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Enhancing Safety Systems on The CS-30 Cyclotron with A PLC-Based Controller

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ABSTRACT

Integration of advanced technologies such as Programmable Logic Controllers (PLC) in particle accelerator safety systems has proven to enhance operational reliability and efficiency in complex environments. Numerous projects have successfully implemented these solutions to ensure operational safety and stability, making facilities more adaptive to scientific and medical needs. A Programmable Logic Controller (PLC) based controller has been implemented on the safety system of CS-30 cyclotron. The PLC with an LCD touch screen interface providing reliability and ease of operation replaced the old control system that relied on logic gates and relay-based interlock systems. The main controller located in the cyclotron control room manages four radiation zones: cyclotron cave, physics cave, solid target cave and Positron Emission Tomography (PET) cave. Each zone has a cave control unit, an area radiation monitor, door sign lights and horns. In order to protect personnel from radiation and electrical hazards, the PLC was programmed to implement four stages of access: permitted, controlled, restricted and no access. As a result, this safety system has effectively replaced the old system and can be applied to other similar facilities.

1. Introduction

Cyclotrons are now widely used in nuclear medicine for producing medical radionuclides [1,2,3]. As particle accelerators, cyclotrons can produce harmful radiation levels, persisting even after the cyclotron has ceased operation [4]. The National Research and Innovation Agency of Indonesia (BRIN) has operated a CS-30 cyclotron facility since 1991. The CS-30 cyclotron facility features four radiation zones: the cyclotron cave, physics cave, solid target cave, and PET cave, with the latter three serving as target areas for the cyclotron. Due to safety concerns, a systematic safety process is essential to ensure human safety and provide adequate flexibility for research activities [5,6]. The safety system is designed to protect personnel from both radiation and electrical hazards by managing access to the four radiation areas and ensuring that no one is present during cyclotron operation.

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Growing of electronics technology has revolutionized various fields such as nuclear medicine, increasing capabilities in advanced control and instrumentation [7,8]. Programmable Logic Controllers (PLCs) have become indispensable in this area, providing flexible and reliable automation for complex processes [9,10]. Numerous cyclotron facilities have adopted safety systems based on Programmable Logic Controllers (PLCs) to significantly enhance overall system efficiency and optimization. The integration of PLCs into the control systems of cyclotrons brings considerable advantages due to their robustness, versatility, and capability to handle complex real-time operations. PLCs offer reliable automation control by incorporating essential software and hardware interfaces that ensure precise and secure operation of the cyclotron [11]. In addition, when integrated with Supervisory Control and Data Acquisition (SCADA) systems, PLCs facilitate effective real-time monitoring, control, and data logging. This integration not only substantially improves system performance but also simplifies maintenance processes, thereby guaranteeing the cyclotron's operational excellence and reliability [14]. The comprehensive benefits of PLCs make them indispensable for achieving the high standards required in modern cyclotron facilities.

Moreover, the development of Programmable Logic Controllers (PLCs for the 10 MeV cyclotron, designed specifically for radioisotope production, underscores their remarkable performance capabilities [15]. These PLCs are adept at managing complex real-time operations, ensuring precise control and meticulous monitoring of critical subsystems such as cooling, vacuum, magnet, radio frequency, and ion source systems. By seamlessly integrating with host computers, these PLCs significantly enhance the overall functionality and reliability of the system [15]. The inherent modularity and scalability of PLCs make them an ideal choice for constructing a robust and reliable operation primarily depending on the effectiveness of the local controller system for the cyclotron [16]. This ensures that the system can meet the rigorous demands and stringent requirements of modern scientific applications, maintaining high standards of performance and safety.

The control system exhibits unique characteristics, meticulously tailored to address the specific needs of each facility. To enhance PLC-based safety systems, it is advantageous to analyze existing control systems specifically engineered to bolster safety mechanisms. For example, the control system developed for the Selective Production of Exotic Species (SPES) project was designed with a high degree of precision to ensure both high reliability and safety, which are critical for the operation of nuclear facilities. By selecting a robust and dependable PLC and implementing both "fail-safe" and "fault-tolerant" configurations, the system can maintain continuous operation even under fault conditions, thereby minimizing downtime and enhancing safety. The integration of EPICS (Experimental Physics and Industrial Control System) for software development, in conjunction with Open Platform Communication (OPC) technology for subsystem integration, ensures the creation of a cohesive and extensible control network. This allows for efficient communication and control across various subsystems, enhancing the overall reliability and functionality of the control system. Furthermore, modern monitoring tools such as Control System Studio (CSS) and LabView were utilized during the development process to evaluate long-term usability and performance [17]. This comprehensive design approach guarantees that the Selective Production of Exotic Species (SPES) control system is well-equipped to meet stringent safety requirements while maintaining superior performance standards over extended periods.

