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Veksler and Baldin Laboratory of High Energy Physics

FINAL REPORT ON THE START PROGRAMME

"A comparative Analysis of Workplace Culture in Particle Accelerator Complexes: The Large Hadron Collider (LHC) and Nuclotron-based Ion Collider Facility (NICA)"

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Report Abstract:

This report delves into the comprehensive analysis of our contributions during the START 2023 internship period. Our work encompasses an extensive review of the intricate aspects of organizational workplace cultures at two distinct particle accelerator complexes: the Large Hadron Collider (LHC) and the NICA (Nuclotron-based Ion Collider Facility). The analysis covers a wide range of aspects, including goal definition, team collaboration, role assignments, safety protocol enforcement, technological infrastructure establishment, and the extraction of experiential knowledge. The ongoing study explores the overarching organizational objectives, the effectiveness of operational implementations, and the potential for cross-pollination of insights and the adoption of best practices. This systematic examination of these components at both complexes provides valuable insights into the world of particle physics research, shedding light on the complexities and nuances of managing cutting-edge scientific facilities.

0. Introduction

Particle accelerators constitute indispensable tools for advancing the frontiers of particle physics. Among the vanguards of this scientific pursuit stand the Large Hadron Collider (LHC) and NICA (Nuclotron-based Ion Collider Facility), representing pioneering installations of considerable magnitude. These forefront endeavors necessitate not solely cutting-edge technological implementations and investigative prowess, but also a meticulously structured and proficient operational framework. By undertaking a comparative analysis of the operational paradigms within these facilities, a reservoir of invaluable insights emerges, casting light upon the adept management of ambitious large-scale scientific undertakings. This manuscript expounds upon a comprehensive methodological approach tailored to juxtapose the organizational architectures, labor milieu, and procedural methodologies encapsulated within the expansive domains of the LHC and NICA complexes. The culmination of this study aspires to yield operational refinements, fortified safety protocols, and the nurturance of collaborative synergies between these eminent bastions of particle accelerator complexes, thereby indelibly enriching the trajectory of high-energy physics exploration.

Overall, this comparison will help us understand how the work organization in the LHC and NICA complexes supports their scientific goals, fosters collaboration, ensures safety and security, manages resources, and drives high-quality research output. By appreciating the strengths and weaknesses of these organizations, we can strive for more efficient and effective work structures in the pursuit of scientific breakthroughs and technological advancements.

- **The main objectives are:**

1. Elucidate the parallels and deviations intrinsic to the organizational frameworks and operational strategies underpinning the expansive constituents of (LHC) and NICA complexes.

2. Dissect the intrinsic strengths and loci for augmentation within the organizational dynamics of both entities.

3. Undertake a scrutinous analysis of the objectives, roles, responsibilities, and operative functions enacted within the purview of the LHC and NICA complexes. This endeavor aims to furnish insights into the compositional configuration of their workforce and the cultivation of collaborative modus operandi.

4. Interrogate the operator functions, shift-based responsibilities, impartment of safety protocols, and the edifice of security measures entrenched within both establishments. The discernments gleaned from this inquiry serve as a conduit for the derivation of pragmatic recommendations poised to amplify operational efficacy and fortify the technological edifice of these scientific bastions.

1. Analysis of Organizational Structure in CCC

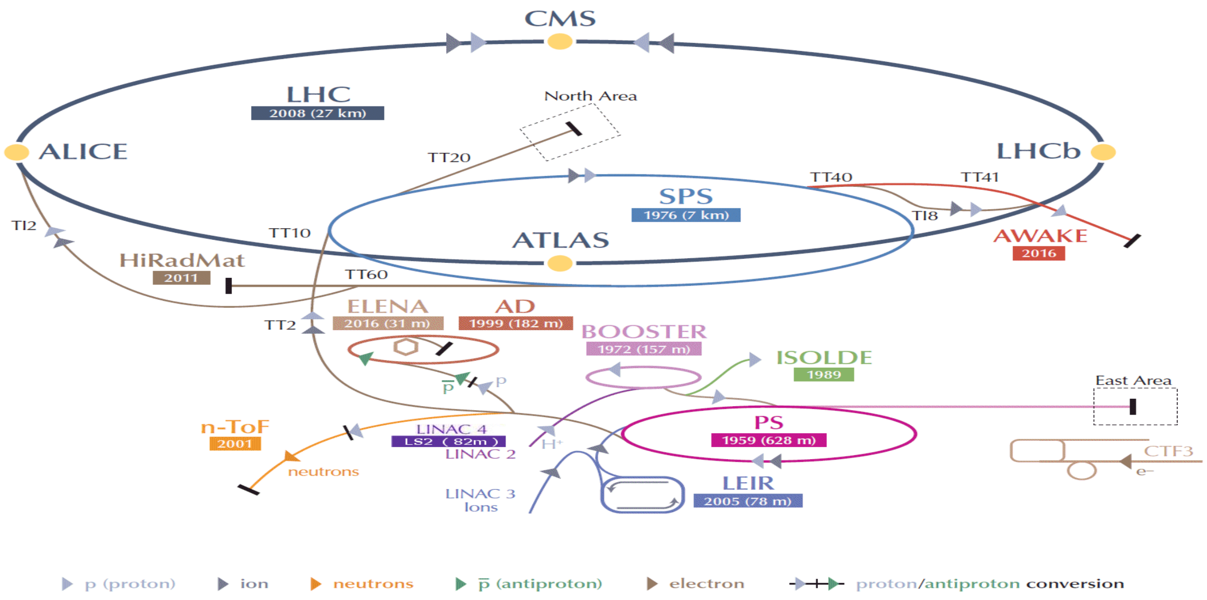

Figure 1. LHC Collider complex at CERN.

