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Development of a Smartphone-Based Digital Reporting System to Optimize Radiation Safety Reporting in the Radiation Oncology Facility

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Abstract

Introduction*: Radiation safety reporting at the Radiation Oncology Facility of RSUD Dr. H. Abdul Moeloek was still paper-based, causing incomplete data, delayed reporting, and fluctuating Safety and Security Indicator (IKK) scores.* ***Objective****: This study aimed to develop and evaluate a smartphone-based digital reporting application to improve radiation safety reporting and safety culture.* ***Method****: This Research and Development study used the ADDIE model with mixed qualitative and quantitative approaches. The application was developed using the AppSheet low-code platform and validated by practitioners and media experts. Evaluation applied a one-group pretest-posttest design involving 30 radiation workers. Data were analysed using regression, paired t-test, and correlation analyses.* ***Results and discussion****: The SPEKTRA application achieved a validation score of 94.5% and was categorized as highly feasible. Post-implementation results showed significant improvements in perceived ease of use, perceived usefulness, intention to use, and safety culture ($p < 0.001$). Perceived usefulness was the dominant predictor of intention to use ($\beta = 0.473$; $p = 0.022$). Application adoption also significantly improved safety culture ($p = 0.034$). The projected IKK score increased from 75 in 2025 to 94 in 2026 through the integrated simulation feature.* ***Conclusion****: SPEKTRA effectively improved technology acceptance, safety culture, and radiation safety reporting management.*

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Introduction

The rapid development of radiation technology in healthcare, particularly in radiation oncology, has significantly improved cancer treatment services worldwide. In Indonesia, the increasing number of cancer cases and deaths, which reached 234,511 in 2020, has accelerated the utilization of ionizing radiation in medical facilities (Globocan, 2020). Radiation oncology services are currently supported by 53 Linear Accelerator units distributed across hospitals in Indonesia (Badan Pengawas Tenaga Nuklir, 2021). Despite its therapeutic benefits, ionizing radiation also presents substantial risks to workers, patients, and the surrounding environment when safety standards are not properly implemented. Several international radiation overexposure incidents have demonstrated that inadequate monitoring and reporting systems may contribute to serious safety failures in radiotherapy practice.

International organizations have emphasized the importance of strengthening radiation safety systems through digital innovation and continuous monitoring. The World Health Organization highlighted that radiation protection should be integrated into healthcare quality systems to reduce unnecessary radiation exposure and improve patient safety (World Health Organization, 2023). Similarly, the International Atomic Energy Agency recommended the implementation of automated digital reporting and monitoring systems to improve radiation safety data management and accessibility (International Atomic Energy Agency, 2023). In Indonesia, radiation safety supervision is regulated by BAPETEN, which requires healthcare facilities to submit the Facility Safety Verification Report (LVKF) as part of regulatory compliance and performance evaluation (BAPETEN, 2024). The LVKF contributes directly to the Safety and Security Index (IKK), which measures institutional radiation safety performance based on licensing, human resources, dose monitoring, occupational health monitoring, environmental monitoring, safety equipment, and reporting system innovation (BAPETEN, 2022). However, many healthcare facilities still rely on manual paper-based reporting systems that create operational inefficiencies, incomplete documentation, and delayed reporting processes (Sari *et al*., 2021; JUPETEN, 2021). These limitations show a gap between regulatory expectations and actual implementation of radiation safety management in clinical settings.

An effective incident learning and reporting system is considered one of the key elements of radiation safety culture in radiotherapy services. Terezakis (2011) stated that radiation oncology safety strategies require integration between incident learning systems, technological innovation, and organizational safety culture. According to the IAEA, radiation safety culture refers to attitudes, values, and behaviors that prioritize safety in all radiation-related activities (IAEA, 2021). Talcott *et al*. (2024) further emphasized that high-performing radiation oncology programs require continuous safety improvement supported by efficient reporting systems and active staff participation. Previous studies also showed that electronic incident reporting systems positively influence safety culture and near-miss prevention in radiotherapy environments (Deraniyagala *et al*., 2015). In Italy, Stendardo (2023) developed an Internet of Things-based abnormal event reporting system that successfully improved reporting efficiency and encouraged more active incident reporting among healthcare personnel. Nevertheless, the implementation of digital systems in radiation safety management still faces several barriers, including infrastructure limitations, workforce readiness, financial

constraints, legal concerns, and resistance to organizational change (Inampudi, 2024; Kajüter, 2022; Saragih, 2025; Kesar & Joseph, 2025).