Additionally, the design and development of the PLC system for the Personnel Safety System (PSS) at Ion Therapy Center (HIT) signifies a remarkable advancement in ensuring comprehensive safety measures [18]. This system plays a pivotal role in radiation protection, access control management, emergency stop handling, protection area monitoring, and the implementation of safety interlocks. The PSS utilizes a Hima "HiMatrix" secure PLC, which is enhanced by decentralized I/O modules and relay output modules, all connected via a secure Ethernet bus to ensure efficient and reliable data transmission. Access control is meticulously managed by the Primion system, which employs RFID cards to regulate entry and exit. Simultaneously, radiation levels are continuously and precisely monitored by a Berthold Technologies dose rate monitor. The integration of sophisticated software and an intuitive graphical user interface (GUI) enables effective real-time monitoring and control of the entire system. Since its inception, the PSS has demonstrated exceptional reliability, maintaining a failure rate of less than 1%. This outstanding reliability ensures the consistent safety and protection of both personnel and patients at the HIT Center, highlighting the system's robustness, efficiency, and overall effectiveness in maintaining high safety standards [18].

Meanwhile, A highly sophisticated PLC-based control system has been developed for a 10 MeV cyclotron [15]. This state-of-the-art system seamlessly integrates and manages critical subsystems, including cooling, vacuum, magnet, RF, and ion source systems. By employing the Portal Totally Integrated Automation (TIA) software along with a comprehensive Human-Machine Interface (HMI), the system guarantees real-time control, data acquisition, and precise monitoring. Noteworthy features such as data logging, alarm systems, and remote access capabilities significantly enhance the overall efficiency and safety of the system [11]. Consequently, this PLC-based control system meets stringent performance standards, providing a reliable and highly efficient solution for the cyclotron's operation [16].

The PLC-based control system at VECC's medical cyclotron facility in Kolkata exemplifies a state-of-the-art safety solution. Utilizing the Siemens S7, it incorporates essential safety features such as redundant inputs and outputs, neutron shutters, shield door interlocks, and radiation monitors to safeguard against neutron and gamma radiation while maintaining air quality. Critical protocols, including the search and secure procedure and emergency crash-off buttons, ensure personnel safety during emergencies. The intuitive graphical user interface (GUI) facilitates real-time monitoring and control [19]. Designed with future scalability in mind, this advanced automation system guarantees safe, efficient, and secure operations within a complex scientific environment.

Programmable Logic Controller (PLC) integration has also been implemented on the CIAE-30 cyclotron, resulting in a substantial enhancement of its performance and operational efficiency. By efficiently coordinating various components, managing sequence control, fine-tuning operational parameters, and the PLC system ensures reliable operation. The hardware, consisting of three CPUs, analog and logical I/O modules, and a comprehensive operations console, works in tandem to provide redundancy and centralized control. The software, developed using the STEP-5 language, simplifies development and maintenance, with each CPU handling specific functions to prevent bottlenecks and distribute loads efficiently. This robust architecture supports full automation for routine tasks and semi-automation for maintenance, facilitating troubleshooting and reducing downtime [20]. Moreover, the PLC-based vacuum control and interlock system also was implemented in the CYCIAE-230 cyclotron, with ongoing enhancements to improve beam control, allowing better proton beam adjustment for treatment [21].

In this project, a Programmable Logic Controller (PLC)-based control system was implemented to replace the previous controller of the safety system. The old control system relied on logic gates or Transistor-Transistor Logic (TTL) combined with relay-based interlock systems. This older approach had several notable disadvantages. Firstly, the architecture of the control system was fixed due to its hardware design, making it inflexible. Secondly, the overall hardware size was quite large, which was not efficient for modern applications. Moreover, the use of mechanical relays in the old system presented a significant drawback, as their performance was heavily influenced by operating time. In modern industries, PLC play a crucial role in managing system functions to ensure they perform in line with specified requirements [22]. The new system offers several advantages. Through PLC programming, the control system design can be configured and modified without the need for hardware replacement, offering much greater flexibility. Additionally, the PLC system is a rugged industrial device, ensuring high reliability and durability in operation. The combination of these features makes the PLC-based control system a far superior choice compared to the older system, overcoming its limitations and significantly improving overall performance and efficiency.