Within the operational framework of the Large Hadron Collider Control Centre (LHC CCC), a discernible organizational architecture manifests, characterized by specialized teams of Operators, each endowed with distinct responsibilities pertaining to diverse machinery entities. In the temporal expanse of accelerator operation, a contingent of 7 individuals assumes duty during each shift dedicated to accelerator activities. This assemblage encompasses a PSB Operator, 2 PS Operators, 2 SPS Operators, 1 LHC Operator, and an LHC EIC (Engineer in Charge) collaboratively engaged with the LHC Operator in the orchestration of LHC operations. Over the course of LHC's operational maturation, the EIC function shall undergo phased diminution, consequently rendering 6 Accelerator Operators as the definitive shift composition. The operational initiatives of these Operators are subject to vigilance and guidance by a cohort of Accelerator Supervisors, typically ranging from 4 to 5 individuals per accelerator, fulfilling the pivotal role of orchestrating and harmonizing activities within the precincts of the control room.

1.1 Workforce Composition at LHC

The organizational framework governing the workforce composition within the Control Centre Complex (CCC) is intricately designed to facilitate the unhindered and efficient functioning of the accelerator installations. Task-specific teams of skilled Operators are meticulously allocated to distinct machinery units, thereby imparting a finely honed expertise and adeptness in their respective domains. In the course of accelerator operations, each operational shift is entrusted to a contingent of seven Operators, delineated as follows: 1 Operator for the Proton Synchrotron Booster (PSB), 2 Operators for the Proton Synchrotrons (PS), 2 Operators for the Super Proton Synchrotron (SPS), 1 Operator for the Large Hadron Collider (LHC), and 1 Engineer in Charge (LHC EIC), who collaboratively engages with the LHC Operator during LHC operations. It is, however, a foreseeable trajectory that the role of the LHC EIC will be progressively phased out, consequently leading to a composition of six Operators per operational shift.

The preservation of the seven-Operator complement for the six designated roles within the CCC is underscored by multifarious imperatives. This configuration furnishes the Operators with the latitude to engage in ancillary consequential undertakings, including software development, thereby fostering a diversification of their skill repertoire and a commensurate contribution to the overarching efficacy of the department. This practice bears profound significance, as it perpetuates a constant influx of seasoned Operators into equipment maintenance and other service collectives housed within the control room milieu. Concomitantly, this bestows upon the department an amalgamated workforce steeped in comprehensive erudition, thereby buttressing the fluid continuum of CCC operations and concomitant accelerator ensembles.

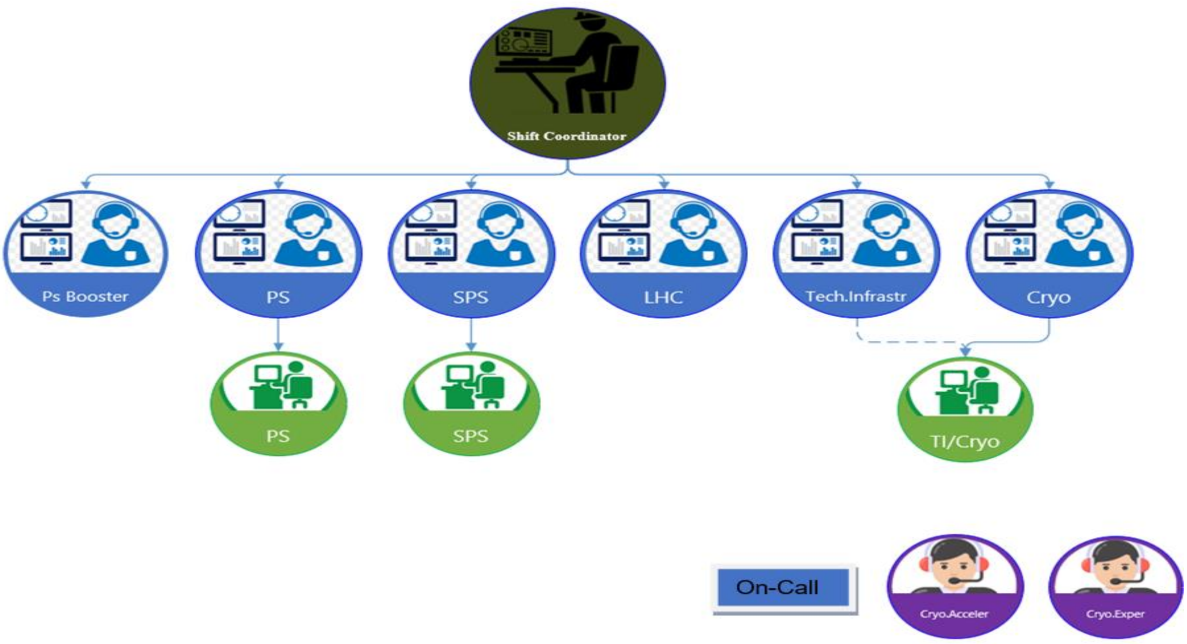

Figure 2. CCC Staff.

1.2 Staff Training Protocol at LHC

The training regimen for operators at the CERN Control Centre (CCC) stands as an indispensable facet of facilitating the secure and streamlined operation of the Large Hadron Collider (LHC), a preeminent instantiation of one of the world's most intricate scientific undertakings. This instructional framework encompasses a multifaceted array of pivotal constituents, meticulously designed to endow operators with the essential proficiencies and erudition requisite for their entrusted responsibilities.

