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Development of Smart Safety System for Nuclear Reactor Application

Shahril Mohd Shah[1], Muhammad Aizat Mohd Arifin[1*], Tan Kai Yong[1], Abdul Ammar Shahrom[1], Khairul Huda Yusof[1], Nurul 'Ain Amirrudin[1], Norazliani Md. Sapari[2] , Mohd Sabri Minhat[3]

[1] *Faculty of Information Sciences & Engineering, Management and Science University, Shah Alam, 40100, MALAYSIA*
[2] *School of Electrical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bharu, 81300, MALAYSIA*
[3] *Agensi Nuklear Malaysia (Nuklear Malaysia), 43000 Kajang, Selangor, MALAYSIA*

*Corresponding Author: aizat.zurich@gmail.com
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Abstract

Safety doors in a nuclear reactor play a vital role in containing radiation, controlling reactor operations, and preventing the release of radioactive materials into the environment. This paper introduces a safety door interlock system designed to minimize radiation and pressure leaks from the reactor hall. When the reactor hall's pressure becomes negative, limit switches on the doors automatically close due to the natural pressure difference between the areas. These limit switches serve as input signals for an Arduino UNO, which, upon activation, triggers outdoor indicator lights to alert personnel that all doors are closed during reactor operation. The current reactor door uses a seal method where the door is only sealed to prevent radiation from leaking outside. Our proposed cost-effective safety interlock system utilizes Arduino UNO, door-attached limit switches, and outdoor indicator lights to ensure the safety of nuclear hall and environment. Additionally, a Wi-Fi module extends the system's mobility for remote monitoring of the reactor and environmental conditions. This paper also introduces a radiation monitoring system for Cherenkov radiation, which only activates when the reactor hall achieves negative pressure, ensuring radiation containment. Data and warnings are transmitted via a Wi-Fi module to a user's phone or PC through the Blynk app. As a result, a negative pressure safety system was achieved, which can monitor the Cherenkov radiation. In conclusion, the proposed safety interlock doors are effective to maintain the safety and integrity of a nuclear reactor.

1. Introduction

The Reactor Triga Puspati, also known as RTP, is Malaysia's sole nuclear research reactor. It commenced operation in 1982 and achieved its first criticality on 28 June 1982. The acronym TRIGA stands for Training, Research, Isotope Production, and General Atomic, highlighting its versatile purposes. The pool-type reactor has a compact core consisting of solid fuel elements (enriched uranium and zirconium-hydride moderator) inside a 7-meter-tall aluminum tank, shielded by high-density concrete. It uses demineralized water as both coolant and neutron moderator, with graphite as a reflector for enhanced neutron efficiency. The reactor generates 1MW of thermal power [1]. The reactor is specially designed with versatility to facilitate extensive nuclear science research and education. It enables investigations on neutron and gamma radiation, including NAA, DNA, radioisotope production for medical, industrial, and agricultural purposes, Neutron Radiography, and SANS. The main focus of the safety management system implementation at Reactor Triga Puspati (RTP) is to ensure the safety of the reactor and its surroundings by continuously and vigilantly monitoring its operational parameters. This is essential to comply with the regulatory requirements set forth by the Atomic Energy Licensing Board (AELB) for reactor licensing, as well as the Basic Safety Standard (BSS) Radiation Protection Regulation 2010 (Act 304), the Occupational Safety and Health Act 1994 (Act 514), and other relevant national safety departments, such as the Department of Occupational Safety and Health (DOSH) [2].

The safety management system is designed to safeguard personnel, properties, and the environment during the reactor's operation. To achieve this, the major aspects emphasized at the RTP are safety equipment, a radiation monitoring system, Internal and external departments collaborate for comprehensive health, safety, and security measures, ensuring a secure environment and safe work instruction [3]. The most critical aspect of ensuring safety at irradiation facilities is the radiation monitoring system itself, as precautionary measures take precedence over mitigation. At RTP, a heterogeneous radiation monitoring system has been implemented with utmost care to minimize personnel exposure to radiation.

