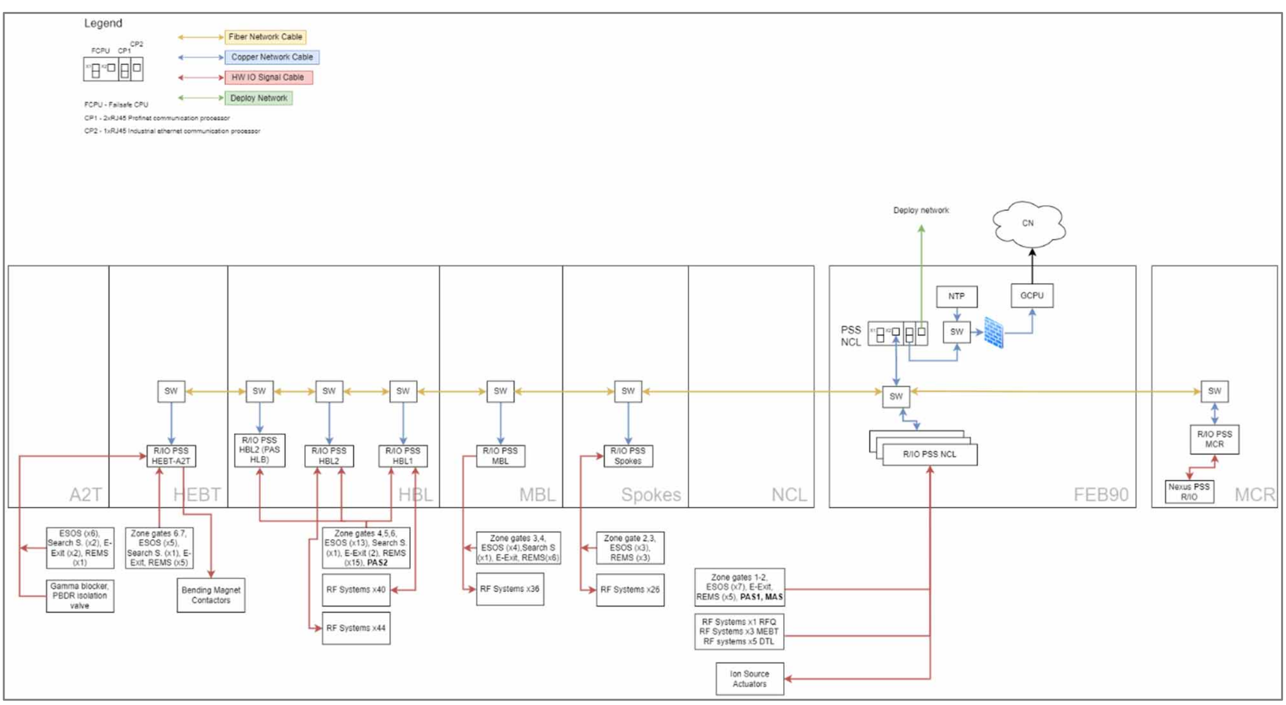

Figure 1: Accelerator PSS architecture

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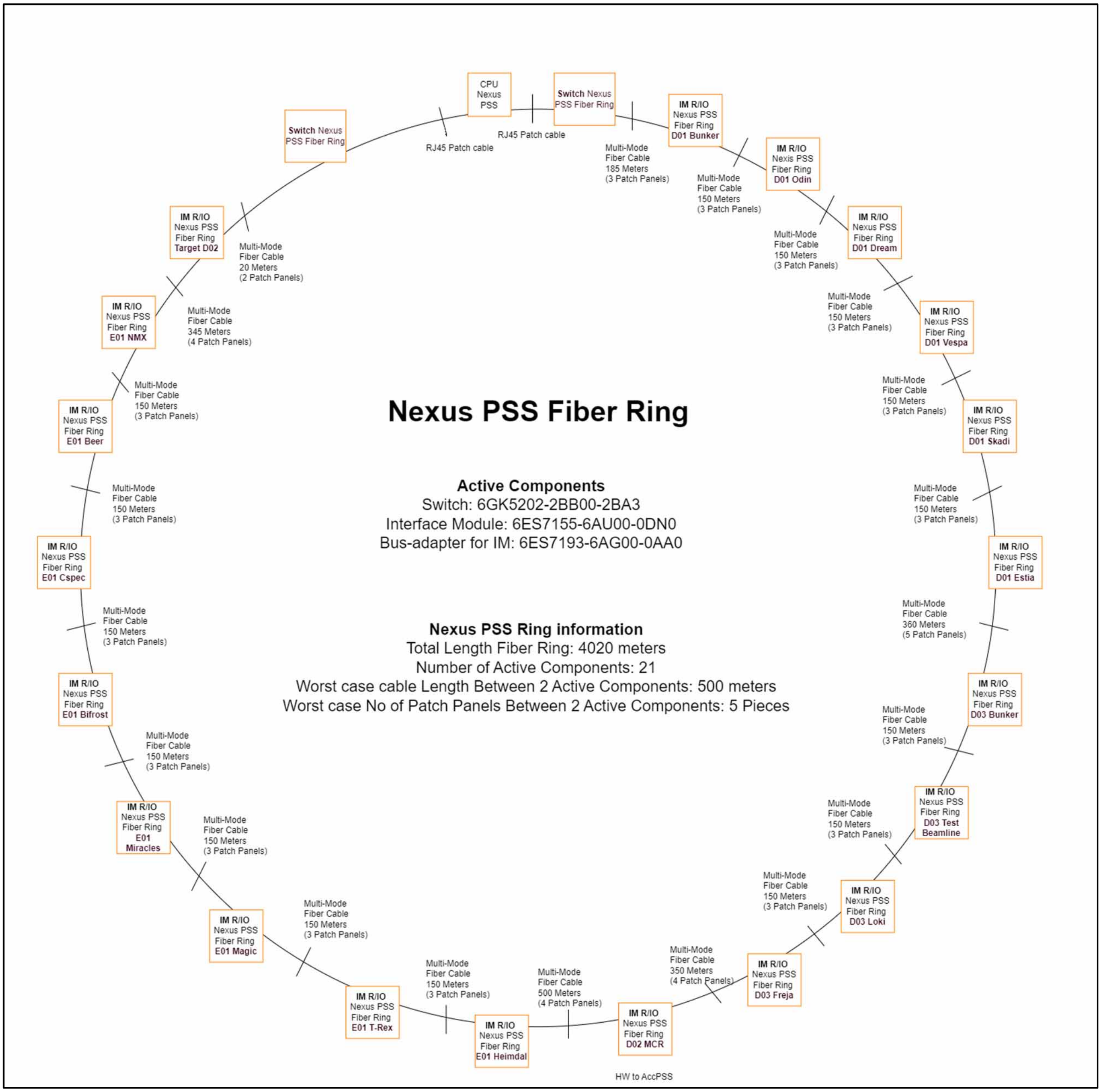

Figure 2: Nexus PSS architecture

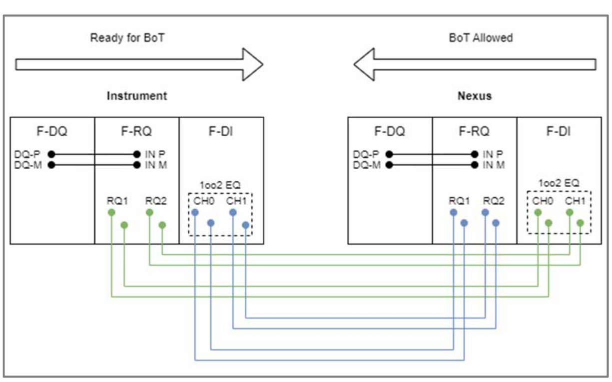

Figure 3: Hardwired connection between Nexus and other PSS

missioning, Accelerator PSS for the entire tunnel will be operational. However, a subset of the final number of EUC will be connected to Accelerator PSS. The RF systems, that comprise a significant portion of Accelerator PSS interfaces, will be installed and commissioned at various stages, including Beam on Dump (BoD), Beam on Target (BoT), the Start of User Program (SOUP), and the culmination with the 5 MW beam at ESS. As such, the commissioning of Accelerator PSS will follow the same stages. Table 1 details the phases for realising the Accelerator PSS based on the readiness of its interfaces.