Commencing with a comprehensive iteration denoted as the LHC Class, this didactic initiation engenders a dynamic live exposition that comprehensively envelops the entirety of the collider's ambit. Anchored in interactivity, this didactic discourse necessitates physical presence and serves as the bedrock for the assimilation of the LHC's underlying physical principles, architectural configuration, and experimental intricacies. Consequent to this foundational session, aspirants partake in immersive LHC simulator modules, engendering tangible experiential insight into the manipulation of the control systems, therein acquainting themselves with the multifarious sub-systems that comprise the operational panorama.

Central to this curriculum are the safety protocols that underpin its edifice, wherein a meticulous assimilation of radiation peril cognition, cryogenic contingencies apprehension, and exigency procedural proficiency is imparted. The didactic paradigm further encompasses the gamut of accelerator operationalities, anomalous operationality diagnosis, and efficacious troubleshooting methodologies, thereby equipping operators with the acumen to adeptly navigate a spectrum of plausible operational exigencies. Acknowledging the LHC's unceasing 24/7 operational tempo, adeptness in the domain of effective interpersonal communication, especially during junctures of shift transitions and critical emergencies, is underscored as an integral instructional facet.

In recognition of the perpetually evolving nature of this research crucible, the training continuum is underscored by a recurrent process of erudition infusion. Facilitated through immersive simulated scenarios and a sustained dissemination of contemporaneous technological advancements, this paradigmatic approach ensures that operators persistently sustain an elevated threshold of cognitive acuity, in seamless consonance with the research facility's incessant metamorphic trajectory.

In fact, we can summarize the training protocol as follows:

1) Lectures,

2) Simulation,

3) Manuals,

4) Test (Exam).

1.3 Work Environment Analysis in LHC

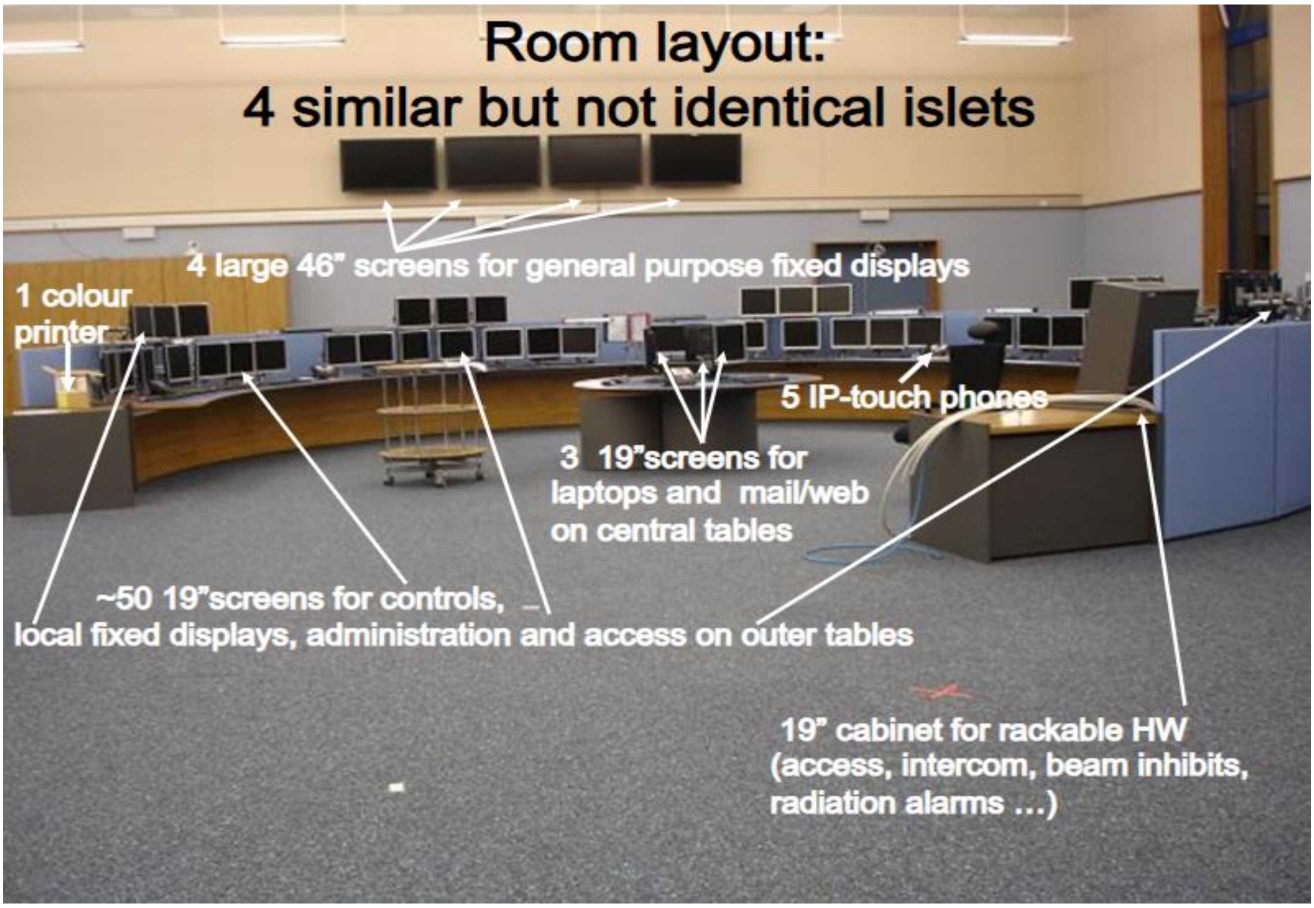

Figure 3. Analysis of one of the action islands in the CCC.

