Web-based personal dose records for occupational radiation exposure monitoring system: Development and pilot testing

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ABSTRACT The existing occupational radiation dose management system for Universiti Kebangsaan Malaysia (UKM) trainee radiographers continues to rely on paper-based records. These manual records are susceptible to damage, inconvenient to access, lack effective security measures, and impede data analysis. The study aims to develop an electronic personal dose records (e-PDR) system to monitor the occupational radiation exposure received by the trainee during their clinical practices. Developed using WordPress and PHP WordPress Blog Script, the e-PDR system leverages the MySQL server to store the database containing records of trainees and their radiation exposure data. The system adopts a Three-Tier Architecture approach, comprising a presentation tier for the user interface, a logic tier for security and user interaction handling, and a data tier for database management. The system ensures data security through robust password mechanisms and authentication features enforced by security plugins. The e-PDR system provides a user-friendly interface for viewing reports through line charts and tables. The feasibility of the proposed e-PDR system is tested through a pilot test using occupational radiation exposure data from a single cohort. The e-PDR system is feasible to be used as a centralized management tool for storing individual radiation dose data in the long term and facilitating exposure trend analysis at local level.

KEYWORDS: Radiation exposure; Individual monitoring; Occupational safety; Dose management system; Clinical training.
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INTRODUCTION

Medical radiation workers play a vital role in healthcare as the use of ionizing radiation continues to grow globally. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2021) reports that medical procedures involving ionizing radiation have increased from 1.7 billion in 1988 to 4.2 billion annually. This rise highlights the importance of monitoring and managing occupational radiation exposure to protect workers from health risks. Monitoring aims to identify unsafe practices and high-risk areas, improving workplace safety. In Malaysia, occupational radiation exposure is stringently regulated under the Atomic Energy Licensing Act 1984. This legislation, informed by the recommendations of the International Commission on Radiological Protection (ICRP), establishes legal requirements for individual radiation monitoring to protect both workers and the public from ionizing radiation hazards (Ridzwan *et al*., 2023; AELB, 2006).

Personal dosimetry is the cornerstone of individual radiation exposure monitoring in Malaysia, measuring cumulative radiation doses over specified intervals, typically monthly or quarterly. Routine personal dose monitoring is critical for regulating dose limits and identifying risks associated with excessive radiation exposure. Furthermore, it serves as a key mechanism for implementing the as-low-as-reasonably-achievable (ALARA) principle, ensuring an adequate level of radiation protection (Behzadmehr *et al*., 2021). As per the Atomic Energy Licensing (Basic Safety Radiation Protection) Regulations 2010 (AELB, 2010), occupational exposure for workers is capped at an effective dose of 20 millisieverts (mSv) per calendar year, with a five-year average not exceeding 20 mSv annually. For apprentices, trainees, and students, the annual limit is 6 mSv. Regularly reviewing personal dose reports is essential for all stakeholders, as these reports provide critical insights into the effectiveness of radiation protection measures (Vassileva *et al*., 2022; Elshami *et al*., 2020) and ensure compliance with safety standards.

Despite these regulatory frameworks, the current dose management system at Universiti Kebangsaan Malaysia (UKM) for trainee radiographers remains reliant on manual record-keeping, which presents several limitations. Physical storage of records restricts accessibility, requiring trainees to visit the faculty during working hours to retrieve their information. Manual record-keeping exposes sensitive data to risks such as unauthorized access, theft, loss, or damage due to natural disasters, fire, or mishandling. To overcome these issues, a web-based personal dose record (e-PDR) system has been proposed (Fadzil *et al*., 2024). This system leverages digital technologies to enhance accessibility, efficiency, and data security. Similar systems have been successfully implemented in countries like the Philippines (Pineda *et al*., 2020), China (Wang *et al*., 2016), and Brazil (Mauricio *et al*., 2011). This study develops an online e-PDR system to monitor UKM trainees' radiation exposure during clinical training, addressing the shortcomings of the current manual approach.

METHODOLOGY

System Development Approach and Requirements Analysis

The System Development Life Cycle (SDLC) framework guides the development of the e-PDR system. SDLC provides a structured approach to software application or system development, consisting of six phases: planning, analysis, design, and development, testing and integration, implementation, and maintenance (Mishra & Dubey, 2013). The functional and non-functional system requirements are identified, analysed, and defined. The website's functional requirements define its intended purpose. To meet user expectations and serve its intended purpose, a website must incorporate some critical features and functionalities. Meanwhile, non-functional requirements focus on the system's qualitative features and outline how the website runs.