2. Methodology

This paper presents the development of a PLC-based controller designed to improve the safety system of the CS-30 cyclotron. A multifaceted approach by several *authors* [5,19], combining comprehensive hazard and risk assessment, rigorous testing and simulation, and stringent validation and verification, has been shown to optimize safety and operational efficiency. Seamless integration with existing systems is a key consideration to ensure reliable performance in complex research environments. The use of this method offers a flexible, scalable, and economically viable alternative to traditional relay-based systems, thereby improving safety standards and operational effectiveness in particle accelerator facilities.

This research determined that the appropriate method to improve the safety system on the CS-30 cyclotron with a PLC-based controller is to implement it in each area of the cyclotron, as each area requires a unique set of safety components, which include an area radiation monitor, a cave control unit, door sign lights, and horns. The area radiation monitor is essential for monitoring radiation levels within the cave. The cave control unit is responsible for managing the operation of the safety system within its respective cave. The door sign lights, installed at the entrance of each cave, provide real-time information about the cave's status and the operating conditions of the cyclotron. The horns are used to emit a loud sound, signaling the process of closing the door. In general, a block diagram of the CS-30 cyclotron safety system is illustrated in Figure 1.

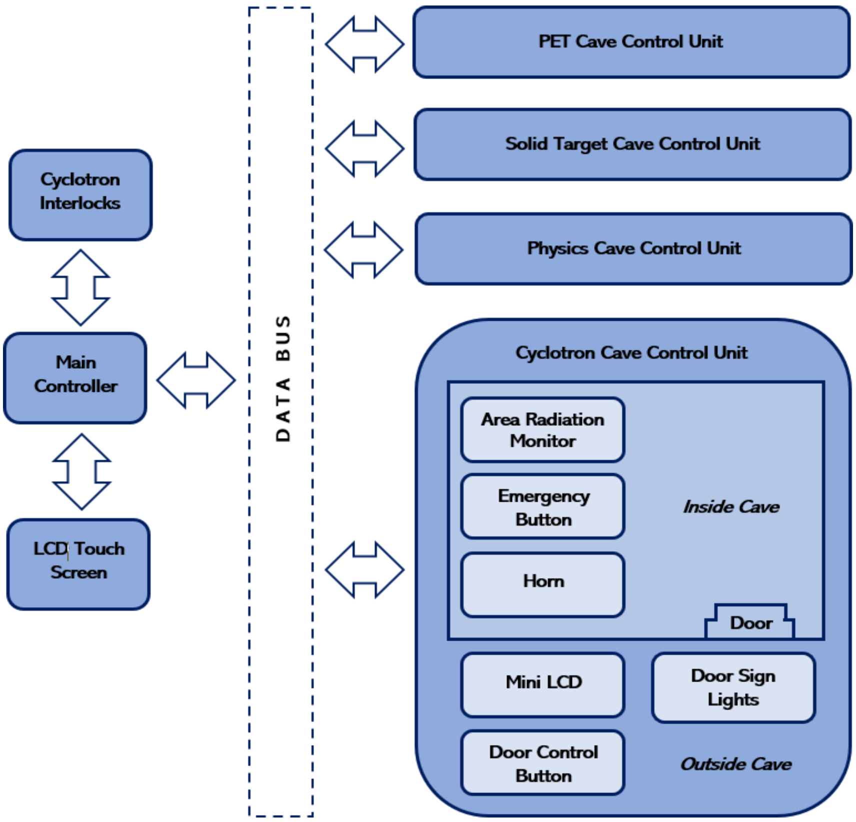

Fig. 1. Block diagram of the safety system of CS-30 cyclotron

2.1 Cave Contol Unit

Cave control units comprise emergency buttons, door control buttons, a mini-LCD, and door sign lights, as shown in Figure 2(a). Emergency buttons are used in critical situations, such as when personnel are trapped in the cave. Pressing this button immediately halts cyclotron operation, shuts down the system, and automatically opens the cave door for evacuation

The door control buttons are used to manually close and open the cave door. To open the cave door, an access key must be obtained from the main controller of the safety system located in the cyclotron control room, and then press the open button on the cave door. For closing the cave door, personnel must press a button on a watchman station before pressing the close button on the door control. The watchman station is strategically designed and positioned inside the cave to allow personnel to inspect the cave's conditions. For safety purposes, pressing the button on the watchman station activates a timer that sets a time limit for closing the door using the cave door control button. The LCD display on the cave control unit provides real-time information about the cave's conditions, ensuring personnel are well-informed of the environment within the cave.