Architectural Configuration The architectural layout of the control room within the LHC has been meticulously formulated, taking into account the imperative exigencies of its operational functions as well as the requisites of the personnel it accommodates. The spatial dimensions of the control room have been judiciously determined through a meticulous estimation encompassing both routine and peak staffing levels.

A capacious expanse measuring 600 m^2 has been thoughtfully allocated as a singular domain, adeptly catering to the operational contingents comprising up to 11 Operations staff members during any given shift cycle. For periods characterized by elevated workforce involvement, wherein multiple personnel necessitate harmonious coaction, an expansible domain is availed to accommodate diverse factions such as Accelerator Operations, Technical Services, and Cryogenics. Each faction assumes distinct roles and attendant responsibilities within the operational ambit.

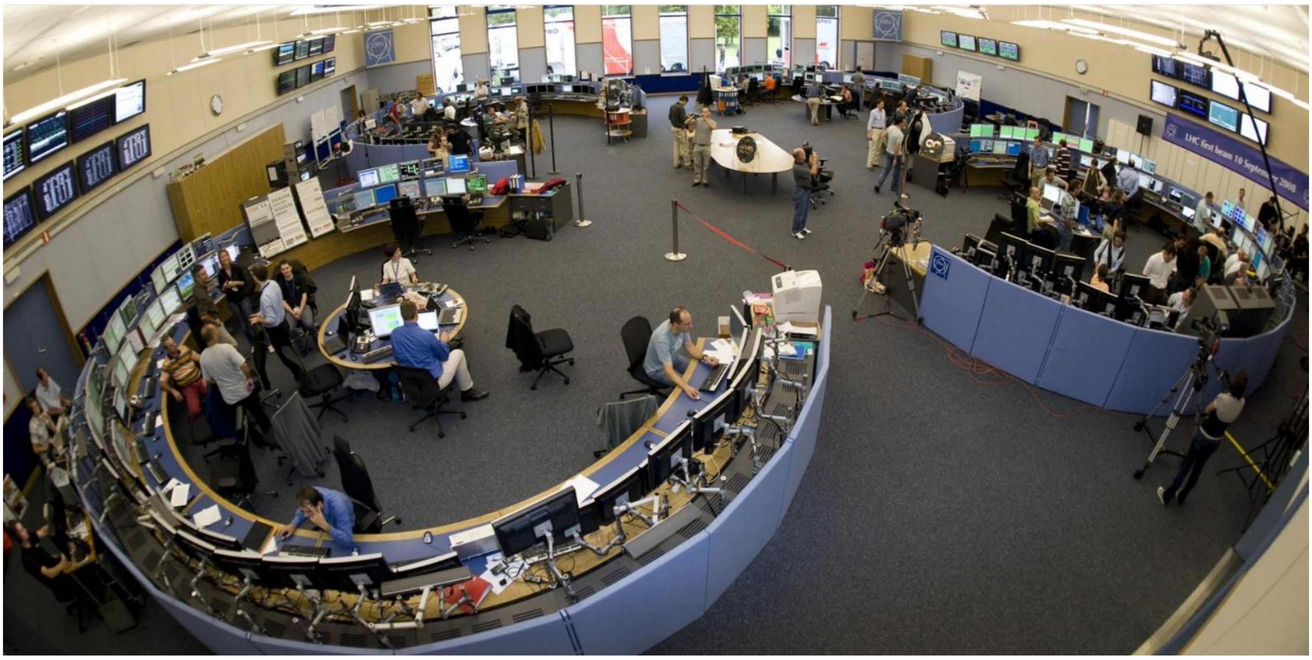

Figure 4. The LHC control room with its four islands arranged as a cloverleaf.

In the pursuit of cultivating an environment conducive to productivity and well-being, the ceiling height has been deliberately configured at twice the standard magnitude. This strategic adjustment serves the dual purpose of circumventing the "parking effect," a phenomenon that arises in confined spaces, while concurrently facilitating an efficient circulation of conditioned air throughout the enclosure.

The absence of internal load-bearing columns further augments the operational fluidity, affording unobstructed manoeuvrability. Architecturally, the upper structure of the control room is anchored upon pre-constrained concrete beams, a design feature that preserves spatial continuity and operational integrity. Augmenting the architectural configuration, exterior fenestrations have been judiciously incorporated, thereby endowing the space with ample ingress of natural illumination. This judicious integration addresses a salient ergonomic concern prevalent in control room settings.

Operational Continuity Considering the ceaseless operational cadence spanning a continuous 24/7 interval, the Central Control Centre (CCC) has been meticulously attuned to cater comprehensively to the exigencies of the staff. The CCC is underscored as not merely a workspace, but an immersive milieu wherein the facets of comfort and convenience are accorded profound significance. Even during phases of accelerator shutdowns, the CCC remains resolutely functional, albeit with a curtailed staff presence ranging from 2 to 4 individuals, ensuring the uninterrupted provision of essential services. This architectural and functional resonance, orchestrated through judicious assessments encompassing demographic projections, utilitarian mandates, and occupational requisites, converges to institute an adaptive, ergonomically optimized, and amenable control room ecosystem harmonized with the dynamic ethos of the operational enterprise.

