Design of a Phospor Photo Stimulation Dosimeter with Webcamera Reader as an Individual Monitor of Occupational Radiation Exposure

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KEYWORDS

Dosimeter, Radiation Exposure, Webcamera Reader.

ABSTRACT:

Introduction: Besides having benefits for diagnostic imaging, radiation also has side effects in the form of biological effects that can endanger radiation workers. In accordance with the provisions of the Nuclear Energy Regulations (Bapeten) No. 4 of 2020, all radiation workers must be monitored for radiation obtained through personal dosimeters.

Objectives: Radiological installations process images with radiography computers, which can respond to radiation exposure when processed with radiography computers in the form of exposure index (EI), so it is necessary to develop using photostimulation phosphor (PSP) material, which can be read with Computer Radiography (CR) which is generally already owned by radiological installations.

Methods: This research is a research and development study conducted by experiments starting with testing the response of PSP materials to exposure parameters including voltage, current, time and irradiation distance to the PSP dosimeter.

Results: The results showed a positive response from various exposure parameters, namely there is a relationship between tube voltage and the response of the Phtostimulation detector plate.

Conclusions: The PSP dosimeter can respond to changes in voltage, distance, time in detecting radiation in the form of an exposure index which indicates that the PSP dosimeter can monitor the radiation received by Radiation workers (Radiographers).

1. Introduction

Besides having benefits for diagnostic imaging, radiation also has side effects in the form of biological effects that can endanger radiation workers. In accordance with the provisions of the Nuclear Energy Regulations (Bapeten) No. 4 of 2020, all radiation workers must be monitored for radiation obtained through personal dosimeters. Generally, personal monitors used in the form of film badges or TLDs that are cumulative in nature that are read every 3 months and must be read by an institution that has an appointment by Bapeten, so that radiation workers cannot directly know the acquisition of radiation doses during work. This results in information about the dose received cannot be immediately (real time) known the dose exposed to the body of radiation workers, therefore it is necessary to develop a dosimeter model that can be read in real time (directly). In accordance with the development of diagnostic imaging modalities, currently radiological installations process images with radiography computers, which can respond to radiation exposure when processed with radiography computers in the form of exposure index (EI), so it is necessary to develop using photostimulation phosphor (PSP) material, which can be read with Computer Radiography (CR) which is generally owned by radiological installations.

2. Objectives

In line with the advancement of diagnostic imaging techniques, contemporary radiological equipment processes images with radiography computers, which can respond to radiation exposure when processed with radiography computers in the form of exposure index (EI). Consequently, there is a need to develop a material based on photostimulation phosphor (PSP) that can be read with computer radiography (CR), which is typically used in radiological installations.

3. Methods

This research and development study was conducted through a series of experiments, beginning with an examination of the response of PSP materials to various exposure parameters, including voltage, current, time, and distance of irradiation. The study employed the use of PSP dosimeters to assess the impact of these parameters on the materials. Following the determination of the response, a dosimeter comprising a post-stimulative phosphor (PSP) material was designed in two stages. The first stage entailed the design of a PSP dosimeter in the form of a badge, while the second stage involved the design of a dose reader based on a radiation occupational health and safety information system. The reading of doses is carried out by means of a conversion from a digital dosimeter, which is the gold standard for the measurement of radiation. The analysis of the design of the PSP dosimeter model is conducted through a correlation test with exposure, voltage, distance and time parameters. The acceptance test of the dosimeter design results was conducted on 30 respondents. The quality of the information generated was evaluated with a t-test before and after the model was developed. Analyses were conducted with univariate and bivariate statistical analyses.

4. Results

The results showed a positive response from various exposure parameters, namely there is a relationship between tube voltage and the response of the Phtostimulation detector plate. Dosimeter design generally must be easy to use and not interfere with the movement of radiation workers, for that PSP which is the main detector is made into a holder for easy use.

PSP dosimeter design with a size that is not large, namely 4 x 5 cm so that it is practical if used by radiographers either in pockets or other sensitive places. The front and back design is differentiated so that it is not wrong in use. The design has a stroke, while the back is plain. This PSP dosimeter is used by officers / radiation workers during the time span of working in the radiation field in working hours at the radiology installation. After the PSP dosimeter is used by the Radiographer during the radiographic examination, to read the dose received by the PSP dosimeter, the reading is done with the radiography computer modality.

The Exposure Index (EI) parameter displayed on the CR modality will then be read with a reader system developed based on the camera and Rosberry application. The data displayed in the radiography computer display will then be lifted with a reader and convert the exposure index into a dose using a dose reader called the RASPBERRY PI BOARD UNIT SYSTEM.

Part of the EI reader machine on the PSP Dosimeter is intended so that radiation workers can record the dose obtained used during work in the radiation field and can immediately know the dose received. This is because in this reader after capturing (capture) the exposure index data that has been read by the CR monitor will be connected to the memory (SID) and will be converted by the application developed capable of converting the data captured by the camera into digital numbers and further conversion through the Rosberri application. Block diagram of PSP Dosimeter reader application work.