The advancement of smartphone technology has created new opportunities for improving radiation safety reporting systems in healthcare facilities. Indonesia recorded more than 370 million smartphone users in 2024, indicating strong potential for mobile-based healthcare applications (DataReportal, 2024). Smartphone applications allow real-time reporting, faster communication, and easier access to safety records compared with conventional paper-based systems. Previous studies showed that digital healthcare systems contribute significantly to communication efficiency, organizational performance, and clinical management processes (Walzer, 2022; Shoba & Gouri, 2011). The increasing adoption of technologies such as cloud computing, IoT, blockchain, telemedicine, and big data further demonstrates the growing dependence of healthcare systems on digital innovation (Borse & Sharma, 2024; Burrai, 2021). However, studies by Rodrigues *et al*. (2013) found that most smartphone applications in radiology primarily focused on education and clinical support rather than radiation safety reporting and monitoring systems. In addition, Ford *et al*. (2009) identified that errors in radiation oncology could occur at multiple stages of treatment planning and delivery, emphasizing the importance of integrated safety reporting systems to minimize risk.

The Radiation Oncology Facility at RSUD Dr. H. Abdul Moeloek continues to face challenges in achieving optimal radiation safety performance, particularly regarding reporting and documentation management. Institutional records showed fluctuating IKK scores, namely 65 in 2019, 68 in 2020 and 2021, 71 in 2022, 75 in 2023, and 70 in 2024. The decline in 2024 reflected weaknesses in reporting systems, safety documentation, and innovation management. The existing reporting process remained highly dependent on manual paper-based administration, resulting in delayed reporting, difficulties in record retrieval, and incomplete safety documentation. Considering the hospital's strategic role as a provincial referral center for radiation oncology services, strengthening radiation safety management has become increasingly important. Based on these conditions, this study aimed to develop a smartphone-based digital reporting application called SPEKTRA to optimize radiation safety reporting systems, improve safety culture, and support IKK achievement through integration with BAPETEN reporting standards.

Method

This study used a Research and Development (R&D) approach with the ADDIE model consisting of Analysis, Design, Development, Implementation, and Evaluation stages. The study combined qualitative and quantitative methods with a One Group Pretest-Posttest design to evaluate the implementation of a smartphone-based digital radiation safety reporting application and its influence on Technology Acceptance Model (TAM) variables, radiation safety culture, and the Safety and Security Index (IKK). The research was conducted at the Radiation Oncology Facility of RSUD Dr. H. Abdul Moeloek from December 2025 to March 2026. The population consisted of 30 radiation workers, including Radiation Protection Officers (RPO), radiation oncologists, medical physicists, radiographers, and nurses. Purposive sampling was applied during the needs analysis stage involving four informants, while expert validation involved two medical physicists or Radiation Protection Officers and two media or information technology experts. Total sampling was applied during the implementation and evaluation stages involving all respondents. The intervention variable was the implementation of the

smartphone-based digital reporting application, while independent variables included Perceived Ease of Use (PEOU) and Perceived Usefulness (PU). Dependent variables included Intention to Use (ITU), radiation safety culture, and optimization of the radiation safety system, while the outcome variable was the Safety and Security Index (IKK) based on BAPETEN standards. The operational definitions of each variable are presented in Table 1.

Table 1
Operational Variables and Definitions

No	Variable	Operational Definition	Measurement Outcome	Data Scale
1	Digital Reporting Application Innovation (Intervention)	Implementation of a smartphone-based radiation safety reporting system replacing conventional methods	Application implementation status: Not Implemented or Implemented	Nominal
2	Perceived Ease of Use (PEOU)	Degree to which users believe the application is easy to learn and operate	TAM-based perception score (1-5)	Ordinal/Interval
3	Perceived Usefulness (PU)	Degree to which users believe the application improves reporting performance	TAM-based usefulness score (1-5)	Ordinal/Interval
4	Intention to Use (ITU)	User tendency to continuously use the application for radiation safety reporting	TAM-based intention score (1-5)	Ordinal/Interval
5	Radiation Safety Culture	User perception of organizational attitudes, values, and behaviors toward radiation safety	Safety culture survey score (1-5)	Ordinal/Interval
6	Optimization of Radiation Safety System	User perception regarding improvements in reporting, documentation, and incident follow-up processes	Optimization perception score (1-5)	Ordinal/Interval
7	Safety and Security Index (IKK)	Quantitative indicator describing radiation safety performance based on administrative compliance and safety readiness	Simulated IKK score based on BAPETEN standards (0-100)	Ratio