1.4 Operator Responsibilities in LHC

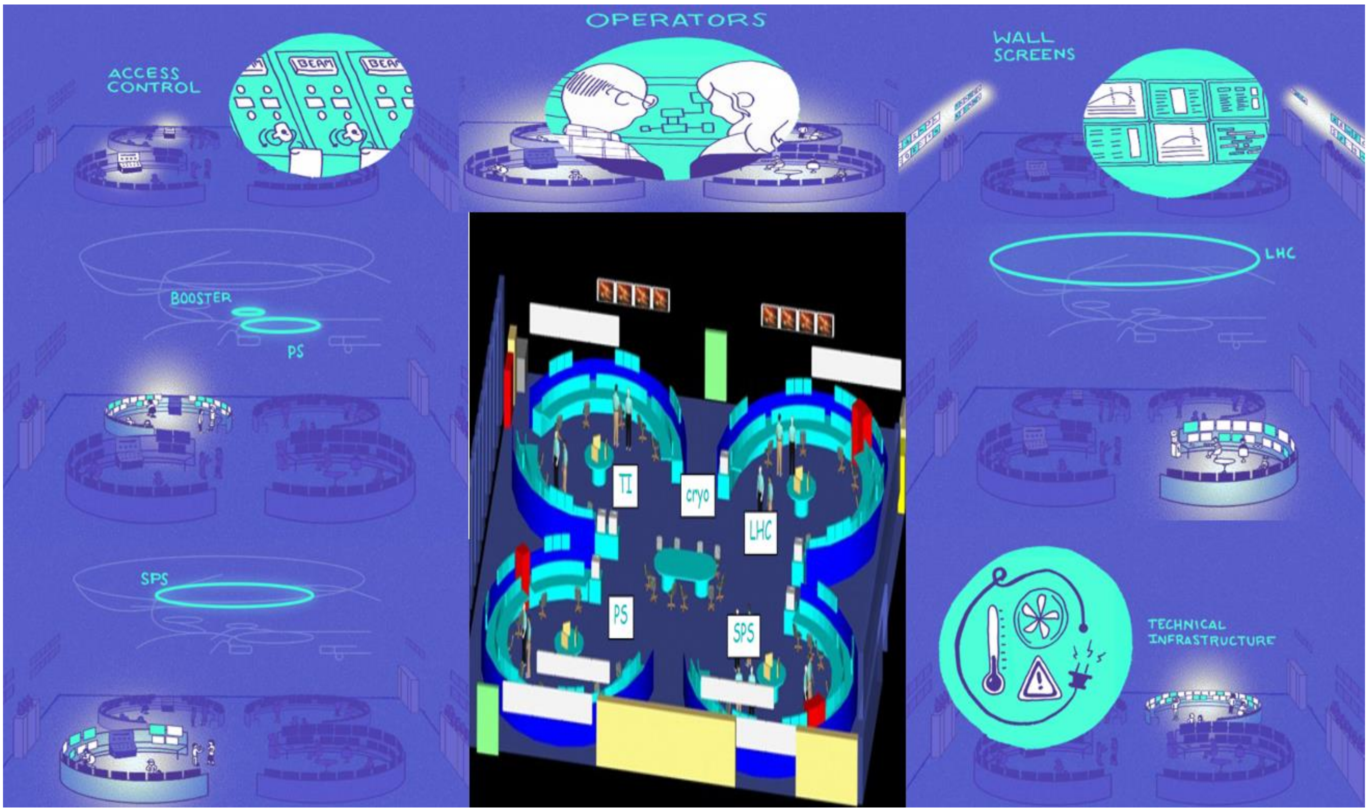

Figure 5. Analysis within the CERN Control Centre.

The subsequent enumeration delineates the distinct assignments allocated to operators within the LHC Control Room, in relation to specific accelerators and experimental domains:

Let's break it down:

1. 2 LINACs: Linear Accelerators, which are used to accelerate charged particles in a straight line.
2. **PSB: Proton Synchrotron Booster**, which is a pre-accelerator that boosts the energy of protons before they are sent to larger accelerators.
3. **PS: Proton Synchrotron**, which accelerates protons to higher energies.
4. **SPS: Super Proton Synchrotron**, a larger accelerator that further accelerates protons to even higher energies.
5. **AD: Antiproton Decelerator**, used to slow down antiprotons for various experiments.
6. **All associated transfer lines:** The beamlines and systems that transfer particles from one accelerator to another or to experimental areas.
7. **AD experimental area:** The area where experiments with antiprotons take place.
8. **ISOLDE (up to the target stations):** An experimental facility where researchers study radioactive isotopes.

9. **North, East, and West experimental Halls:** Experimental areas where scientists conduct various research experiments.
    - Note: West area operation stops at the end of 2004, meaning it will no longer be active after that time.
10. **nTOF experimental facility (up to the target station):** Neutron Time-of-Flight experimental facility for studying neutron reactions.
11. **CNGS facility (from 2006):** CERN Neutrinos to Gran Sasso facility, used to study neutrinos.
12. **LEIR (from 2006/7?):** Low Energy Ion Ring, which accelerates and stores ions at low energies.
13. **LHC (from 2007):** The Large Hadron Collider, a massive accelerator designed to collide particles at very high energies.

The Accelerator Operators will have the responsibility of operating, maintaining, and ensuring the smooth functioning of these accelerators and facilities to facilitate a wide range of scientific experiments and studies.