The PSP dosimeter that has been exposed to radiation is read with a Computer Radiography (CR) system to produce an exposure index value that is read on the CR monitor so that it can be converted in dose units, a reader is developed with the Rosberry PI Board system with the following construction: Raspberry Pi board is made with different types, namely Raspberry Pi type A, A + Raspberry Pi type B., B + Raspberry pi 2, Rasberry pi 3, Raspberry Pi zero.

The camera consists of a small circuit board (25mm by 20mm by 9mm), which is connected to the Raspberry Pi's Camera Serial Interface (CSI) bus connector via a flexible ribbon cable. The camera's image sensor has a native resolution of five megapixels and has a fixed focus lens. The software for the camera supports full resolution still images up to 2592x1944 and video resolutions of 1080p30, 720p60 and 640x480p60/90.

The use of an SD card with at least 32GB of storage for Raspberry Pi OS installation is recommended. For Raspberry Pi OS Lite, we recommend at least 32GB. can also use any SD card with a capacity less than 2TB. This memory capacity makes it possible to record all the doses obtained by the worker for a long time.

The camera consists of a small circuit board (25mm by 20mm by 9mm), which is connected to the Raspberry Pi's Camera Serial Interface (CSI) bus connector via a flexible ribbon cable. The camera's image sensor has a native resolution of five megapixels and has a fixed focus lens. The software for the camera supports full resolution still images up to 2592x1944 and video resolutions of 1080p30, 720p60 and 640x480p60/90.

The process of reading the exposure index on a PSP dosimeter is done by the following process:

1. The PSP detector is inserted into the Radiography computer reader (CR) so that the monitor on the CR displays the exposure index.
2. The Exposure Index displayed on the monitor is captured with a data capture device through the Rosberry Camera Circuit and forwarded to the Dose Calculator Informa System application on the PSP dosimeter, which consists of the following parts:
   a. Flow of Information System Monitor Exposure Index & Dose Value with PSP Dosimeter Using IoT as follows:
      This information system is designed to monitor the Exposure Index (EI) value obtained from the film badge used by the radiographer. This system utilises an IoT-based camera device connected to a Raspberry Pi to capture and read the EI value from the CR console screen within a certain time scale. The collected EI data is then converted into estimated radiation dose in millisievert (mSv) and stored in the server for monitoring and analysis.
   b. System Component. The components of this PSP dosimeter reading information system consist of:
      - IoT-based Camera Tool: This camera is responsible for capturing the CR console screen image that displays the Exposure Index (EI) value.
      - Raspberry Pi: Serves as the initial data processing centre connected to the IoT camera. Raspberry Pi will read the EI value from the image captured by the camera.
      - Information System Server: Stores and processes the EI data sent from the Raspberry Pi, and converts the EI value into an estimated dose in mSv.
      - Database: Stores EI and radiation dose data for each user (radiographer).
      - User Interface: Consists of two types of users, namely radiographers and system admins, to view and monitor the submitted data.
   c. System Flow
      - Image Capture by Camera
      - Exposure Index (EI) value reading. The ERD compiled will correlate all radiation worker data (Radiographer), exposure index data recorded and recapitulated in the database, which is needed as a radiation protection record.
      - Data Transmission to Server:
        After the EI value is read, the Raspberry Pi sends the EI data to the information system server via a network connection.
      - Conversion of EI Value to Radiation Dose:
        The information system server receives the EI data and converts the EI value into an estimated radiation dose in millisievert (mSv) using the conversion formula from Gold standard (Digital dosimeter).
      - Data Storage and Recapitulation:
        The converted EI values and radiation doses are stored in the system database. Data Access by Users (radiographers or management)
      - Monitoring and Safety of radiation work:
        This Monitoring System can be used by radiation workers with procedures and work menus available in the system.

The development of PSP dosimeter begins with ensuring the ability of PSP to respond to radiation. Furthermore, the PSP response test was carried out on the thorax, cranium, abdomen, extremities, and vertebrae, each of which measured the exposure index value of the main beam, a distance of 1 metre, a distance of 2 metres, and on the consultation table. PSP response testing is also carried out with phantom objects and without phantom objects, with the aim of seeing the difference in response when there are objects and no objects, so as to obtain the sensitivity of the PSP dosimeter response. From the test data, an evaluation was carried out to see the exposure index value seen in Computed Radiography (CR).

Table 1. Test Results of PSP Dosimeter Response to Exposure Index at various exposures for specific examination objects

NO	OBJECT	EXPOSED FACTOR				EXPOSURE INDEX	
		Tube Voltage (kV)	Voltage (mA)	Time (second)	Distance (meter)	WITHOUT PHANTOM	PHANTOM
1	Thorax	58	200	0,028	File primary	2453	728
					1 meter	690	7
					2 meter	7	7
					Consul Table	7	7
2	Cranium	80	320	0,08	File primary	3661	1760
					1 meter	438	728
					2 meter	7	7
					Consul Table	7	7
3	Abdomen	80	250	0,08	File primary	3615	1745
					1 meter	230	674
					2 meter	7	7
					Consul Table	7	7
4	Ekstremitas	70	320	0,063	File primary	3461	3061
					1 meter	403	303
					2 meter	7	7
					Consul Table	7	7
5	Vertebra lateral	100	320	0,14	File primary	3982	2433
					1 meter	624	146
					2 meter	673	583
					Consul Table	7	7

Based on the results of table 1 above, several correlations of exposure parameters can be obtained as follows: Correlation of Exposure factor to exposure index on PSP dosimeter. Dose measurement is carried out by placing the main beam PSP dosimeter with the exposure factor according to the examined organ.