In this project, RTP had been compared to some other nuclear reactor safety systems built with different types of radiation monitoring system. After numerous considerations, Yogyakarta Nuclear Area (YNA) project system had been selected as a reference for comparison. Yogyakarta Nuclear Area (YNA) is one of the nuclear facilities owned by BATAN. It has many nuclear facilities such as nuclear reactors, accelerator, irradiator, and waste management system. YNA has a nuclear emergency response program and there is a preparedness system to support this program. Radiation monitoring systems are vital to acquire and record nuclear radiation exposure in the facility and its environment. YNA has developed an Internet of Thing-based radiation area monitor to improve the system, not only to acquire radiation exposure, but also to distribute the acquired data to the cloud server through the internet network. The distributed radiation data can be utilized to analyze nuclear emergence potential in the nuclear emergency response and preparedness system. The area monitor system is designed as a sensor network, consisting of Geiger Muller detector and high voltage power supply, signal conditioning system, and Arduino as counter and data processor. Data is acquired by a detector, and it is transmitted to the server through wireless network using the node of MCU communication module [4].

The YNA research is used to develop an emergency response program that analyzes a potential nuclear emergency. It is used only to monitor the radiation in the reactor hall and to predict potential emergencies so that it can prepare for any nuclear disaster. The difference of this project is a smaller scope and priority on health and welfare of the people that are involved and exposed to the nuclear radiation. The proposed radiation monitoring system is focused on the area in the nuclear hall and for every personnel directly involved in activities at the facility. The YNA research has provided a lot of information regarding data collection and warning systems that can be sent through cloud servers or internet networks. The system for radiation monitoring also can be adjusted for a smaller scale and for multiple purposes. For this project, the same method used in the YNA project was considered, which is IoT method for area radiation monitoring system. The main reason is that this method can be used for many applications such as data gathering and warning systems, as particularly aimed in this project.

In conclusion, this project is a commitment to improve the RTP current reactor safety and monitoring system into a better system that can minimize personnel exposure and help contain the radiation in the reactor hall if any accident occurs.

2. Methodology

The block diagram of the proposed design, as depicted in Figure 1, illustrates the essential components and connections within this advanced system. This system had been meticulously engineered with primary focus on safety and control, making it a vital component of the nuclear reactor application. At its core, the entire system is under the precise command of an Arduino UNO microcontroller, ensuring efficient and reliable operation. In this integrated system, the Arduino UNO serves as the central intelligence – managing all input and output devices with precision and accuracy. The array of input devices includes limit switches, which are crucial for monitoring and controlling specific parameters, a color sensor to capture critical data, and a door bypass switch to manage access control seamlessly. The system's output capabilities are equally robust, with a dedicated Wi-Fi Module at its disposal. This Wi-Fi Module empowers the system with two-way communication capabilities, allowing it to send and receive crucial information. This information can be seamlessly monitored on either or both a PC and a phone, providing real-time data and control options for enhanced safety and efficiency.

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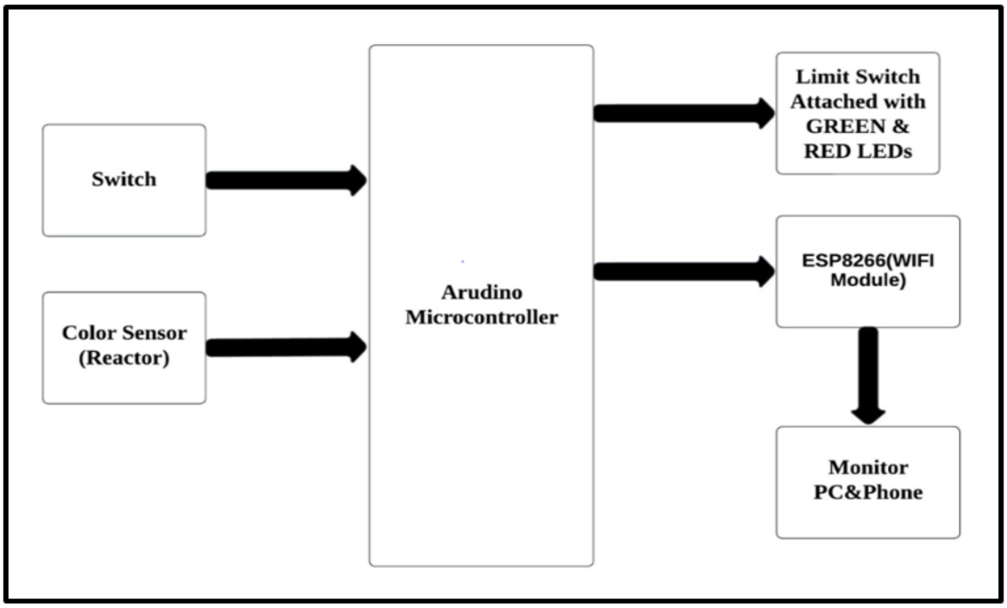