Research instruments included interview guidelines, expert validation sheets, and questionnaires developed according to the ADDIE stages. Interview guidelines consisted of open-ended questions related to radiation safety indicators, reporting systems, and safety culture dimensions to identify reporting problems and user expectations regarding the digital application. Expert validation sheets were used to assess application feasibility before implementation, involving medical physicists, Radiation Protection Officers, and media experts. Practitioner validation focused on compliance with BAPETEN regulations, Facility Safety Verification Report (LVKF) procedures, and radiation safety content accuracy, while media experts evaluated usability, interface design, data security, User Interface (UI), User Experience (UX), responsiveness, workflow efficiency, CRUD functionality, and device compatibility. The validation instrument referred to the Information System Success Model by DeLone and McLean (1992), Safety Culture theory by Reason (1997), and the Technology Acceptance Model by Davis (1989). Questionnaires adapted from Davis (1989) and Reason (1997) were distributed during

pre- and post-implementation phases to measure Perceived Ease of Use (PEOU), Perceived Usefulness (PU), Intention to Use (ITU), actual system use, radiation safety culture, and optimization of radiation safety reporting systems using a five-point Likert scale.

The research process followed the ADDIE framework beginning with field observations and needs analysis through in-depth interviews with Radiation Protection Officers, medical physicists, radiographers, and radiation oncologists to identify system requirements and application features. The application prototype was developed using the AppSheet No-Code Development Platform integrated with Google Sheets or Excel databases, followed by expert validation, implementation, and field testing. Qualitative interview data were analyzed thematically using NVivo software, while quantitative data were analyzed using JAMOVI statistical software. Statistical analyses included Shapiro-Wilk normality testing, paired t-tests, multiple linear regression, simple linear regression, Spearman correlation, F-tests, and coefficient of determination (R^2) analysis to evaluate the relationship between PEOU, PU, ITU, Actual System Use, and radiation safety culture variables. Hypotheses were accepted when p-values were less than 0.05 with positive regression coefficients. This study obtained ethical approval from the Health Research Ethics Committee of the Health Polytechnic of Yogyakarta under ethical clearance number No. DP.04.03/e-KEPK.1/068/2026, and all respondents participated voluntarily with confidentiality protections applied throughout the research process.

Result and Discussion

1. Result

The SPEKTRA application was developed through three phases consisting of database preparation, interface and feature development, and system testing using the AppSheet platform integrated with Google Sheets. Before development, a qualitative needs assessment was conducted through in-depth interviews with a medical physicist, radiation protection officer, radiographer, and head of installation as triangulation informant. The interview data were analyzed using NVivo software to identify user needs and operational problems in the existing reporting system. The thematic analysis results presented in Table 2 showed several major issues, including inefficient manual documentation, difficulty retrieving historical records, low incident reporting participation due to blame culture, and the need for a centralized smartphone-based reporting system with real-time monitoring and notification features. These findings became the basis for developing the SPEKTRA application, which integrated all seven BAPETEN IKK parameters along with automatic IKK simulation, PDF report generation, and reminder notifications. The application was subsequently tested for functionality, access security, automatic calculations, and compatibility across Android and iOS devices before undergoing feasibility validation by two radiation safety practitioners and two media or software experts. The validator profiles are shown in Table 3.

Table 2
NVivo Thematic Results of User Needs Assessment

No	Main Theme	Interview Findings	Informants
1	Inefficiency of Manual Reporting	Manual documentation and re-entry processes consumed excessive time and increased the risk of human error	Radiation Protection Officer, Medical Physicist

2	Difficulty in Historical Data Retrieval	Historical radiation safety records were difficult to retrieve during inspections and evaluations	Radiation Protection Officer, Medical Physicist
3	Low Incident Reporting Participation	Staff were reluctant to report near-miss incidents due to fear of blame and complicated reporting procedures	Radiographer
4	Need for Real-Time Digital Reporting	Informants required a smartphone-based reporting system that could support rapid and real-time data entry	All Informants
5	Requirement for Centralized Database	Users expected a cloud-based centralized database integrated with automatic documentation and monitoring features	Medical Physicist, Radiation Protection Officer
6	Need for Notification and Monitoring Features	Informants requested reminder notifications, dose monitoring alerts, and dashboard monitoring systems	Head of Installation, Radiation Protection Officer
7	Support for Radiation Safety Culture	Anonymous reporting and simplified reporting workflows were considered important to improve safety culture and reporting participation	Radiographer, Head of Installation
8	Institutional Support for Digital Innovation	Management supported the implementation of smartphone-based reporting systems and integration into operational SOPs	Head of Installation

Table 3
Validator Profiles

No	Code	Age	Gender	Education	Expertise
1	V1	28	Male	Professional Master's Degree	Medical Physicist
2	V2	34	Female	Professional Master's Degree	Medical Physicist and Radiation Protection Officer
3	V3	28	Male	Bachelor's Degree	Programmer
4	V4	39	Male	Bachelor's Degree	Front-End Developer

The practitioner validation was conducted to evaluate the suitability of the SPEKTRA application from the perspective of radiation safety standards and regulatory compliance. Validation covered ten indicators grouped into three aspects which are Content and Regulatory Quality, Educational and Safety Culture Aspects, and Language Quality, shown in Table 4.