Table 1 shows. The highest tube voltage used in the examination of the spine (lateral vertebrae) is 100 kV, tube current 320 and exposure time 0.14 seconds, after measurement on the main beam will produce a different exposure index (IE) without a phantom 3982 and with a phantom IE of 2433. Furthermore, for thinner objects, namely the head (cranium) with an exposure factor of 80 kV tube voltage, 200 mA tube current and time of 0.08 seconds, it produces a different exposure index, namely without phantom IE = 3660 and with phanton IE = 1760, then followed by the object of the abdominal cavity (abdomen) with an exposure factor of 80 kV, 250 mA tube current and time of 0.08 seconds, it produces a different exposure index, namely without phantom IE = 3615 and with phantom IE = 1745.

If the PSP dosimeter response to the beam with different exposure factors, resulting in different main exposure indices can be seen in the following table:

Table 2 Test Response of PSP Detector on Exposure Factor, Dose and Exposure Index on Main Beam

No	Check	Faktor ekspose			Dosis (mGy) (Dosimeter)	IndeksEksposure (EI)	
		Voltage (kV)	Current (mA)	Time(s)			
						Without phantom	With phantom
1	Thorax	58	200	0,028	0,2392	2453	728
2	Cranium	80	320	0,080	2,529	3661	1760
3	Abdomen	80	250	0,080	1,977	3615	1745
4	Extremitas	70	320	0,063	1,514	3461	3061
5	Vertebra	100	320	0,14	6,779	3982	2433

Based on table 2 above, it can be seen that in the main beam, the dose measured in the main beam, with a certain exposure factor on each object shows the highest dose on the spinal organs, which is 6.779 mGy with the highest exposure index (IE) without a phantom of 3982, and with a phantom IE = 2433, while the lowest exposure factor is on the object of the chest cavity (thorax) with a dose of 0.2392 mGy, the exposure index without a phantom IE = 24533 and with a phantom IE = 728. Based on these results, all test results show that with a dose in the same main beam, all produce a greater exposure index (IE) without a phantom, compared to using a phantom.

Correlation of PSP dosimete distance from the main beam to the exposure index. The test results show that as the distance increases both without a phantom and with a phantom, the further the distance, the exposure index value decreases.

In the Thorax object examination, there was a decrease in IE without a phantom in the main beam of IE = 2453 decreased at a distance of 1 metre IE = 690, while with a phantom in the main beam IE = 728 decreased at a distance of 1, with IE = 7. At a distance of 2 metres and behind the veil produces the same exposure index of IE = 7.

Correlation of tube voltage to exposure index on PSP dosimeter. Tube voltage is a parameter that determines the quality of X-rays and will determine the amount of radiation exposure. In this study to be carried out by changing some of the tube voltage and exposure to the PSP dosimeter and then assessed the response given by the PSP obtained the following results:

Table 3. PSP Dosimeter Response to Changes in Tube Voltage

TUBE VOLTAGE (kV)	**INDEX EXPOSURE (PSP Result)**	**DOSIS mGy**
40	28,67	0,07520
50	28,70	0,12500
60	28,82	0,84600
70	28,88	0,98700
80	28,96	1,00000
90	29,03	1,42012
100	29,11	1,69128

Based on table 3 above, the PSP dosimeter responds the higher the exposure index value and also the higher the Dose rate. Based on these data, it is known that the PSP dosimeter can respond to changes in tube voltage shown in the exposure index indicator displayed in the radiography computer.

After testing the PSP dosimeter response to all parameters of exposure distance, time and tube voltage, the PSP dosimeter design is carried out.

The relationship between exposure factor and dose is obtained by testing the dosimeter in response to changes in tube voltage and also the relationship between changes in exposure factor when the PSP dosimeter is irradiated simultaneously with a gold standard pocket dosimeter that can show the amount of radiation directly.

Table 4. Exposure index relationship of PSP response and Dose rate according to Gold standard

No	Index Exposure	Dose Rate
1	28,67	0,0752
2	28,7	0,125
3	28,82	0,846
4	28,88	0,987
5	28,955	1
7	29,03	1,42012
7	29,105	1,69128

Based on table 4 above, it can be seen that the lowest IE is 38.67 equivalent to a dose rate of 0.0752 µSv/hour, followed by IE 28.7 equivalent to a dose rate of 0.125 µSv/hour, and the highest at IE 29.105 equivalent to a dose rate of 1.69128 µSv/hour. This shows that the higher the exposure index responded by the PSP dosimeter which is juxtaposed with the pocket dosimeter as a gold standard, the higher the IE, the higher the resulting dose rate. Based on these results, the conversion calculation between the exposure index and the dose rate is then carried out. Based on these results, the equation was obtained:

$Y= 4.6481x-104.48$

With : Y= dose rate in units of µSv/hour

X = exposure index

Based on the conversion of the exposure index value to the dose, it is used to design the equation in the PSP dosimeter monitoring information system with a webcamera reader.