Each cave door has door sign lights indicating information about the cyclotron operation and cave conditions. The information displayed includes:

- cyclotron is operating (beam on),
- cave with high radiation level,
- cave with low radiation level,
- cave in emergency condition,
- cave in restricted access condition,
- and the interlock function in the safety system has been bypassed.

Through these indicators, the operator gets sufficient information about the condition of the cyclotron before taking action in the cave.

(a) The cave control unit is at the front of each cave

(b) Area radiation monitor for all caves

Fig. 2. (a) Cave control unit located at the front of each cave (b) Area radiation monitor for all caves

2.2 Area Radiation Monitor

Model 375 Digital Area Monitors by Ludlum Measurement Inc. (7) were employed, with detectors strategically positioned in each cyclotron cave [12]. These monitors transmitted real-time radiation level data to the control room, as shown in Figure 2(b). Primarily designed to protect personnel from radiation hazards, the area radiation monitors operated when the cyclotron was inactive. A beam spill monitor measured radiation levels during cyclotron operation. If post-operation radiation levels remained dangerously high, the area radiation monitor signaled the safety system to restrict cave access, preventing personnel entry until conditions were safe.

2.3 Main Controller of Safety System

A Siemens S7-200 PLC was employed to develop the control system for aligning well with the design requirements of the control system, offering a balance of simplicity and effectiveness in managing the various inputs and outputs of the safety system [13]. The controller processes data to and from each cave of the cyclotron in real time, ensuring accurate and timely responses to any safety concerns. By utilizing the Siemens S7-200 PLC, the safety system can reliably handle the complex interactions and operations necessary to maintain a safe environment for personnel working with or around the cyclotron.

In addition, the PLC is integrated with the interlock system of the cyclotron machine. In the event of an emergency, the PLC sends a signal to the interlock system to immediately halt cyclotron operation. This action results in the shutdown of both the ion source subsystem and the Radio Frequency (RF) subsystem of the cyclotron. Without the operation of these two critical systems, the cyclotron ceases to produce a beam.

Fig. 3. Main controller of the safety system using the S7-200 PLC

2.4 Interclock System

The PLC in the cyclotron interlock system is programmed to detect various critical inputs and emergency conditions through switches and sensors. For example, when an emergency button is pressed, the PLC triggers the ion source and RF system to shut down immediately, stopping irradiation process. The PLC also manages a hierarchical access system with levels such as "no access" (doors locked, cyclotron operational) and "permitted access" (operations stopped for safety) which will be explained in more detail in the next section. Additionally, the PLC is integrated with a touchscreen interface that provides real-time visualization of the cyclotron's operating conditions and the interlock status in each zone, enabling a quick and safe shutdown to protect personnel from radiation and electrical hazards.

2.5 LCD Touch Screen Interface

Unlike the previous button-based control system, the new system employs a user-friendly interface with an LCD touch screen, specifically the Simatic Panel TP-177 Micro type. This LCD is designed with several control pages dedicated to different areas, including the cyclotron cave, physics cave, solid target cave, and PET cave. The LCD touch screen provides real-time visualization of the input and output conditions of the PLC. For instance, on the cyclotron cave page, the LCD displays critical information such as the status of the cave door and the radiation levels within the cave. This advanced interface significantly enhances the usability and efficiency of the control system. An illustration of the control page display on the LCD interface is presented in Figure 4 :

Fig. 4. LCD touchscreen for the safety system interface

3. Results

The primary function of the CS-30 cyclotron safety system is to safeguard personnel from radiation hazards and electrical hazards. The PLC-based program categorizes access to the cyclotron into four distinct stages:

- No access: All cave doors are completely closed, prohibiting entry. In this stage, the cyclotron can operate and generate beam current. Additionally, the ion source system, the RF system, and other systems with electrical hazards are permitted to function.
- Restricted access: Entry is limited to experienced personnel with authorized access keys. Electrical systems may operate, but beam current generation and simultaneous operation of ion source and RF systems are prohibited.