2. Analysis of Organizational Structure in NICA Complex

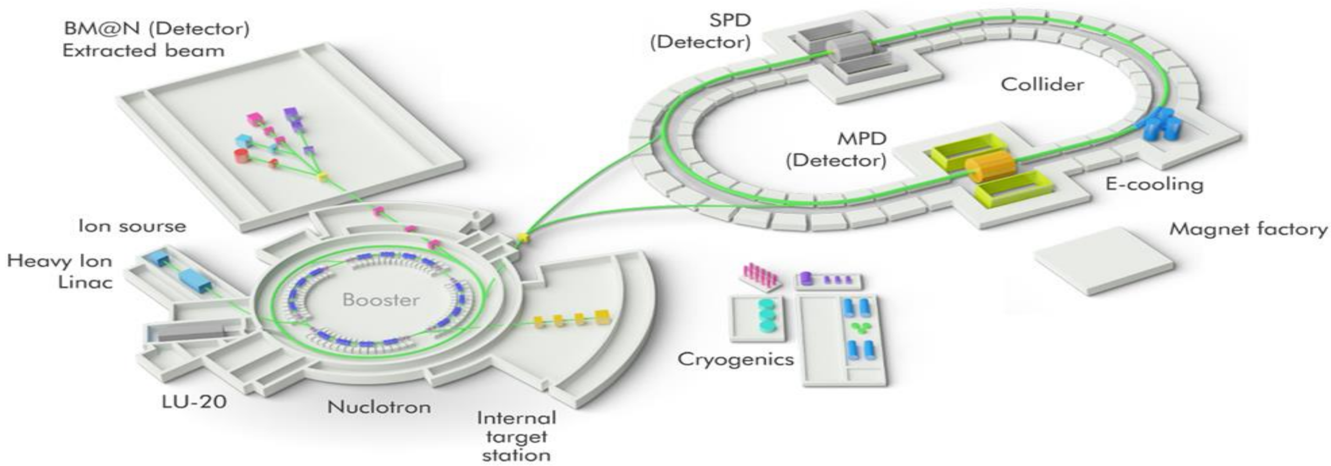

Figure 6. NICA schematic layout.

The organizational structure analysis of the Nuclotron-based Ion Collider Facility (NICA) complex is characterized by a highly compartmentalized framework. Each constituent part within the complex operates autonomously, featuring its own dedicated control room. The NICA complex encompasses a multitude of integral components, each contributing significantly to its overall operational functionality. These components include the Bm@n Detector for beam extraction, Ion Source, Heavy Ion Linac, LU-20, Booster, Nuclotron, Integral Target Station, Cryogenics system, SPD Detector, MPD Detector, Collider, E-cooling system, and Magnet Factory.

The strategic distribution of NICA Control rooms is observable across various buildings within the complex, with each control room playing a pivotal role in the monitoring and regulation of specific operational aspects. In subsequent discussions, we will delve into a comprehensive exploration of the roles and responsibilities of the various operators within the NICA complex, as well as the specific locations of these control rooms.

It is noteworthy that all NICA operators are centrally monitored from the main control room, serving as a central hub for overseeing and coordinating the complex's multifaceted operations.

2.1 Workforce Composition at NICA

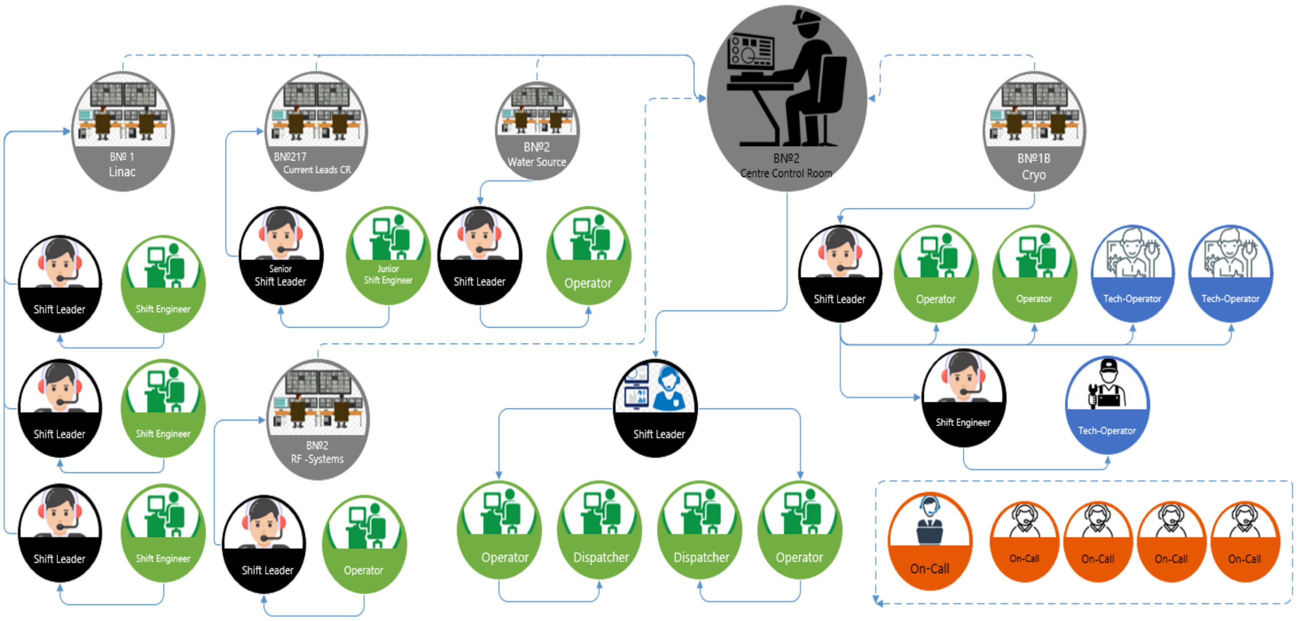

Figure 4: Organization of staff in NICA control rooms.