Table 4
Practitioner Expert Validation Results

No	Assessment Aspect	Indicator	V1	V2	Average	Category
1	Content & Regulatory Quality	Compatibility of input features with LVKF BAPETEN format	5	5	5.0	Excellent
2		Completeness of data variables (Dose, Exposure, Equipment)	5	4	4.5	Excellent
3		Accuracy of radiation terminology	4	5	4.5	Excellent
4		Compatibility of incident reporting workflow with SOP	5	5	5.0	Excellent
5	Educational & Safety Culture	Clarity of data entry instructions	4	4	4.0	Good
6		Alert feature for dose limit warning	5	5	5.0	Excellent

7		Relevance of notifications for increasing awareness	4	4	4.0	Good
8	Language Quality	Proper use of Indonesian language	4	4	4.0	Good
9		Ease of understanding technical terminology by non-physicists	3	4	3.5	Fair
10		Sentence structure within application menus	4	4	4.0	Good
	Total Score		**43**	**44**	**43.5**	
	Average Score		4.3	4.4	4.35	
	Feasibility Percentage		86.0%	88.0%	87%	Very Feasible

Based on Table 4, practitioner validation results showed an average feasibility score of 4.35 with a feasibility percentage of 87%, categorized as "Very Feasible." The highest evaluations were obtained in the Content and Regulatory Quality aspect, indicating compliance with LVKF standards and BAPETEN reporting procedures, while the Language Quality aspect received relatively lower scores due to difficulties in understanding technical terminology by non-specialist users. These findings showed the need for simplifying technical language within the application. Media expert validation was conducted to assess the technical quality, usability, and performance of the SPEKTRA application through User Interface (UI), User Experience (UX), and Performance indicators, with the detailed results in Table 5.

Table 5
Media Expert Validation Results

No	Assessment Aspect	Indicator	V3	V4	Average	Category
1	User Interface (UI)	Layout and navigation	5	5	5.0	Excellent
2		Readability and contrast	4	5	4.5	Excellent
3		Consistency of icons and visual design	4	5	4.5	Excellent
4	User Experience (UX)	Logic flow simplicity	5	5	5.0	Excellent
5		Application responsiveness	4	4	4.0	Good
6		Efficiency of operational steps	5	5	5.0	Excellent
7	Performance	CRUD functionality	5	5	5.0	Excellent
8		Data security (Password/Encryption)	5	4	4.5	Excellent
9		System stability (Crash/Bug Handling)	4	5	4.5	Excellent
10		Screen compatibility (Responsive Design)	5	5	5.0	Excellent
	Total Score		**46**	**48**	**47**	
	Average Score		4.6	4.8	4.7	
	Feasibility Percentage		92.0%	96.0%	94.0%	Very Feasible

Based on Table 5, media expert validation showed that validator V3 obtained a score of 46 (92%) and V4 obtained 48 (96%), with a combined average score of 4.7 and feasibility percentage of 94%, categorized as "Very Feasible." The highest evaluations were found in User Interface and User Experience aspects, particularly layout, navigation,

workflow, and operational efficiency, while application responsiveness received a slightly lower "Good" rating, indicating a need for performance optimization. Overall, the Performance aspect was rated highly, confirming that the SPEKTRA application is reliable, secure, and compatible across multiple smartphone devices. A combined validation recap with practitioner results in Table 6.

Table 6
Validation Recapitulation

No	Practitioner Assessment Aspect	Average	Percentage	Media Assessment Aspect	Average	Percentage
1	Content & Regulatory Quality	4.75	95.0%	User Interface	4.67	93.4%
2	Educational & Safety Culture	4.67	93.3%	User Experience	4.67	93.3%
3	Language Quality	3.75	75.0%	Performance	4.75	95.0%
	Average	4.75	95.0%		4.70	94.0%
	Combined Average	4.73 (94.5%)				

Based on Table 6, practitioner validation obtained an average score of 4.75 (95.0%), while media expert validation reached 4.70 (94.0%), resulting in a combined score of 4.73 (94.5%) categorized as "Very Feasible." Overall, both expert groups indicated that the SPEKTRA application met regulatory and technical requirements, with the highest performance in Content and Regulatory Quality, as well as Performance, while Language Quality was identified as the main area for improvement, particularly in simplifying technical terminology for non-specialist users. The reliability test was conducted to assess the consistency of the questionnaire, with the results presented in Table 7.