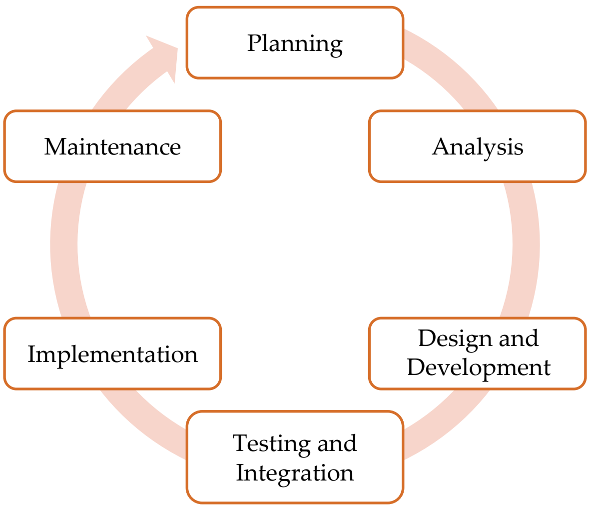

Figure 1. SDLC framework for e-PDR system development.

Website Development Tools and System Design

The e-PDR system was developed on the WordPress WCMS platform for website development and management, with the domain obtained from UKM's Centre for Information Technology. WordPress is a free and open-source web content management system (WCMS) that enables users to create and manage web pages with little knowledge of programming languages or technical skills by offering a diverse selection of pre-built templates and intuitive tools such as plugins. The e-PDR system follows a three-tier architecture (Schuldt, 2009):

I. Presentation Tier: User interface designed using WordPress to ensure user-friendly access to data.
II. Logic Tier: PHP scripts and WordPress plugins handle user authentication, logic, and database interactions. Security policies, including password management, encryption, and access control, are enforced by a security module.
III. Data Tier: MySQL serves as the repository for personal dose report data, storing personal information, radiation exposure details, and reports.

Pilot Test

The occupational radiation exposure data for the 19^{th} cohort of UKM trainees from 2021 to 2024 was retrieved from the manual records. This raw data was uploaded to the e-PDR system's backend. All modules and functionalities of the e-PDR system were systematically tested to ensure they functioned correctly.

RESULT AND DISCUSSION

Website Architecture and Data Flow Diagrams

The e-PDR system is built using a webbed navigation structure, illustrated in Figure 2. This structure, also referred to as a networked or mesh navigation structure, is a non-linear, highly interconnected system of web pages. It enables users to explore the site through multiple pathways, offering a flexible and dynamic navigation experience. The pages are extensively interlinked via a navigation menu positioned at the top of the website, ensuring seamless access to all sections of the system.

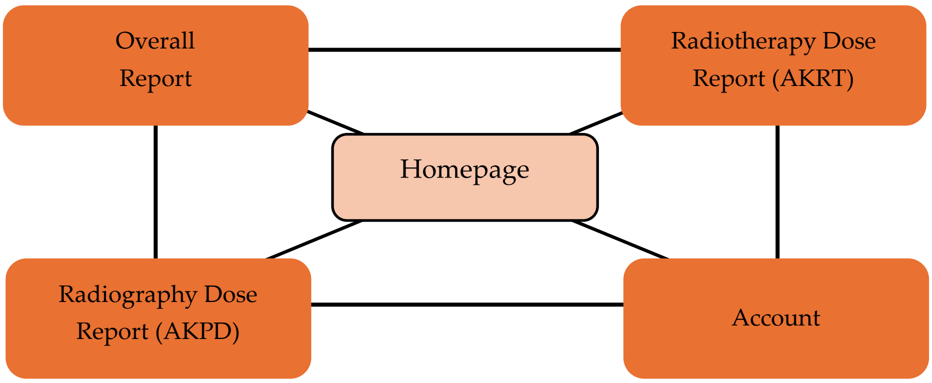

Figure 2. Web architecture diagram of e-PDR system.

A data flow diagram (DFD), as depicted in Figure 3, provides a detailed graphical representation of the e-PDR system design. Access to the system requires every user to log in with a unique username and password, credentials provided by the system administrator. Alternatively, new users can register via the registration page to gain access to the system. Based on the validated role, users are granted access to specific functionalities. Regular users can view and download reports, facilitating efficient access to personal or system data. Admin users, on the other hand, are provided with enhanced privileges, including the ability to upload, modify, delete, and view reports, ensuring comprehensive administrative control over the system's content. This DFD highlights the e-PDR system's commitment to security, data integrity, and user-centric design by implementing a robust authentication mechanism, intuitive navigation (Othman *et al*., 2024), and clearly defined role-based functionalities (Lizcano *et al*., 2009).