The composition of the workforce at the Nuclotron-based Ion Collider fAcility (NICA) is characterized by diversity and specialization, reflecting the complex and multifaceted nature of NICA and the essential roles played by each component in its overall functionality. The distribution of personnel across various control rooms and the presence of an On-Call team are critical to ensuring the efficient operation and maintenance of the complex. Below is a breakdown of the workforce composition based on the provided information:

1. **Building №2 Central Control Room:** This central hub is staffed with 1 Shift Leader, 2 operators, and 2 dispatchers.
2. **Building №1 Linear Accelerator & HILAC & LU-20 Control Room: This** control room has 2 operators responsible for operating the Linear Accelerator, Heavy Ion Linear Accelerator (HILAC), and LU-20.
3. **Building №2 WATER Source Control Room:** This control room is equipped with 2 operators dedicated to managing the water source, which is essential for cooling and thermal regulation throughout the complex.
4. **Building №1A Main Power Supplies Control Room:** This control room, with 2 operators, oversees the critical task of managing the main power supplies.

5. **Building №2** RF-System Control Room: This control room, staffed with 2 operators, is responsible for managing the Radio Frequency (RF) system, a pivotal element in maintaining precise particle acceleration.
6. **Building №217** Current Leads Control Room: This control room, which has 2 operators, focuses on managing current leads, which are crucial for controlling electrical currents within the complex.
7. **Building №1B Cryogenics Control Room:** This control room requires an extensive team of 7 operators due to the complexity and significance of the cryogenics system.
8. **On-Call Team:** The On-Call team comprises multiple skilled operators who remain available to address unforeseen situations or emergencies within the NICA complex.

In summary, the workforce composition at the NICA complex is specifically tailored to meet the precise requirements of each component, highlighting the significance of expertise and coordination in ensuring the seamless operation of this scientific facility.

2.2 Operator Training Procedures at NICA

The training protocols for operators within the NICA (Nuclotron-based Ion Collider fAcility) complex are of paramount importance in ensuring a capable and safe workforce. Each operator undergoes a meticulously structured training regimen, employing a diverse range of pedagogical methods. Given the complex's diverse control rooms, each is associated with distinct training protocols. Training encompasses a comprehensive array of resources, including informative materials, which enable operators to acquire essential knowledge. Subsequently, during their operational shifts, a seasoned operator acquaints the trainee with job requirements and safety procedures through a hands-on mentoring period that spans a predetermined duration. Following this mentorship, trainees are subject to a rigorous examination, typically comprising approximately 20 or more questions. The primary objective of this examination is to assess the trainee's preparedness for assuming operational responsibilities.

Moreover, a structured system for periodic evaluation is firmly established. Operators are subjected to an annual examination, administered by their respective shift supervisors, thus ensuring the perpetual competence of the workforce. This continuous training and assessment framework guarantees that operators remain proficient and up-to-date in their roles, ultimately contributing to the secure and efficient operation of the NICA complex.

In summary, the training process at NICA relies on three fundamental components:

- Lectures;
- Manuals;
- Annual examinations.

2.3 Work Environment Analysis in NICA

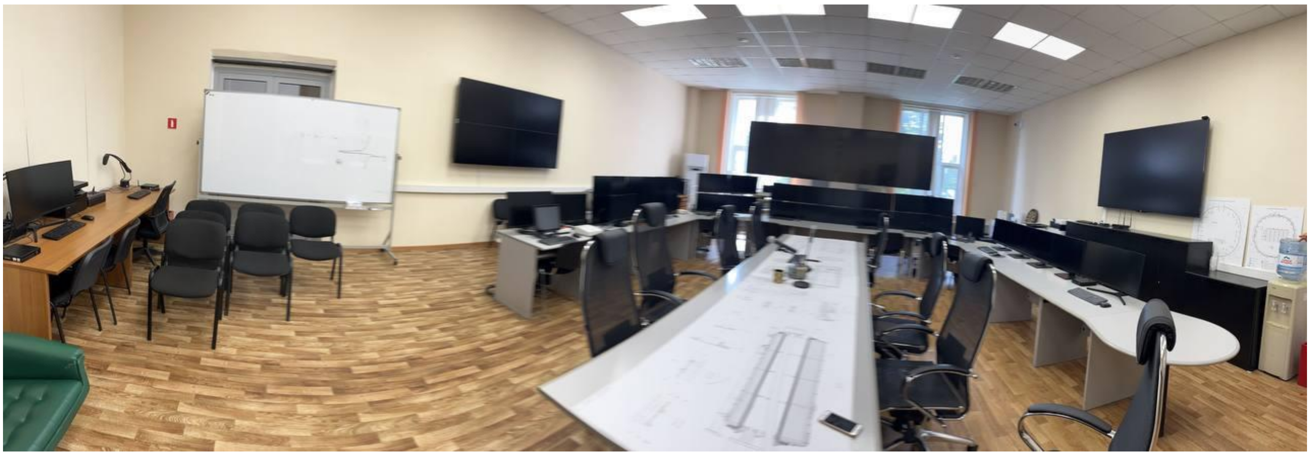

Fig 1. The NICA Centre Control Room.

Building Layout and Infrastructure

The work environment within the NICA (Nuclotron-based Ion Collider fAcility) complex is distinguished by a multitude of specialized control rooms, each tailored to fulfill precise operational requisites. While comprehensive coverage of all aspects of this environment proves challenging, a general examination underscores that the various control rooms adhere to fundamental infrastructure standards. These standards encompass provisions for robust internet connectivity, essential services, and adequate computer facilities.