Fig. 1 *Block diagram*

As shown in Figure 2, a circuit diagram illustrating the input of the system that starts at a limit switch. The limit switch acts as a pressure sensor to determine the status of the door. The limit switch will give the signal to Arduino UNO to trigger the color sensor to turn on the blue and red light. The condition for this situation to occur is when the door is fully locked and the pressure in the room is lower than the surrounding atmospheric pressure. If there is a disturbance or error, the Arduino UNO will send a signal to the green light to turn on and the color sensor to turn off. This indicates the door is unlocked and all system in the room is turn off until the room is properly secure. After all the systems are turned on, the Wi-Fi module will activate the internet to connect with a smart phone. The blue light is monitored via the Blynk app when it connects to the Wi-Fi module. The specifications for Wi-Fi connectivity that supports the proposed system, as obtained [5], are presented in Table 1.

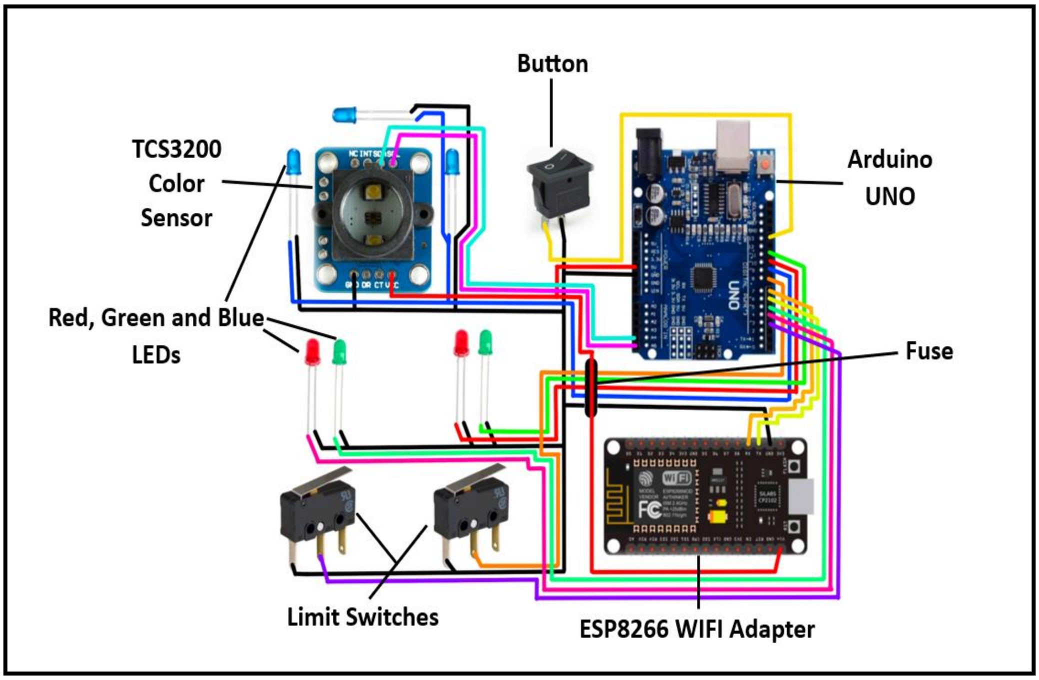

Fig. 2 *Circuit diagram for Smart Safety System for Nuclear Reactor*

Table 1 *ESP8266 Wi-Fi Module Specification*

Parameter	Specification
Microcontroller	ESP8266
Processor	TenSilica L 106
Build-in WiFi	2.4GHz supports 802.11 b/g/n
ADC Pin	1(10bit Resolution)
GIPIO	10
Operating Voltage	3.0V-3.6V
Operating Current	80mA
Operating Temperature Range	-40°C to 125°C
Wi-Fi connection distance range	Up to 1km

The illustration of the proposed project as a reactor hall are shown in Figure 3. The color sensor is in the middle of the hall that acts as a nuclear reactor. Doors were set at all sides of the reactor hall so that we could experiment with the system with a multiple limit switch.