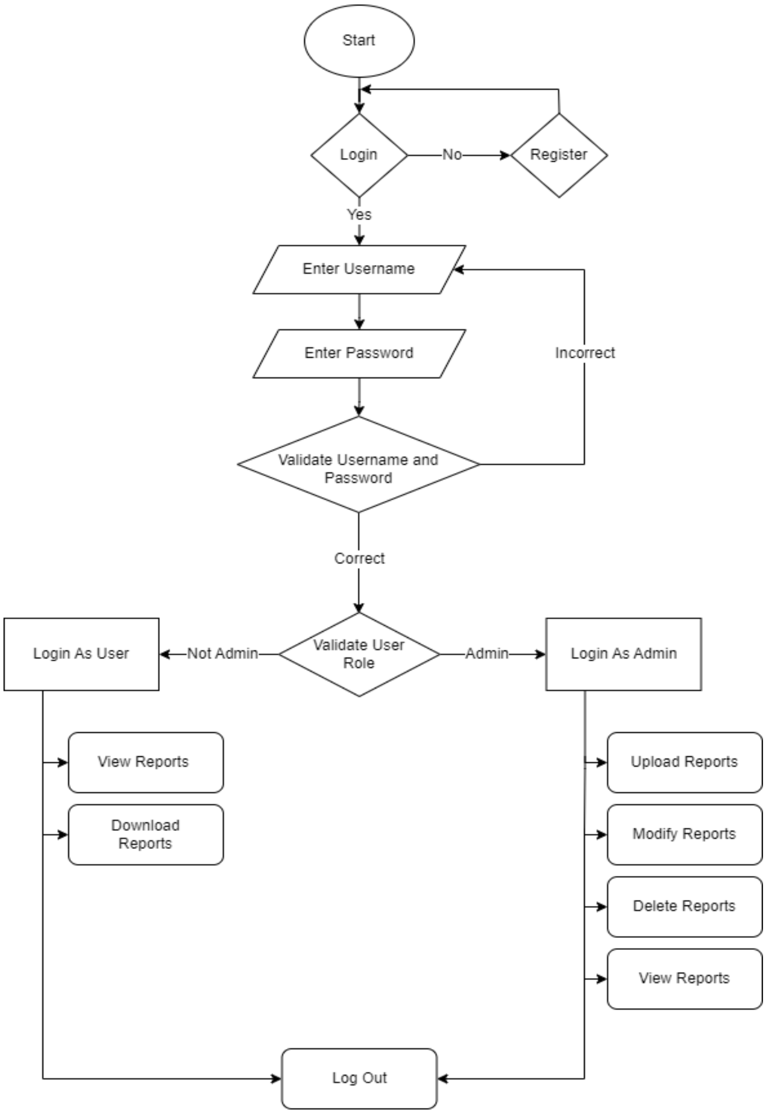

Figure 3. Web architecture diagram of e-PDR system.

Website Architecture and Data Flow Diagrams

When authorized users successfully sign in, they are redirected to the home page of the e-PDR system, as depicted in Figure 4. The home page welcomes users with a personalized message and features navigation buttons that provide access to the system's interior pages (Srivastav & Nath, 2014). Additionally, a graphical chart is displayed on the home page, presenting the user's personal dose report in a visual format. This graphical representation allows users to monitor their dose distribution patterns throughout their clinical training, offering a clear and accessible overview of their radiation exposure (Botwe *et al*., 2015). The e-PDR system includes three main interior pages: AKPD, AKRT, and the Overall Report. These dose report modules enable users to view, download, and print their personal dose reports directly to their devices. In the administrator module, administrators have enhanced access, allowing them to view all users' personal dose reports for monitoring and oversight purposes. Each interior page incorporates alarm and trigger limits for Hp(10) and Hp(0.07) values based on the average cohort's clinical baseline exposure, as recommended by the radiation regulatory body (ICRP, 2007). Values exceeding the alarm limit of 1.2 mSv are highlighted in yellow, while values surpassing the trigger limit of 6.0 mSv are flagged in red. In such cases, a notification box appears to alert users and prompt further investigation. This system ensures both transparency and adherence to radiation safety standards.