The spatial allocation for these control rooms typically spans an area ranging from approximately 5 to 25 square meters, affording ample space for the deployment of requisite equipment and personnel to execute their designated tasks. However, it merits attention that select control rooms exhibit suboptimal infrastructure and ventilation systems, factors which may exert an influence on the overall quality of the work environment.

In light of these observations, this research inquiry culminates with a proposition directed towards the enhancement and establishment of a more conducive work environment within NICA. The proposed plan centers on rectifying the identified deficiencies, with particular emphasis on elevating infrastructure standards, optimizing ventilation systems, and improving the overall working conditions. This proposal is underscored by the unwavering commitment to foster an environment that fosters effective operations and perpetuates the triumph of the NICA complex.

2.4 Operator Responsibilities in Control Rooms at NICA

The NICA (Nuclotron-based Ion Collider fAcility) in Dubna, Russia, is a research facility for nuclear physics experiments, particularly focused on heavy-ion collisions. Operators at NICA have various responsibilities to ensure the safe and efficient operation of the facility and the successful execution of experiments. These responsibilities can include:

1. Accelerator Operation: Operators are responsible for controlling and monitoring the operation

of the accelerator complex, including the Nuclotron and associated systems. This involves setting up and maintaining the beam parameters, ensuring stable beam delivery to the experimental areas, and making adjustments as necessary.

2. Safety: Safety is a paramount concern in any particle accelerator facility. Operators must adhere to strict safety protocols, be aware of potential hazards, and take immediate action in case of emergencies or abnormal situations.
3. Beam Tuning: Tuning the accelerator to provide the desired beam properties, such as energy, intensity, and focus, is a critical part of the operator's role. They must use diagnostic tools to optimize beam quality for experiments.
4. Experimental Setup: Operators often work closely with researchers to prepare the experimental setup. This may involve installing and aligning detectors, target materials, and other equipment needed for specific experiments.
5. Data Acquisition: Operators may assist in the setup and monitoring of data acquisition systems, ensuring that data from experiments are collected accurately and efficiently.
6. Troubleshooting: When issues arise with accelerator components or experimental equipment, operators are responsible for troubleshooting and, if possible, resolving the problems to minimize downtime.
7. Beam Delivery: Operators ensure that the beam is delivered to the appropriate experimental areas and that beam switches and beamlines are properly configured for different experiments.
8. Maintenance and Repairs: Routine maintenance and occasional repairs of accelerator components and associated systems fall under the operator's purview. They may need to work closely with maintenance personnel to address technical issues.
9. Documentation: Accurate record-keeping and documentation of accelerator settings, beam parameters, and experimental conditions are essential for data analysis and reproducibility.
10. Communication: Operators need to maintain effective communication with researchers, engineers, and other staff to coordinate experiments and address any issues promptly.
11. Training: Training new personnel and ensuring that all staff are aware of safety protocols and operational procedures is part of the operator's role.
12. Adherence to Regulations: Operators must adhere to all relevant regulations and guidelines for the safe operation of a nuclear physics facility.

It's important to note that the specific responsibilities of operators at NICA in Dubna may vary depending on the individual's role, the experimental needs, and the facility's operational protocols. Safety and precision are of utmost importance in this kind of research environment, so operators play a crucial role in ensuring the success of experiments and the protection of personnel and equipment.

3. Conclusion

In conclusion, this report has presented a comprehensive overview of The Large Hadron Collider (LHC) at CERN and Nuclotron-based Ion Collider Facility (NICA) at JINR. The aim of this report was to provide insights into the Analysis of Organizational Structure, Workforce Configuration, Staff Training Protocol, Work Environment, Operators Responsibilities in the Control Room, and scalability considerations of both Particle Accelerator Complexes. The comparative study will delve into the similarities and differences between The Large Hadron Collider (LHC) and Nuclotron-based Ion Collider Facility (NICA), shedding light on the strengths and potential areas for improvement in both Particle Accelerator Complexes. As stated in the scope of study section, the aim is to publish the results of this comparative analysis as a future reference for researchers, engineers, and professionals in the field. The anticipated publication will contribute to the wider understanding of Particle Accelerator Complexes: The Large Hadron Collider (LHC) and Nuclotron-based Ion Collider Facility (NICA) and investigating the management and regulation of control mechanisms within the workplace, along with an examination of the environmental factors that influence it, and proposing strategies for its optimization to align with the ideal conditions for the workforce.

In summary, this report serves as a preliminary step in an ongoing comparative research study. It has established a foundational framework by presenting the data that has been collected thus far and emphasizing the importance of forthcoming analyses. The eventual publication arising from this research endeavor is anticipated to constitute a valuable resource for the scientific community. It will contribute to the progression of the working environment at two prominent particle physics facilities, namely, the Large Hadron Collider (LHC) at CERN and the Nuclotron-based Ion Collider Facility (NICA) at JINR.

Acknowledgment

I deeply appreciate the Veksler and Baldin Laboratory of High Energy Physics at JINR for granting me the invaluable opportunity to intern in Summer 2023. Immersing myself in this dynamic research environment has been a privilege. I extend heartfelt thanks to Mr. Nikita Baldin for his exceptional guidance, mentorship, and unwavering support throughout my internship. His insights, expertise, and dedication have significantly enriched my learning and personal growth. I'm grateful to the laboratory team for their warm reception, knowledge sharing, and collaborative spirit. Exposure to cutting-edge research and immersion in the academic community enhanced my understanding of high-energy physics.

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