Table 7
Questionnaire Reliability Test

No	Variable	Number of Items	Cronbach's Alpha	Minimum Standard	Interpretation
1	Perceived Ease of Use (PEOU)	5	0.9833	0.6	Reliable
2	Perceived Usefulness (PU)	5	0.9758	0.6	Reliable
3	Intention to Use (ITU)	3	0.9315	0.6	Reliable
4	Safety Culture (SC)	10	0.9902	0.6	Reliable

Table 7 shows that all research variables (Perceived Ease of Use, Perceived Usefulness, Intention to Use, and Safety Culture) had Cronbach's Alpha values above 0.60, indicating good internal consistency and reliability of the questionnaire. The next stage involved descriptive statistical analysis of pre-and post-implementation data to examine changes in respondents' perceptions after the implementation of the SPEKTRA digital reporting system.

Table 8
Descriptive Statistics of Pre-and Post-Implementation data for TAM Variables and Safety Culture

No	Variable	Pre-Implementation Mean	SD	Min	Max	Post-Implementation Mean	SD	Min	Max
1	PEOU (Perceived Ease of Use)	2.253	0.573	1.40	3.40	4.240	0.425	3.40	4.80
2	PU (Perceived Usefulness)	2.427	0.483	1.60	3.60	4.200	0.403	3.60	4.80
3	ITU (Intention to Use)	2.011	0.344	1.33	2.67	4.267	0.414	3.33	5.00
4	SC (Safety Culture)	2.260	0.351	1.70	3.10	4.003	0.354	3.30	4.80

Based on Table 8, all variables increased after SPEKTRA implementation: Perceived Ease of Use (PEOU) rose from 2.253 to 4.240 with standard deviation decreasing from 0.573 to 0.425, Perceived Usefulness (PU) increased from 2.427 to 4.200 with standard deviation from 0.483 to 0.403, Intention to Use (ITU) showed the largest increase from 2.011 to 4.267, and Safety Culture (SC) increased from 2.260 to 4.003 with relatively stable variability. Overall, mean differences ranged from 1.743 to 2.256 points across variables, indicating a consistent improvement in user perception and safety culture after implementation of the SPEKTRA application, and the post-implementation data were then used for classical assumption testing (normality, multicollinearity, and heteroscedasticity) prior to multiple regression analysis.

Table 9
Normality Test

No	Variable	Shapiro-Wilk W	p-value	Interpretation
1	PEOU	0.937	0.073	Normal
2	PU	0.934	0.063	Normal
3	ITU	0.962	0.357	Normal

Based on Table 9, the Shapiro-Wilk test results show that all variables obtained p-values greater than 0.05, showing that the data were normally distributed and met the assumptions required for multiple regression analysis.

Table 10
Multicollinearity Test

No	Variable	Tolerance	VIF	Interpretation
1	PEOU	0.709	1.41	No multicollinearity
2	PU	0.709	1.41	No multicollinearity

The results in Table 10, show that the VIF values for both independent variables were below 10.00, confirming that no multicollinearity existed between the independent variables in the regression model.

Table 11
Heteroscedasticity Test

No	Test	Statistic	p-value	Interpretation
1	Breusch-Pagan	0.754	0.686	No heteroscedasticity

The Breusch-Pagan test results presented in Table 11. show a p-value greater than 0.05, showing homogeneous residual variance and confirming that the regression model was free from heteroscedasticity problems. After all classical assumptions were fulfilled, multiple regression analysis was performed to determine the influence of Perceived Ease of Use (PEOU) and Perceived Usefulness (PU) on Intention to Use (ITU).

Table 12
Coefficient of Determination of the Regression Model

Model	R	R^2	Adjusted R^2	F	df1	df2	Sig
1	0.520	0.270	0.216	5.000	2	27	0.014

The R^2 value of 0.270 shows that 27.0% of the variance in ITU can be explained jointly by PEOU and PU, while the remaining 73.0% is influenced by other variables outside the model.

Table 13
Multiple Regression Coefficients

No	Predictor	B	SE	Lower 95%	Upper 95%	t	Sig.	β
1	Constant	1.868	0.808	0.211	3.526	2.313	0.029	-
2	PEOU	0.078	0.193	-0.319	0.475	0.404	0.690	0.079
3	PU	0.494	0.204	0.076	0.912	2.424	0.022	0.473

Table 13 shows that every one-unit increase in PU increases ITU by 0.494 units, assuming PEOU remains constant. Meanwhile, every one-unit increase in PEOU increases ITU by 0.078 units, assuming PU remains constant. The PU variable emerged as the dominant predictor with a standardized beta coefficient of 0.473, substantially higher than the contribution of PEOU ($\beta = 0.079$), showing that perceived usefulness is the primary determinant influencing users' intention to adopt the SPEKTRA application.