- Controlled access: Personnel are allowed limited and controlled entry to the cave. During this stage, ion source, RF, and other electrically hazardous systems remain inactive, safeguarding personnel from potential risks while allowing for essential maintenance tasks.
- Permitted access: Personnel are allowed to enter the cave without any restrictions. Cyclotron operation and all electrical systems are interlocked and disabled.

This hierarchical access ensure a structured and safe interaction with the cyclotron, providing a systematic approach of access levels while mitigating potential hazards associated with its operation, as illustrated in Figure 5 :

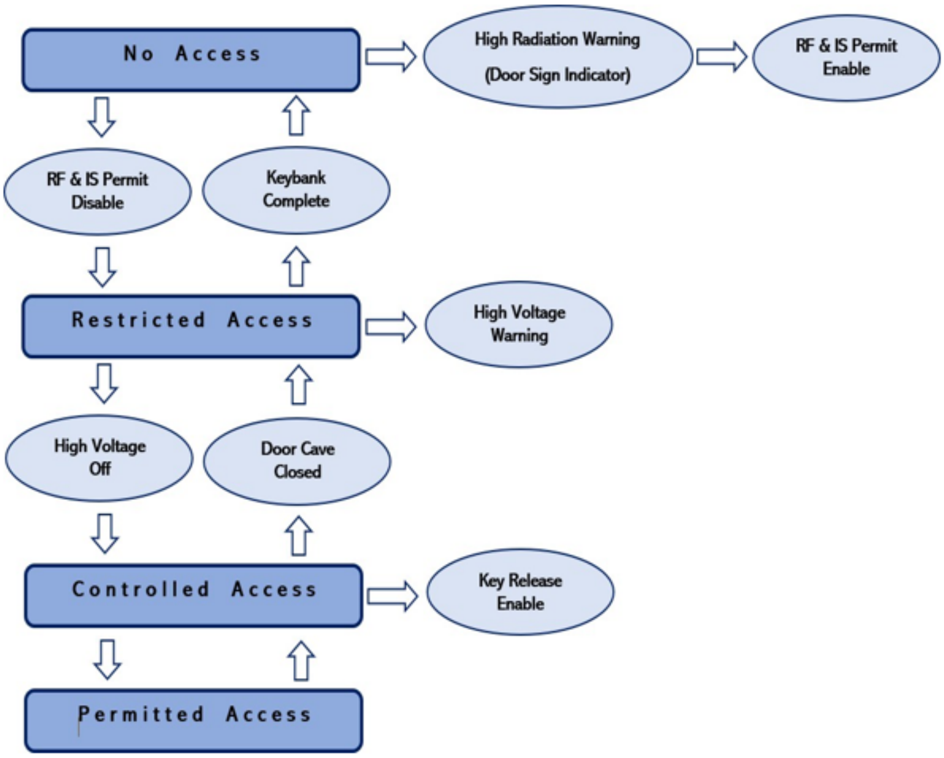

Fig. 5. Access stage diagram of the safety system of the CS-30 cyclotron

PLC programming employed a graphical interface that interconnected basic hardware function blocks to implement control logic. This approach facilitated flexible design modification without hardware alterations. Consequently, the existing design elements can be reused, accelerating development and reducing costs. Moreover, the ability to reuse well-tested design components enhances the overall reliability of the system, as it leverages established solutions and minimizes the risk of introducing new errors. This methodology not only streamlines the development process but also ensures a higher degree of consistency and dependability in the control system's performance.

The PLC-based control system operates by integrating several key components, including detectors, sensors, and emergency detection systems, which initially send data to the data collection unit. This unit is responsible for gathering the information and then forwarding it to the PLC control system. The PLC functions as the central controller, managing the interaction with the actuation and interlock systems to regulate operational processes and ensure safety. Additionally, the human interface allows operators to monitor and control the system directly, ensuring effective control and a quick response to potential hazards or emergencies. This process is illustrated in Figure 6 :