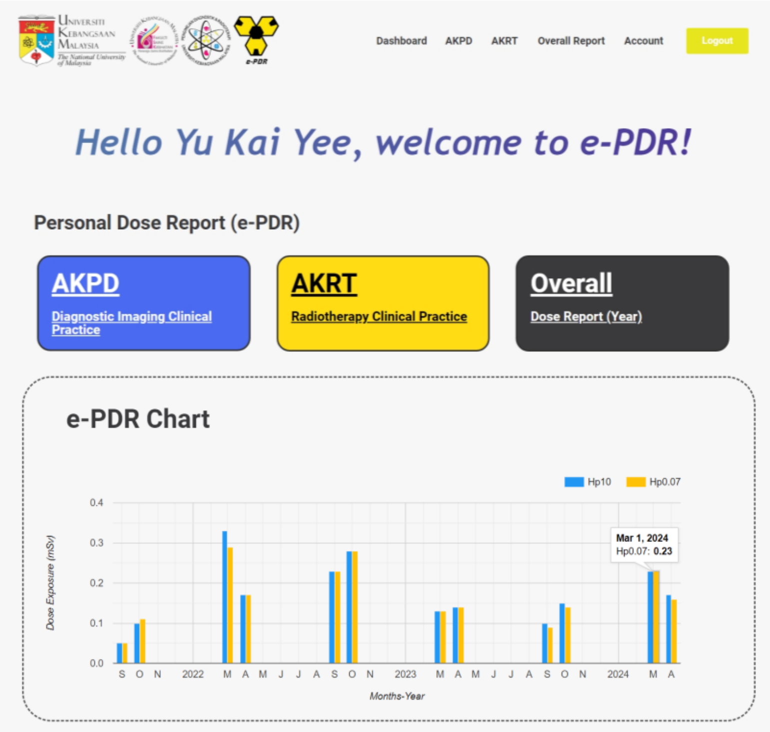

Figure 4. The homepage architecture of the e-PDR system allows the user to keep track of their radiation exposure pattern throughout clinical training.

Small-scale Trial Run

The pilot test of the e-PDR system demonstrated that all modules and functionalities were successfully validated against the system requirements, ensuring its feasibility for practical implementation. Table 1 summarizes specific features of the e-PDR system that were tested to ensure they meet user and system specifications. Key features, such as the login and registration interfaces, met expectations by authenticating users and enabling first-time registration, confirming the system's ability to manage user access securely (Karim *et al*., 2020). The administrator module successfully managed dose report data by allowing users to add, read, update, and delete information, while the user module enabled users to view and download their personal dose reports for better accessibility.

Table 1. Essential testing for ensuring that the web-based application capable of handling expected and unexpected usage scenarios.

Requirements	Testing					Status
	Functionality	Usability	Security	Performance	Accessibility	
Login Interface	☑	☑	☑	☑	☑	Pass
Registration Interface	☑	☑		☑	☑	Pass
Administrator Module	☑		☑	☑	☑	Pass
User Module	☑	☑	☑	☑	☑	Pass
Notification Module	☑	☑		☑	☑	Pass

The notification module highlighted dose values that exceeded predefined alarm and trigger limits, aiding in radiation safety (ICRP, 2007). The system also demonstrated strong security practices by restricting access based on user roles and requiring strong password authentication, in line with cybersecurity standards (Taherdoost, 2022; Syafrizal *et al*., 2020). Usability and performance tests verified that the system was user-friendly and could handle multiple users without issues. This pilot test confirmed the e-PDR system's readiness for deployment and highlighted the need for regular updates to keep pace with safety standards and user needs.

CONCLUSION

The e-PDR system was successfully developed and tested as an effective tool for managing occupational radiation exposure profiles. Pilot testing confirmed its ability to meet essential requirements, providing enhanced data management compared to traditional manual methods. Key features, including user authentication, dose visualization, and safety alerts, proved reliable in maintaining radiation safety standards. The system's robust security, user-friendly interface, and capability to handle multiple users highlight its practicality and efficiency. To ensure its long-term adaptability, future enhancements could include advanced data analytics for trend analysis and predictive modeling, AI-driven insights for exposure reduction, and seamless integration with hospital information systems (HIS) and monitoring devices. Expanding the system to support mobile applications could improve accessibility and user engagement, while a multilingual interface could cater to a broader user base in international settings. Future work may also explore incorporating blockchain technology to further enhance data security and integrity, ensuring compliance with evolving regulatory requirements. These improvements would position the e-PDR system as a comprehensive and innovative tool for radiation safety and occupational health management.

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