After the design of personal dosimeter monitor tool with PSP, then to determine the response of the dosimeter tool developed, testing with PSP dosimeter is used by Radiogrefer when doing radiography work.

Research respondents are radiographers who use PSP dosimeters at the time of data collection with the following characteristic:

Table 5 Characteristics of respondents according to gender

NO	Description	Distribution	
		Total	%
1	Man	15	50
2	Woman	15	50
	Total	30	100

Based on the table above, the respondents who were tested using the PSP dosimeter monitor were 50% male and 50% female. The characteristics of respondents based on education are as follows:

Table 6: Characteristics of respondents according to education

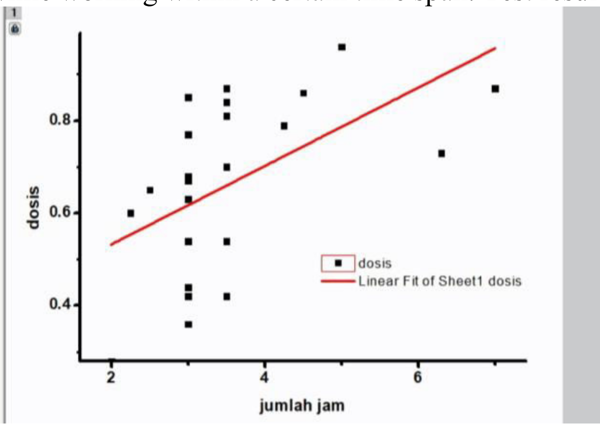
NO	Education	Distribution	
		Total	%
1	Diploma	8	26,67%
2	Bachelor	22	73,33%
	Total	30	100

Based on the table above, it is obtained that out of 30 respondents, 8 people (26.67%) have a diploma education and 22 people (73.33%) have a bachelor's degree.
The characteristics of respondents according to the length of service are described as follows:

Table 7: Characteristics of respondents according to length of service

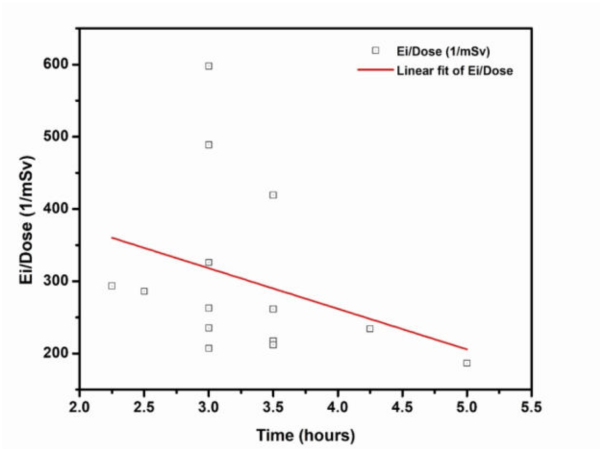
NO	Age	Distribution	
		Total	%
1	< 5 years old	1	3,33 %
2	5-10 years old	17	56,67 %
3	> 10 years old	12	40,00%
	Total	30	100

Based on the table above, out of 30 respondents, it was obtained that the working period was less than 5 years, 1 person (3.33%), a working period of 5-10 years, 17 people (56.67%) and more than 10 years there were 12 people (40.00%).
PSP dosimeter Response Test Results on Radiographers. The use test of the PSP dosimeter personnel monitor tool in the radiology installation is intended to describe the dose acquisition recorded in the PSP dosimeter when used by radiographers while working within a certain time span. Test results were obtained as follows:



Graphic 1. Time and Dose Relationship Graph on the use of PSP Dosimeter for Radiographers
Relationship between Time and Dose in PSP Dosimeters used by Radiographers. In accordance with the tabulated results of the use of PSP dosimeters in Radiology services, statistical tests were carried out to see the relationship between time and exposure index and dose.

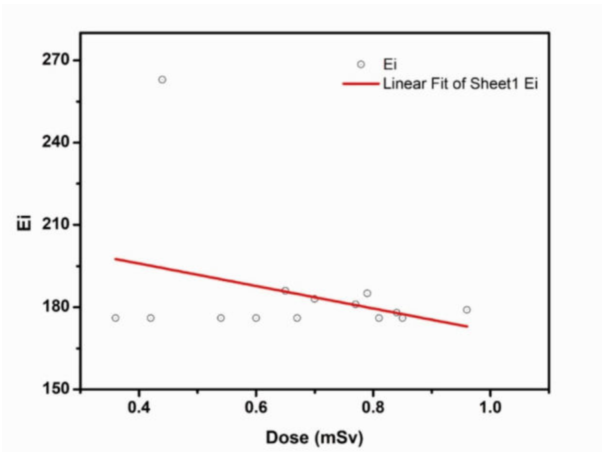
From the graph above, the longer the Radiographer is in the radiography examination room, the greater the radiation that responds to the PSP dosimeter used by the Radiographer. From the graph, the lowest time used by radiographers is 2 hours and the highest is 7 hours. While the lowest dose responded by PSP is 0.36 mSv and the highest is 1, 08 mSv.
Relationship between time and exposure index in PSP dosimeters used by radiographers. The use of PSP dosimeters by radiographers can also be analysed for the relationship between radiographer work time and exposure index. This is shown in the graph below:



Graphic 2. Relationship graph of time and exposure index, on the use of PSP Dosimeter for Radiographers

shows that it appears that the longer the time used, the response given by the PSP dosimeter is the lower the exposure index shown. The lowest time of the sample was 2 hours and the highest was 7 hours with the lowest exposure index of 7 and the highest of 209. The graph shows a linear relationship the longer the time, the lower the exposure index.

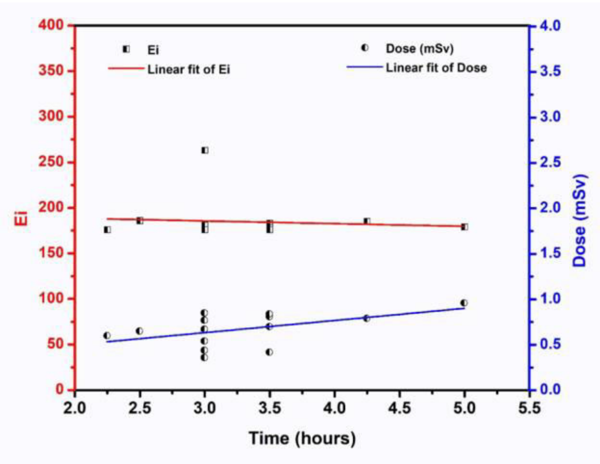
Relationship between Exposure Index and Dose in the Use of PSP Dosimeter. To be able to know the relationship between exposure index and exposure index on the use of PSP Dosimeter can be seen according to the graph below:



Dose and exposure index relationship graph, on the use of PSP Dosimeter for Radiographers

Based on the graph above, it can be seen that the greater the exposure index, the greater the dose. It can be seen that the lowest measured dose is 0.36 mSv and the lowest exposure index is 7 and with 4 samples it appears that the higher the dose the lower the exposure index.

Relationship between time, exposure index and dose rate on PSP dosimeter. The use of the PSP dosimeter by Radiographers during work compared to the gold standard pocket dosimeter can be depicted in the graph below:



Graph Relationship of time, dose and exposure index, on the use of PSP Dosimeter for Radiographers

The graph above shows simultaneously the relationship of time to exposure index and dose in the use of PSP Dosimeter by radiographers. Based on the results of these graphs, there are differences in the graph of the relationship between time and dose and the graph of time and exposure index. The graph above shows the linearity of time to exposure index which shows the higher the time the greater the exposure index recorded by the PSP dosimeter. Likewise, the graph of exposure time also shows the linearity of exposure time to the radiation dose recorded by the PSP dosimeter. Based on the two graphs of time to exposure index and radiation dose recorded in the PSP dosimeter, it can be continued to see the relationship between exposure index and dose recorded through the PSP dosimeter.

Statistical Test Results of Respondents' Assessment of the PSP Dosimeter design results. Research related to statistical tests of respondents' assessment of the results of the PSP design was conducted on 40 respondents of radiation workers (Radiographers) in radiological installations who routinely use radiation measuring devices in the form of TLD. After being used for 1 week, the results of the Wilcoxon test before and after being developed were obtained with the following results:

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Table 9 Test of differences in respondents' opinions regarding the design of the PSP Dosimeter by

No	Aspects assessed	Significance value	Meaning	Notes
1	PSP's ability to monitor dosage	0,00	There are differences before and after development	Mean rank Before : 11,5
2	Easy accessibility	0,00	There are differences	

	of dose data		before and after development	After : 210
3	Timeliness of data on dosing	0,00	There are differences before and after development	
4	Accuracy of dosage information shown	0,00	There are differences before and after development	

Based on the table above, the respondents said that the PSP dosimeter had a significant difference before and after using the PSP Dosimeter with a significance value of 0.00 (<0.05) with a mean rank before being developed of 11.5 and after being developed of 210, which means that the respondents' opinion of the PSP Dosimeter is better from the aspects of PSP's ability to monitor doses, ease of accessibility of dose data, timeliness of data on doses and accuracy of dose information shown.

PSP Dosimeter Reader Function Test Results. The PSP reader function test is intended to ensure that the device functions to read the exposure index read from the PSP dosimeter to the CR modality, the parameters tested include:

1. The ability to convert exposure index data into the Rosberry Reader application system. The data conversion capability is known from the amount of Raspberry camera capture data into the dose reading information system.
2. The ability of the Dose Reader application system to convert the exposure index into the dose rate.
3. The ability of the Dose Reader application to store a database of worker dose records.
4. The ability of the Dose Reader application to display the Dose Recapitulation of Radiation Workers.

The ability of the application to display dose recapitulation according to user needs according to the recap menu. This is assessed by respondents after being developed with a difference value of 0.00 which means there is a significant difference before being developed and after being developed.