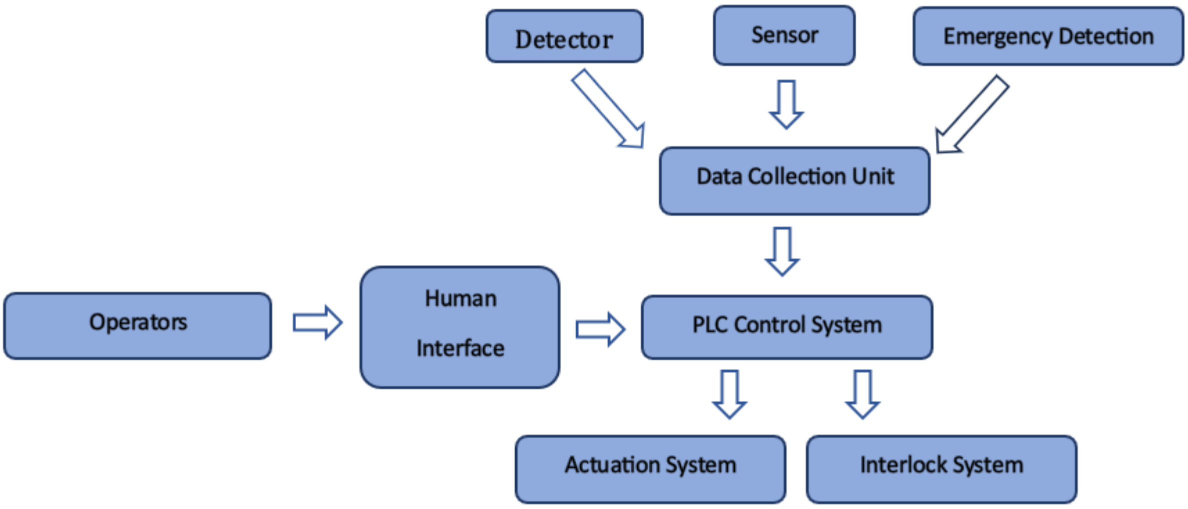

Fig. 6. The process of data control uses a PLC system.

4. Conclusions

The CS-30 cyclotron safety system has been successfully developed using a controller based on the Siemens PLC S7-200, paired with a TP-177 Micro LCD touch screen interface. The system is designed to provide a tiered access control structure for the cyclotron: comprising permitted, controlled, restricted, and no access stages. These access stages systematically ensure safe interactions for personnel, protecting them against radiation hazards and electrical hazards resulting from cyclotron operation. The comprehensive design effectively mitigates risks associated with cyclotron operation. The system's demonstrated reliability and effectiveness suggest its potential adaptability to other cyclotron or accelerator facilities.

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References
[1] International Atomic Energy Agency. "*Cyclotron Produced Radionuclides: Physical Characteristics and Production Methods.*"TRS-468. Vienna: IAEA, 2009.
[2] Synowiecki, Mateusz Adam, Lars Rutger Perk, and J. Frank W. Nijsen. "Production of Novel Diagnostic Radionuclides in Small Medical Cyclotrons." *EJNMMI Radiopharmacy and Chemistry 3*, no. 1 (February 20, 2018). https://doi.org/10.1186/s41181-018-0038-z.
[3] Kambali, Imam, Rajiman Rajiman, Parwanto Parwanto, Marlina Marlina, Kardinah Kardinah, Nur Huda, Ferdi Dwi Listiawadi, *et al*. "Spectral Analysis of Proton-Irradiated Natural MoO3 Relevant for Technetium-99m Radionuclide Production." *Journal of Mathematical and Fundamental Sciences 52*, no. 2 (September 6, 2020): 222. https://doi.org/10.5614/j.math.fund.sci.2020.52.2.6.
[4] Otto, T. *Particle Acceleration and Detection: Safety for Particle Accelerators.* Cham: Springer International Publishing, 2020. https://doi.org/10.1007/978-3-030-57031-6.
[5] Zhang, H., and E. Matias. "Development of an Accelerator Safety System Using IEC 61508 and Design Pattern." In *Proceedings of The Eighth International Conference on Systems, Canadian Light Source Inc.*, University of Saskatchewan, Saskatoon, Canada, 2013: 117-122.
[6] Moutinho, L. M., Castro, I. F. C., Peralta, L., Abreu, M. C., & Veloso, J. F. C. A. "Brachytherapy dosimeter with silicon photomultipliers." *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* (2015): 358–360. https://doi.org/10.1016/j. nima.2015.01.072