Table 14
Omnibus ANOVA

No	Source	Sum of Squares	df	Mean Square	F	Sig.
1	PEOU_Post	0.023	1	0.023	0.163	0.690
2	PU_Post	0.816	1	0.816	5.878	0.022
3	Residual	3.749	27	0.139		

Based on the multiple regression analysis, the simultaneous test produced an F-value of 5.000 with a significance level of $p = 0.014$ ($p < 0.05$), showing that PEOU and PU jointly had a significant effect on ITU. Partially, the PU variable obtained a t-value of 2.424 with $p = 0.022$ ($p < 0.05$), showing a positive and significant effect on ITU. In contrast, the PEOU variable showed a t-value of 0.404 with $p = 0.690$ ($p > 0.05$), showing no significant partial effect on ITU.

Table 15
Paired Sample t-Test

No	Post	Pre	Statistic	df	p
1	PEOU_Post	PEOU_Pre	27.5	29	<0.001
2	PU_Post	PU_Pre	22.8	29	<0.001
3	ITU_Post	ITU_Pre	23.1	32	<0.001

Based on Table 15, the paired t-test results revealed significant differences between pre and post implementation scores for all variables. PEOU showed a significant increase after implementation ($t = 27.5$, $df = 29$, $p < 0.001$), showing a substantial improvement in respondents' perceptions of application usability. PU also showed a significant increase between pre- and post-implementation conditions ($t = 22.8$, $df = 29$, $p < 0.001$), showing improved perceptions regarding the usefulness of the system. Similarly, ITU exhibited a significant difference before and after implementation ($t = 23.1$, $df = 32$, $p < 0.001$), showing that the implementation significantly influenced users' intention to adopt the application.

The evaluation stage was conducted to assess the impact of the SPEKTRA application on safety culture and the optimization of the overall radiation safety system within the radiation oncology facility.

Table 16
Normality Test

No	Variable	Shapiro-Wilk W	p-value	Interpretation
1	Actual System Use (ASU)	0.939	0.087	Normal
2	SC Pre	0.972	0.589	Normal
3	SC Post	0.981	0.852	Normal

The Shapiro-Wilk test results show that both variables used in the regression model fulfilled the assumption of normal distribution with p-values greater than 0.05.

Table 17
Heteroscedasticity Test

No	Test	Statistic	p-value	Interpretation
1	Breusch-Pagan	2.735	0.098	No heteroscedasticity

The Breusch-Pagan test produced a p-value of 0.098 (>0.05), showing that no heteroscedasticity problem existed in the regression model.

Table 18
Paired t-Test Results for SC Pre vs SC Post

No	Variable	SD	Mean Difference	SE Diff	t	df	Sig.	Cohen's d
1	SC Pre	0.39	1.68	0.100	16.69	29	<0.001	3.048
2	SC Post	0.35						

Based on Table 18, the paired t-test produced a t-value of 16.696 with $p < 0.001$, confirming that the increase in SC scores from pre- to post-implementation was highly significant. The Cohen's d value of 3.048 greatly exceeded the threshold for a large effect size ($d \geq 0.80$), showing that the implementation of the SPEKTRA application had a substantial and meaningful impact on safety culture within the radiation oncology facility. After all assumptions were satisfied, simple regression analysis was conducted to examine the effect of Actual System Use (ASU) on Safety Culture (SC).

Table 19
Coefficient of Determination of the Simple Regression Model

Model	R	R^2	Adjusted R^2	F	df1	df2	Sig
1	0.388	0.150	0.120	4.950	1	28	0.034

The R^2 value of 0.150 indicates that 15.0% of the variance in Safety Culture scores could be explained by digital adoption variables, while the remaining 85.0% was influenced by other factors outside the model.

Table 20
Simple Regression Coefficients

No	Predictor	B	SE	Lower 95%	Upper 95%	t	Sig.	β
1	Constant	2.339	0.751	0.801	3.876	3.116	0.004	-
2	ASU	0.393	0.177	0.031	0.755	2.225	0.034	0.388

Table 20 shows that every one-unit increase in Actual System Use (ASU) would increase the Safety Culture (SC) score by 0.393 units. The standardized beta coefficient ($\beta = 0.388$) confirms a moderate positive relationship between the two variables. To further confirm the findings, Spearman correlation analysis was performed.