5. Discussion

1. Correlation test of exposure factor on exposure index of PSP dosimeter with web camera reader

Assessment of the PSP dosimeter response is seen from the correlation test data and the influence of the exposure factor can be analysed. Based on the graph, it can be seen that the greater the distance of the dosimeter response in the form of the exposure index, the smaller the exposure index recorded. This is in accordance with Collet, et al., (2020) that the increase in radiation dose is called ‘dose creep’, this is caused by the use of a higher exposure factor which causes increased noise in the radiograph image(Collett et al., 2020).

2. Correlation test of voltage to exposure index on PSP dosimeter with web camera reader

From the data obtained, a graph is made of the effect between the radiation dose value seen from the consul table and the exposure index value.

a. Analysis of exposure index value against radiation dose

Radiation dose to the exposure index value at a distance of 1 metre The performance of the PSP dosimeter shows that the further the distance the smaller the exposure index and the measured dose(Supriyono et al., 2018).

The significance value of 0.00 (<0.05) was obtained, which means that there is a positive relationship between distance and radiation dose measured on the personal dosimeter with PSP. This means that the greater the distance, the smaller the dose measured on this monitor. This statement is in accordance with Ereinsen, 2020, that the combination of DAP and EI can be used as a dose indicator. Based on this research, one of the things that affects EI and dose is distance, this is also in accordance with Emeraldi, et al., (2018) that the use of EI as a dose indicator, but before clinical application, it is important to do, one of which is distance. Based on these results, the greater the distance, the smaller the exposure index, which shows that the dose hitting the PSP dosimeter is also smaller. This shows that the use of PSP dosimeters can be used to monitor radiation dose at a certain distance(Emeraldi& Hazmi, 2018).

3. Test of Relationship between distance and PSP dosimeter response

The relationship graph of the exposure index value of the thorax object can be seen in Figure 6.5 with the exposure index value without a phantom in the main beam is 2453; at a distance of 1 metre 690; at a distance of 2 metres and on the consultation table is 7. While the exposure index value using a phantom in the main beam is 728; at a distance of 1 metre, 2 metres, and on the consultation table is 7.

In this study, the farther the distance, the radiation intensity that hits the PSP dosimeter material is also less, so the exposure that hits the PSP is also less so that the exposure index read on the CR system is smaller(Lee et al., 2021). If you look at the graph above, the exposure index responded by the PSP dosimeter is at a distance of 2 metres and behind the officer's control desk. The relationship between the exposure index and the distance in the examination of the chest frame (lungs) is seen in the fixed exposure factor but the changing distance will produce a different exposure index. Based on the graph above, the R square value of 0.874 is obtained, this means that distance indicates that distance has a strong influence on the dose response recorded in the PSP dosimeter(Ko et al., 2018). This shows that the PSP dosimeter can respond to differences in distance that can result in changes in the exposure index recorded in the PSP dosimeter. This is in accordance with the requirement that the dosimeter must be sensitive to detect radiation at any distance. For radiation workers, when conducting radiographic examinations are generally at a certain distance, so a detector is needed that is able to respond to radiation at a certain distance, so that it can respond wherever the dosimeter is used(Englbrecht et al., 2020).

Conversion of Exposure Index (EI) to Dose on PSP Dosimeter with webcamera reader.

the p value = 0.00 indicates that there is a relationship between the exposure factor and the radiation dose shown in the use of the PSP dosimeter. Thus, the higher the exposure factor, the greater the amount of signal read in the CR system, as well as when the gold standard dosimeter is used, the radiation dose recorded in the PSP dosimeter(Bleiker et al., 2020).

Model of personnel radiation monitor with PSP

The design of the personal radiation monitor with PSP is designed to be as small as possible so that it does not interfere with the radiographer's work activities in carrying out radiographic examinations. This is in accordance with the requirements set by the Nuclear Energy Regulatory Agency, that personal radiation monitors, have a simple shape and also more importantly can record the exposed dose(Faggioni et al., 2017). This PSP dosimeter was chosen because PSP material has several advantages, it can detect the scattering exposure received with a certain distance in the form of an exposure index detected on the radiography computer modality which has been widely owned by radiology services. In accordance with Nowak (2020), the exposure index has a strong relationship with the dose, namely the Dose area Product (DAP), so that if it is used as a dosimeter it can detect the amount of radiation obtained by officers. Thus if this PSP dosimeter tool is used by radiographers, it can be seen directly with the CR modality(Nowak et al., 2020).

Test Results Personnel radiation monitor measuring instrument with phosphor photostimulation with web camera reader

Based on the data above, a statistical test of persion correlation between working time with exposure that provides exposure index and dose rate of pocket dosimeter used by radiographers as gold standard. From the test to 40 respondents in accordance with table 6.8.

Based on the results of the statistical test above, the p value of 0.00 <0.5, there is a relationship between radiation dose and Radiographer working time when using a PSP dosimeter. This is in accordance with the results of the findings of Yvet, 2023 (213) Photo-stimulated phosphors (PSP) are materials that store energy absorbed in excited electrons and release it in the form of light when exposed to laser energy, thus when the time of use is long, the longer the PSP used by workers, the more photons so that the dose recorded in the dosimeter is also the same. This is in accordance with the results of the statistical test above, where the value is positive, which means that the longer the time, the greater the recorded dose.