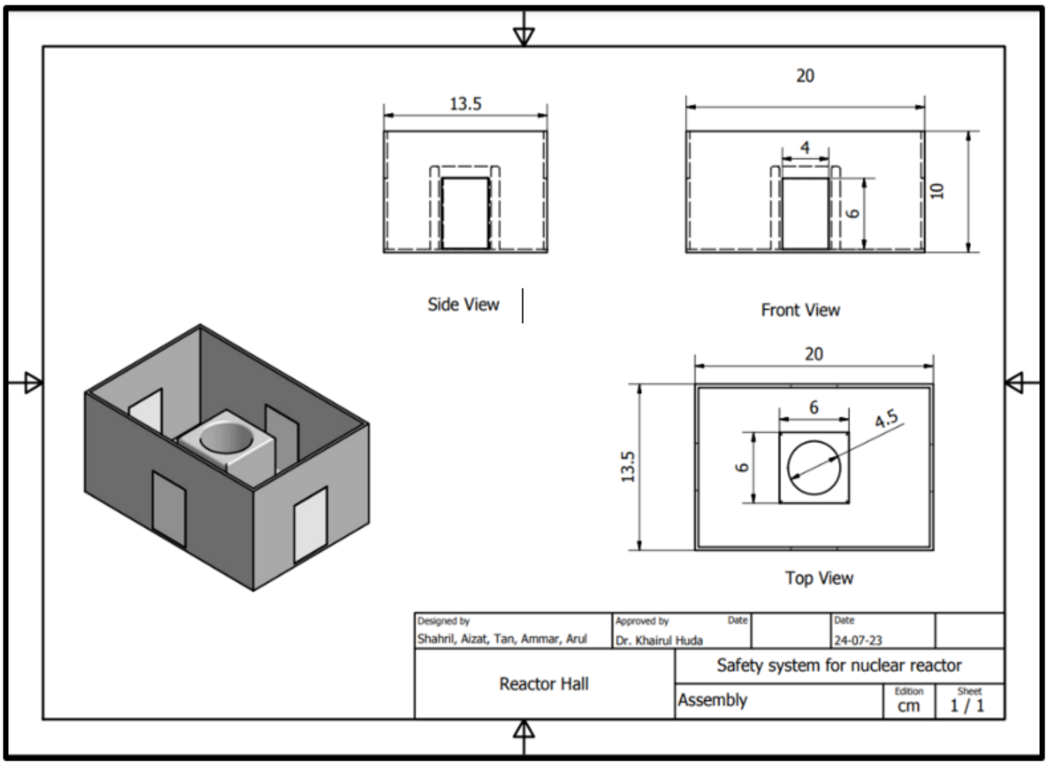

Fig. 3 *3D Proposal project illustrator*

Figure 4 presented an overview flowchart and sequence of processes within the safety system designed for nuclear reactor applications. Initially, the system checks for an optional setting, whether it is in the 'ON' or 'OFF' position. If set to 'OFF' (NO), the entire system is disabled. The second optional setting pertains to the Bypass mode. If this setting is also configured as 'OFF' (NO), the system proceeds to the pressure sensor device, which is responsible for detecting negative pressure levels below atmospheric conditions. Otherwise, if the Bypass mode is engaged, it will halt the entire system optionally. When negative pressure is detected, several actions are triggered; consequently, the reactor door is closed, the green indicator light turns off, the red indicator light illuminates, and the reactor is activated, indicated by a blue light, signaling an elevated risk level. Simultaneously, a signal is transmitted to both a designated phone and PC via a Wi-Fi extension module integrated into the Arduino UNO, alerting them about the issue. Conversely, if the pressure sensor does not detect negative pressure, the reactor door remains open, and the green indicator light continues to emit its reassuring glow.