[7] Heranudin, & Bakhri, S. “A preliminary design of application of wireless identification and sensing platform on external beam radiotherapy.” *Journal of Physics: Conference Series 962* (2018): 012060,. https://doi.org/10.1088/1742-6596/962/1/012060
[8] Alrumayan, F., M. Shawoo, and M. Vora. "Status Report of the Cyclotrons C-30, CS-30 and RDS-111 at KFSHRC, Saudi Arabia." In *Proceedings of Cyclotrons 2013*, Vancouver, BC, Canada, 2013.
[9] Risler, R., S. Banerian, R. C. Emery, I. Kalet, G. E. Laramore, and D. Reid. "Recent Improvements and Operational Status of the Seattle Clinical Cyclotron Facility." In *Proceedings of Cyclotrons and Their Applications 2007,* Eighteenth International Conference, University of Washington Medical Center, Seattle, WA, USA, 2007.
[10] C. Liu, J., J. S. Bull, J. Drozdoff, R. May, and V. Vylet. “Radiation Safety Systems for Accelerator Facilities.” *Radiation Protection Dosimetry* 96, no. 4 (August 1, 2001): 429–39. https://doi.org/10.1093/oxfordjournals.rpd.a006630.
[11] Mouat, M. M., I. A. Aguilar, E. Klassen, K. S. Lee, J. J. Pon, T. M. Tateyama, and P. J. Yogendran. "Upgrade of TRIUMF's 2C STF Control System." In *Proceedings of EPAC 2006*, Edinburgh, Scotland, 2006.
[12] Ludlum Measurements Inc. *Manual of LUDLUM Models 375*. Texas: Ludlum, 2009.
[13] Siemens AG. *S7-200 Programmable Controller System Manual*. Nuernberg: Siemens, 2008.
[14] Abdorrahman, A., S. Malakzade, H. Afarideh, G. R. Aslani, A. Afshar, M. Ghergherehchi, and J. S. Chai. "Control System of 10-MeV Baby Cyclotron." In *Proceedings of Cyclotrons 2013*, Vancouver, BC, Canada, 2013.
[15] Hassani, M., S. Y. Ghorashinejad, and H. Afarideh. "Development of Control System for 10 MeV Cyclotron." In *Proceedings of Cyclotrons 2016*, Zurich, Switzerland, 2016.
[16] Kim, Huisu, Jongchul Lee, Mitra Ghergherehchi, Sangchul Mun, Ho Namgoong, Donghyub Ha, and Jong-Seo Chai. "PLC Control System for Vacuum and 20 kW RF Amplifier." *Proceedings of Cyclotrons 2016*, Zurich, Switzerland, 2016.
[17] Bassato, G., A. Andrighetto, L. Costa, M. Giacchini, Minglong Li, G. Prete, and J. Vásquez. "Safety Requirements in SPES Control System: Preliminary Design." In *Proceedings of ICALEPCS 2009*, Kobe, Japan, 2009.
[18] Scheloske, S., S. Hanke, J. Mosthaf, T. Knoch. "Overview of the Personnel Safety System at the Heidelberg Ion Therapy Facility." In *Proceedings of PCaPAC08*, Ljubljana, Slovenia, 2008.
[19] Pathak, Sabyasachi, Suprakash Roy, Umashankar Panda, Aditya Mandal, Barun Das, and Sumit Som. "Safety Control System for Medical Cyclotron Facility, Kolkata." *Conference paper, InPAC2019*, Variable Energy Cyclotron Centre, Kolkata, India, November (2019).
[20] Li, Zhenguo. "PLC Application in the Control of CIAE-30 Cyclotron." In *Proceedings of an unspecified conference*. China Institute of Atomic Energy, Beijing, China, 1998.
[21] Hu, Mingzhi, Xiaofeng Zhu, Jingyuan Liu, Hongru Cai, Zhiguo Yin, Tianjue Zhang, Ping Liu, Yang Wang, Bohan Zhao, Shangmeng Jiang, Aolai He, Qiqi Song, Fangdi Yang, and Tianyi Jiang. "PLC Based Vacuum Control and Interlock System of the CYCIAE-230 Superconducting Cyclotron Beam Line." In *Proceedings of Cyclotrons 2022, 23rd International Conference*, Beijing, China, 2022. https://doi.org/10.18429/JACoW-CYCLOTRONS2022-MOPO008.
[22] Chuvanich, Suvalee. "A Low-Cost Automatic Tester of PLC Functions." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 51, no. 1 (2024): 52-69. https://doi.org/10.37934/araset.51.1.5269.