Beam on Target Commissioning

Shortly after conclusion of beam on dump commissioning, ESS will transition to intentional neutron production

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Table 1: Accelerator PSS Phases

PSS interface	BoD	BoT	SOUP	5 MW
Ion Source	X	X	X	X
RFQ and DTL RF systems	X	X	X	X
MEBT RF systems	X	X	X	X
Spokes RF systems	X	X	X	X
MBL RF systems	X	X	X	X
HBL RF systems (part 1)	X	X	X	X
HBL RF systems (part 2)	-	-	X	X
HBL RF systems (part 3)	-	-	-	X
Bending magnets	-	X	X	X
Gamma blocker	-	X	X	X
PBDR isolation valve	-	X	X	X
Safety Helium Collector (SHC) valves	X	X	X	X
Radiation monitors (x34)	X	X	X	X
Physical access control system	X	X	X	X
Nexus	-	X	X	X

phase that will comprise of sending an 870 MeV proton beam to target, and start the hot commissioning of day-one neutron instruments with the produced neutrons. This stage of the beam commissioning at ESS entails several PSS be fully developed, installed and validated, including Accelerator PSS, Target Station PSS, Bunker PSS, 4 day-one Instrument PSS, and the Test Beamline PSS.

PSS Commissioning Strategy

Commissioning multiple PSS for the ESS intentional neutron production phase is an intricate undertaking, as it involves the integration and testing of various PSS components, interfaces and functions. As prescribed by the PSS development methodology, each PSS shall go through a rigorous Verification and Validation (V&V) process. The following are the V&V steps of the PSS required for the ESS beam on target operation:

Hardware Factory Acceptance Test (HW FAT) PSS is built using commercial-off-the-shelf (COTS) components. However, certain assemblies of these components should be designed and manufactured. The HW FAT for PSS verifies that the as-built assemblies, e.g. electrical enclosures housing PLC modules, power supplies, etc., are manufactured as per the specified design.

Hardware Site Acceptance Test (HW SAT) Upon finalizing the PSS installation at site, the Hardware SAT for PSS commences. It verifies that the hardware is installed as specified in the design documents following the expected operational environment for COTS components. It includes testing of field devices and loop checks between PSS and its interfacing systems.

Software pre-FAT SW pre-FAT is a virtual commissioning of PSS in which the system functions (safety instrumented functions, search procedures, key exchange procedures, etc.) are tested using a simulation tool in the development environment. It also includes the software peer review, carried out by an independent software reviewer, to reveal potential software design defects and avoid systematic failures.

Local Functional Testing It is a site integration test (SIT) that verifies the installed hardware and software, as deployed to the production environment, work together properly, ensuring that their combination is serving the purpose of PSS safety functions and procedures. Some of the EUC local to the system may need to be connected to PSS and tested during SIT. For the ESS intentional neutron production phase, each PSS shall individually undertake a thorough local functional testing.

Integrated Functional Testing It is a final integration (FIT) test that verifies all the required PSS for intentional neutron production work together properly, ensuring that their combination is serving the purpose of PSS for this stage of beam commissioning. Upon successful completion of the FIT, the PSS will be ready to transition to operation phase.

CONCLUSION

In conclusion, the successful commissioning of a safety-critical system, such as PSS, with its vast network of interfaces, underscores the importance of close collaboration among all stakeholders involved. As such, the synergy between PSS team, interfacing systems owners, facility safety teams and operations staff is not just desirable but indispensable.

ACKNOWLEDGEMENTS

We would like to extend our heartfelt gratitude to all those who have contributed to the development of the PSS at ESS so far. The collaborative efforts of our dedicated team members, ESS safety teams, interfacing system owners, PSS external reviewers and functional safety assessors have been instrumental in bringing the project to the current stage.

REFERENCES

[1] European Spallation Source ERIC, `http://www.ess.eu`

[2] *Functional safety - Safety instrumented systems for the process industry sector,* IEC 61511-2016, 2016