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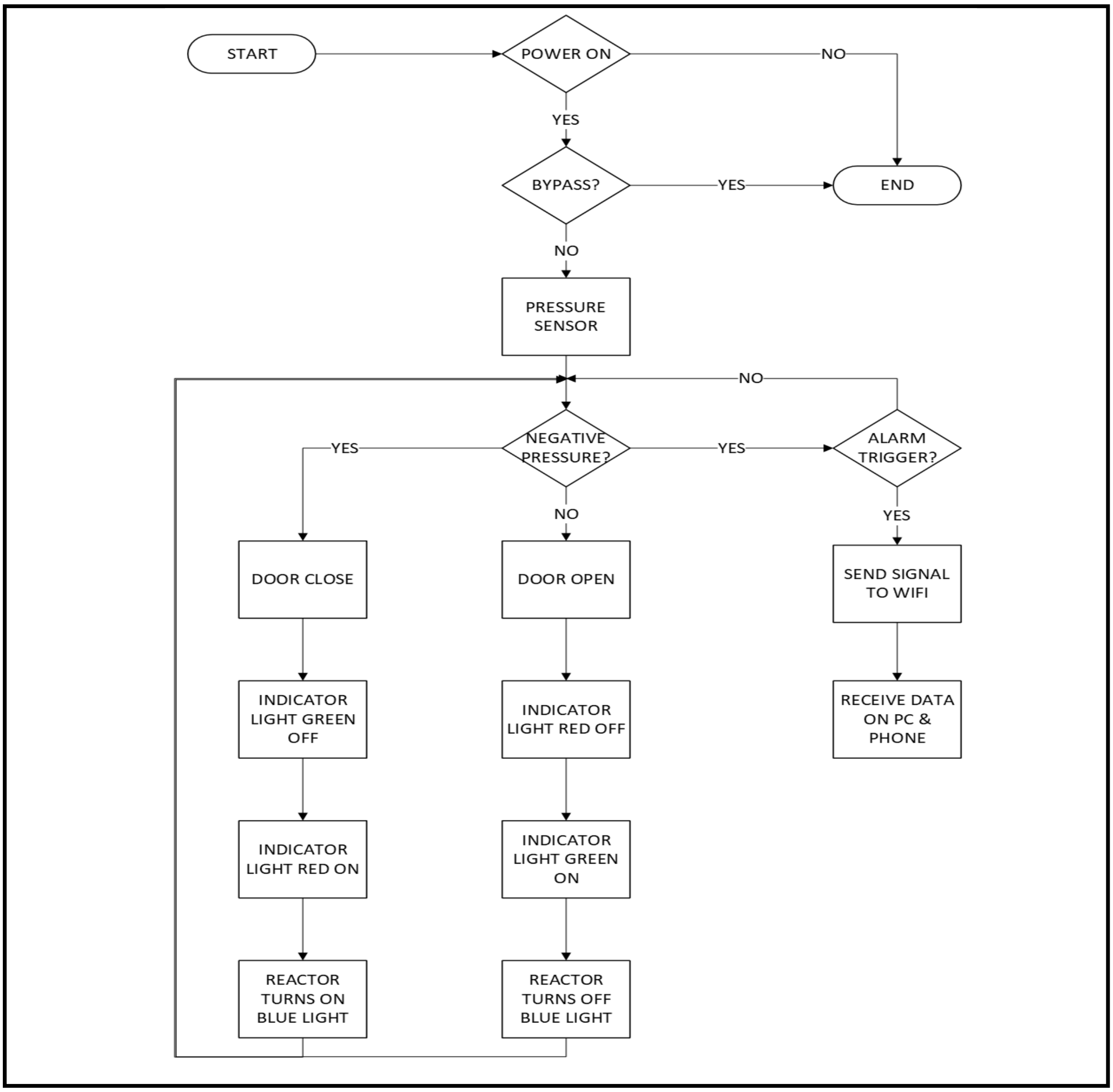
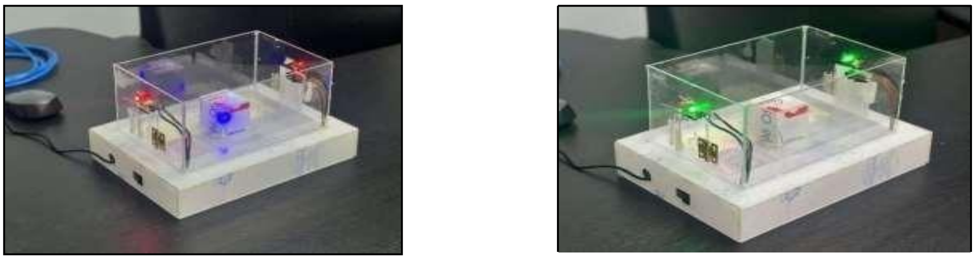