If this PSP dosimeter is used by Radiographers in radiodiagnostic services, it is expected to help monitor the radiation dose obtained by workers. There is a strong correlation between the index (EI) and dose (Dose Area Product) with a strong correlation test value of ROC>0.987. The amount of exposure imposed on the PSP Dosimeter shows a strong relationship when used by radiographers working in radiodiagnostic installations. This indicates that the greater the exposure obtained by radiographers using the PSP monitor, the greater the exposure index read in the CR device, the higher the exposure index value and the greater the radiation dose monitored. This is in accordance with the findings of Brent, et al., (2021) who stated that the strong correlation between EI and DAP is indicated by all R-squared values > 0.987. Comparison between placement ROIs showed a significant difference between EI for both placements.

Radiation services performed by radiographers are services that use X-ray radiation, as well as high-energy radioactivity. Therefore, radiographers who work in this service must also monitor the dose they receive during their work(Brent et al., 2021).

In this study, PSP dosimeters were used by radiographers working in radiotherapy installations with Cobalt 60 and Linac aircraft with 3 MeV energy. The results showed a strong relationship (p value =0.001 <0.05) between the length of time working in the radiotherapy service room and the exposure index recorded on the PSP dosimeter read on the radiography computer. With the difference in exposure index, it can be used to calculate the dose in a particular area, namely the Dose area product.

Conversion of exposure index to radiation dose on PSP Dosimeter

PSPimage plate as a detector has a sensitivity value that captures radiation energy that penetrates the material. This study aims to determine the effect of using the sensitivity factor of exposing the image plate to X-rays. The analysis was done based on the characteristic curve formed by density versus exposure log. The research was conducted by measuring the density value recorded on the image plate for each step level using a variation of the flow tube (Little et al., 2020).This is relevant to the results of this study, it can be seen that the image plate material which has a basic material Photo stimulant phosphor, with the presence ofdifferences in this response, can be used as a radiation dose measurement tool in the implementation of radiography activities. If the Imejig Plate which is composed of Phospor photo stimulation material can be used to monitor the radiation gain in the organs of radiation workers(Alghamdi et al., 2020).

The results showed a different response along with changes in tube voltage to the response of the imaging plate indicated by the exposure index read on the Radiography Computer. This is in accordance with the results of research by N Janah (2014) that the sensitivity of the tube voltage most affects the image plate. The best response sensitivity value on the iCRco brand Image Plate Computed Radiography was obtained using a voltage exposure factor of 90 kV with currents of 6.3 mAs and 8 mAs. This is based on the curve formed by the linear correlation value (Ginjaume et al., 2019)

In this study, each change in tube voltage for each specific examination (thorax, cranium, extremities, vertebrae) showed a different exposure index response as well as a different characteristic curve, indicating that IP can be used to detect the specific amount of dose exposure obtained if this IP is developed into a raadiation monitoring tool. The magnitude of the relationship between tube voltage and dose response is shown by the regression equation which indicates that the greater the tube voltage used, the higher the radiation dose monitored by the IP(Serhatlioglu et al., 2003).

The X-ray energy absorbed by the phosphor layer (per mA per unit area) was calculated theoretically as the radiographic sensitivity index using the incident X-ray photon spectrum with the Birch-Marshall formula and the sensitivity spectrum for the range 40-140 kV. The radiosensitive medium was treated as a layer involving bulk loading. The relative radiographic sensitivity of the ST-II CR plate best approximated that of the HGM/UR2 film screen at 60 kV; it was much lower for the ST-II CR plate on both sides of 60 kV. The relative sensitivities at 40 and 140 kV of the ST-II CR plate to the HGM/UR2 film screen decreased by 16 and 30%, respectively. These results imply that, in the CR system, the mAs value should be increased by 16 and 30% at 40 and 140 kV, respectively. These results are explained by the relative position of the K absorption edge of the phosphor. The theoretically calculated results are in good agreement with the experimental results obtained with an acrylic resin phantom. These results will be useful in preventing under or overexposure in CR systems and thereby controlling the dose delivered to patients (Kaplan et al., 2018)

i. Relationship between Voltage and Dose Rate in PSP dosimeter monitor with web camera reader.

Voltage is a parameter that will determine the potential difference between the anode and cathode of the X-ray plane tube (Seeram, 2000) so that the use of this PSP dosismeter also needs to be tested to ensure the PSP dosimeter response if it can provide a difference in dose rate or dose value indicating that this dosimeter is sensitive to radiation. These results can be analysed as follows:

At 40 KV voltage, the dose rate value is 0.0752, at 50 KV voltage, the dose rate is 0.125, at 60 KV voltage, the result is 0.846, at 70 KV voltage, the dose rate is 0.987, at 80 KV voltage, the dose rate is 1, at 90 KV voltage, the dose rate is 1.42, and at 100 KV voltage, the result is 1.69128. So from the graph above it is concluded that the higher the voltage applied, the greater the dose rate. In accordance with the graph above, the regression equation is obtained as with R is 0.9381 so that the following regression equation is obtained:

Y = 0.0271X-1.0203

This shows that the PSP dosimeter can respond strongly to changes in voltage to the exposure index as well as dose strongly, thus it can be used optimally to detect radiation if used by radiation officers.