Table 21
Spearman Correlation Test Results

No	Variable 1	Variable 2	Spearman ρ	p-value	Category	Interpretation
1	ASU	SC Post	0.401	0.028	Moderate	Significant

The Spearman test showed a positive correlation ($\rho = 0.401$, $p = 0.028$) consistent with regression results. The paired t-test indicated a significant increase in Safety Culture after implementation ($t = 16.696$, $p < 0.001$, Cohen's $d = 3.048$), while simple regression showed $F = 4.950$, $p = 0.034$, $B = 0.393$, and $R^2 = 0.150$, a modest but significant effect.

Table 22
Historical Trend of IKK Scores from BAPETEN Inspections (2019-2026)

No	Year	IKK Score	Category	Description
1	2019	65	Fair	Routine BAPETEN assessment
2	2020	68	Fair	Routine BAPETEN assessment
3	2021	68	Fair	Routine BAPETEN assessment
4	2022	71	Good	Routine BAPETEN assessment
5	2023	76	Good	Routine BAPETEN assessment
6	2024	70	Fair	Routine BAPETEN assessment
7	2025	75	Good	Routine BAPETEN assessment
8	2026	94	Excellent	Assessment scheduled for August 2026

Based on Table 22, the IKK scores during the 2019-2025 period fluctuated and remained unstable. The score declined from 76 in 2023 to 70 in 2024 before increasing again to 75 in 2025. The decline in 2024 indicated weaknesses in documentation management, reporting systems, and radiation safety records, which are among the parameters assessed within the IKK evaluation.

Table 23
IKK Assessment Parameters and Weighting

No	Parameter	Weight (%)
1	Compliance of ionizing radiation utilization licensing conditions	30
2	Competency of human resources in radiation safety	25
3	Radiation dose monitoring	10
4	Health monitoring of radiation workers	10
5	Availability of radiation safety and security equipment	10
6	Environmental radiation exposure monitoring	10
7	Availability of innovation and updating of reporting, documentation, and record management systems	5
	Total	**100**

The SPEKTRA application mainly contributed to IKK Parameter 7 (innovation in reporting and documentation) and indirectly improved radiation dose and worker health monitoring through real-time digital reporting.

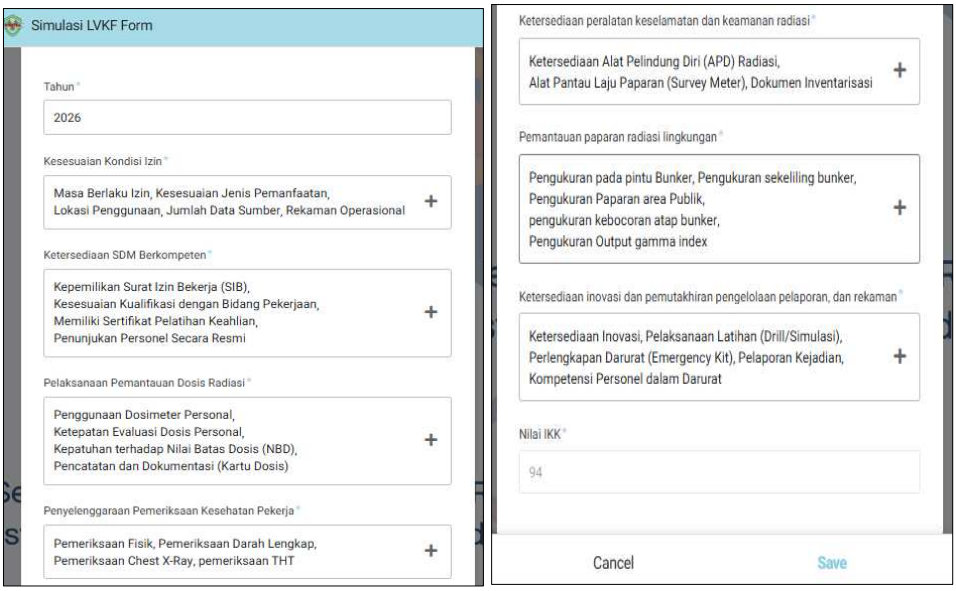

Figure 1. Display of the IKK Simulation Menu in the SPEKTRA Application

The 2026 IKK simulation using the SPEKTRA application produced an estimated score of 94, an increase of 19 points from the 2025 score of 75. This increase represents the most significant improvement in the facility's IKK history over the last five years.