Fig.4 *Project flowchart*

3. Results and Discussion

Figure 5(a) shows the condition of the project at the start of the system for safety interlock system. This indicates that the doors are not sealed and negative pressure has not been achieved. The green light will turn on as an indicator that the room is not sealed and the reactor will not turn on. Figure 5(b) shows a room in the negative pressure state where the red light is turned on as an indicator that the room is in negative pressure. When the room is sealed, the reactor will turn on, thus emitting a blue light that acts as a Cherenkov radiation Illustrations.

Meanwhile, in Figures 5 (a) and (b) show examples of negative pressure system that shall work with the radiation monitoring system as a safety feature for the reactor. This system relies on a ventilation system to create a pressure difference, ensuring air flow into the containment area, capturing radioactive particles, and use of airlocks to maintain pressure when personnel or equipment enters or exits [6]. Continuous pressure monitoring will trigger alarms and safety protocols to minimize the spread of radioactive materials during emergencies.

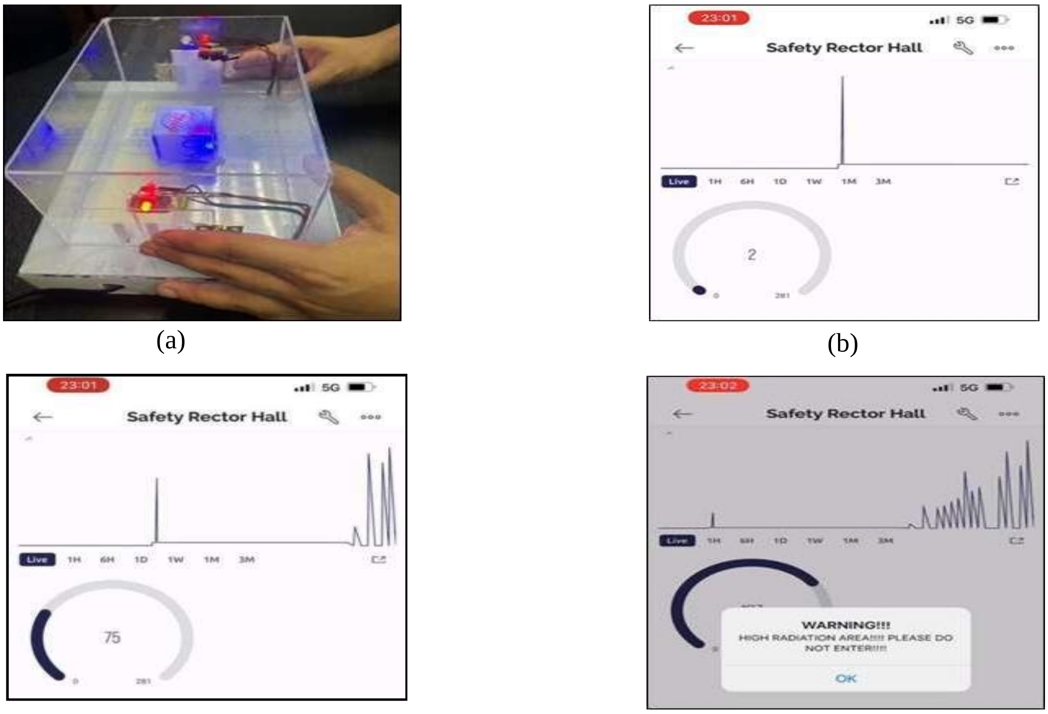


(a) (b)

Fig. 5 *(a) Red LED indicating that the reactor hall is already in a negative pressure state, thus the reactor is turned on, (b) green LED indicating that the reactor hall is NOT in a negative pressure state, thus the reactor is NOT turned on*

As shown in Figure 6(a), a starting condition of a radiation monitoring system. It begins when all doors are sealed, achieving negative pressure. When all the safety conditions for negative pressure have been achieved, the red light will turn on and the reactor will start thus producing Cherenkov radiation with a blue light. Figure 6(b) displays the radiation signal before the operation starts. Figure 6(c) displays that the signal has been collected and displayed to the phone. Figure 6(d) illustrates the example of Warning System and alarm that will trigger every minute.

However, in Figure 6(a) shows the condition when all the safety requirements for negative pressure have been achieved and the reactor starts thus producing Cherenkov radiation. Figure 6 (b), (c), and (d) is a radiation monitoring system that can be monitored using a phone. This system is one of the critical aspects to ensure reactor safety. Other critical aspects are real-time radiation monitoring, involving redundant sensors to detect abnormal radiation levels. These sensors, including gamma-ray detectors, neutron detectors, and ionization chambers, cover a wide spectrum of radiation types. Integration with the reactor's control systems allows for automatic shutdown and data analysis for long-term safety. Regular calibration and maintenance should ensure measurement accuracy, minimize radiation risks, and enhance facility safety.



(a) (b) (c) (d)

Fig. 6 *(a) Blue LED represents the radiation in the reactor hall, (b) blue LED represents the radiation in the reactor hall, (c) Radiation signal that can be monitored through phone (in operation mode) and (d) radiation signal that can be monitored through phone (notification for Warning System)*

4. Conclusion

In conclusion, implementing a robust radiation monitoring system with negative pressure in the nuclear reactor hall necessitates a comprehensive safety strategy that underscores the unwavering commitment of the nuclear industry to safeguard human health, environmental integrity, and public welfare. The radiation monitoring system, with its real-time data collection, diverse sensor types, redundancy, and integration with reactor control systems, stands as a sentinel against potential radiation hazards. Its ability to promptly detect and communicate abnormal radiation levels empowers operators and safety personnel to make informed decisions and take swift actions, thereby preventing potential risks from escalating and ensuring the containment of any adverse effects.

Simultaneously, the concept of negative pressure within the nuclear reactor hall serves as a crucial physical barrier against the release of radioactive contaminants. By maintaining a lower air pressure within the reactor hall compared to surrounding areas, this feature prevents the escape of potentially hazardous substances, and aids in confining any inadvertent releases within a controlled environment. This preventive measure not only adds an additional layer of protection for workers and the environment but also underscores the industry's commitment to minimize potential consequences of unforeseen events.

Together, the radiation monitoring system and negative pressure implementation exemplify a holistic approach to safety in nuclear reactor operations. The integration of advanced technology, rigorous protocols, and continuous improvement efforts creates a dynamic defense system that can adapt to evolving challenges and maintain a high standard of safety.

In essence, these safety features embody the core principles of responsible nuclear energy utilization: proactive risk mitigation, real-time response capabilities, and an unyielding dedication to safeguard the well-being of society and the environment. As the nuclear industry continues to advance, these safety measures serve as a testament to its commitment to transparency, accountability, and the pursuit of excellence in ensuring safe and sustainable operation of nuclear reactors.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Shahril Bin Mohd Shah, Mohd Sabri Bin Minhat;* ***data collection:*** *Tan Kai Yong;* ***analysis and interpretation of results:*** *Abdul Ammar Bin Shahrom, Khairul Huda Binti Yusof, Nurul 'Ain Binti Amirrudin, Norazliani Md. Sapari;* ***draft manuscript preparation:*** *Shahril Bin Mohd Shah, Muhammad Aizat Bin Mohd Arifin. All authors reviewed the results and approved the final version of the manuscript.*

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