Table 24
Comparative Analysis of IKK Achievement Scores per Parameter (2025 vs 2026 Simulation)

No	Parameter	Weight (%)	2025 Score	Weighted Score 2025	2026 Score	Weighted Score 2026
1	Licensing compliance	30	86	25.8	100	30
2	Competent human resources	25	84	21.0	100	25
3	Radiation dose monitoring	10	80	8.0	88	8.8
4	Worker health monitoring	10	78	7.8	85	8.5
5	Availability of safety and security equipment	10	80	8.0	82	8.2

6	Environmental radiation exposure monitoring	10	78	7.8	85	8.5
7	Innovation and updating of reporting, documentation, and records	5	30	1.5	100	5
	Total	**100**		**75**		**94**

Based on Table 24, the 2026 IKK achievement scores represent simulation results derived from self-assessment after the implementation of the SPEKTRA application, showing a projected increase of 19 points compared to the 2025 score. The most significant improvement occurred in Parameter 7 related to innovation and updating of reporting systems, documentation, and records, increasing from 30% to 100% due to the transition from manual reporting to an integrated digital reporting system with real-time reporting, monitoring, onboarding, and training features. Parameter 1 concerning licensing compliance improved from 86% to 100% through automatic reminder and notification features, while Parameter 2 regarding competent human resources increased from 84% to 100% due to structured digital recording of personnel competency and certification data. Improvements were also observed in radiation dose monitoring and worker health monitoring through real-time and systematic digital recording functions integrated within the application. In addition, Parameters 5 and 6 related to radiation safety equipment and environmental radiation exposure monitoring showed moderate improvements, supported by the strengthening of radiation safety culture as indicated by the statistical analysis results ($F = 4.950$, $p = 0.034$, $R^2 = 0.150$).

2. Discussion

The needs assessment showed that radiation safety reporting at the Radiation Oncology Facility of RSUD Dr. H. Abdul Moeloek was still performed manually using paper-based documentation, resulting in incomplete data, delayed reporting, and difficulties in retrieving historical records. This condition contributed to the decline of the Safety and Security Index (IKK) score from 76 in 2023 to 70 in 2024, showing that weaknesses in the reporting system directly affected radiation safety performance. Similar findings have been reported in previous health information system studies, which identified manual reporting systems as a major source of inefficiency and data inaccuracy in healthcare services. To address these problems, the SPEKTRA application was developed as a smartphone-based digital reporting platform to improve accessibility, reporting efficiency, and documentation management in radiation oncology facilities. The application adopted a role-based access control system that classified users into Admin users consisting of Radiation Protection Officers and Medical Physicists, and User-level users consisting of radiographers and nurses. In addition, the application integrated an IKK simulation feature to support self-assessment and continuous quality improvement before official BAPETEN inspections, while the use of the AppSheet low-code/no-code platform enabled rapid development and cross-platform accessibility on Android and iOS devices.

The expert validation results showed that the SPEKTRA application achieved a combined feasibility score of 4.35 with a feasibility percentage of 87%, categorized as “Very Feasible.” These findings indicate that low-code/no-code platforms can produce digital systems with adequate technical quality and operational reliability for radiation safety management. Media experts provided high evaluations regarding user interface,

user experience, and system functionality, indicating that the simplified development approach did not reduce application performance. However, the language quality aspect received the lowest score, particularly regarding the difficulty of understanding technical radiation terminology for non-specialist users such as nurses. This finding highlights the importance of user-centered design principles in simplifying technical language to ensure better usability among multidisciplinary healthcare workers.

Conclusion

This research developed an innovative smartphone-based digital reporting application called SPEKTRA, designed based on user needs analysis and aligned with BAPETEN regulatory standards and the operational requirements of radiation oncology facilities. The application achieved a combined expert validation score of 4.73 or 94.5%, categorized as "Very Feasible," confirming the successful implementation of the Research and Development approach. The implementation of SPEKTRA significantly improved Perceived Ease of Use (PEOU), Perceived Usefulness (PU), and Intention to Use (ITU) with $p < 0.001$ in paired t-tests, while multiple regression analysis showed that PEOU and PU simultaneously influenced ITU ($F = 5.000$; $p = 0.014$; $R^2 = 0.270$), although only PU had a significant partial effect ($t = 2.424$; $p = 0.022$), showing that perceived usefulness was the dominant factor influencing user intention. Furthermore, the implementation of SPEKTRA showed a positive and significant relationship with the improvement of Safety Culture ($F = 4.950$; $p = 0.034$; $R^2 = 0.150$; $\beta = 0.388$) with a very large effect size (Cohen's $d = 3.048$), and contributed to the increase of the Safety and Security Index (IKK) score from 75 in 2025 to a projected simulation score of 94 in 2026 through the IKK Simulation feature. The most substantial contribution was observed in Parameter 7 concerning innovation and the updating of reporting, documentation, and record management systems.

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