It is known that at a voltage of 40 KV the index exposure value obtained is 28.67, at a voltage of 50 KV the index exposure value is 28.7, at a voltage of 60 KV the index exposure value obtained is 28.82, at a voltage of 70 KV the index exposure obtained is 28.88, at a voltage of 80 KV the index exposure is 28.95, at KV 90 the index exposure obtained is 29.03, and the index exposure of 29.10 is obtained from a voltage of 100 KV. ex Exposure

It is known that at a voltage of 40 KV obtained index exposure value of 28.67, at a voltage of 50 KV index exposure value is 28.7, voltage 60 KV index exposure value obtained is 28.82, at a voltage of 70 KV obtained index exposure of 28.88, voltage 80 KV index exposure is 28.95,

iii. Relationship of Index Exposure on PSP with Dose Rate

This PSP dosimeter has detected the exposure index after being exposed to a certain amount of radiation. Based on measurements with the Ram ion digital dosimeter used simultaneously, a certain dose was obtained according to table 6.17.

In this graph, the relationship between dose rate and exposure index is obtained. With a dose of 0.075 mSv, the index exposure result is 28.67, at an index exposure of 28.70 the dose rate is 0.125 mSv, with a dose rate of 0.846 the index exposure value is 28.82, at a dose rate of 0.987 the index exposure value is 28.88, at a dose rate of 1 the index exposure value is 28.955, at a dose rate of 1.42 µSv the index exposure value is 29.03, and at a dose rate of 1.69 the index exposure value is 29.10. According to the graph above, the line equation Y = 3.6481X-104.48 is obtained which is then used to develop the PSP dosimeter dose reading information system.

1) Results of PSP Usage Test by Radiographers in Hospital Radiation Installation

The test of the use of the PSP dosimeter personal monitor in the Radiation Installation is intended to obtain a study of the relationship between the length of time the radiographer uses the PSP dosimeter and the exposure index recorded on the PSP dosimeter(Supriyono et al., 2018).

The relationship between time in the radiation field in the implementation of radiotherapy irradiation has a significance value of 0.007 (<0.05), which means that there is a relationship between the time in the radiation field and the exposure index recorded in the PSP personal dosimeter monitor. In accordance with these results, the longer the time in the radiation field, the higher the exposure index recorded on the PSP dosimeter monitor. This is according to Xiaotong Fan (124), (2019) with Photo-stimulated luminescence (PSL) is a process in which trapped charges are released by photons and produce luminescence through recombination. The variegated optical characteristics of photo-stimulated phosphors (PSPs) have attracted growing attention and a large amount of work covering the mechanism and application of PSPs has been addressed. The optical data storage capacity resulting from the many defect states allows PSPs to be applied to information storage. In addition, PSP provides potential applications for anti-counterfeiting, due to the colour change resulting from the tunneling process. Recently, near infrared (NIR) light PSPs have been developed, showing great potential for in vivo bio-imaging, as PSLs characteristic of stable and high noise signal ratio. In this review, we will introduce the development and process of PSP, and the challenges and future progress have also been pointed out(Pandey et al., 2010).

2) Statistical test results of respondents' assessment of the design of PSP dosimeter

The respondents' assessment after using the PSP dosimeter showed a t-test value of 0.00 which means there is a difference before the development and after the development of the PSP dosimeter. To determine the assessment of the PSP dosimeter, it appears that the mean rank value after development (210) is greater than before development (11.5), this shows that respondents prefer the PSP dosimeter from several aspects assessed. .

The results of the t-test based on the questionnaire given to respondents from the 4 aspects of the ability to monitor radiation, the accuracy of dose data, timeliness and the recording of dose data show an absolute difference with a value of 0.0 meaning that before being developed and after being developed has a significant difference, This result is also supported by the results of the mean rank after being developed of 222> from before being developed 111 which means that the PSP dosimeter with a web camera reader is rated by respondents better. This is in accordance with the provisions of the Nuclear Energy Regulatory Agency, the main dosimeter requirement is to be able to monitor radiation quickly. The PSP dosimeter model with webcamera reader is designed using devices that are already in radiological installations which are generally only used for image processing, with this model in addition to CR devices used to process images can also be used to monitor radiation for both officers and patients. This is an advantage of the PSP dosimeter model compared to personal radiation monitors Film badge, TLD commonly used by radiation workers. If the Film badge and TLD have been recording radiation cumulatively within a period of 1-3 months, then the PSP dosimeter with web camera can monitor directly in real time as soon as the radiographer finishes the task in the radiation field, this is very supportive of the radiation protection programme, namely monitoring the fast time (real time) so that radiographers can preventively detect the radiation received and can take precautions against biological effects that occur. Based on the results of dose acquisition received by respondents, the lowest dose rate received by respondents was 0.08 µSv/hour and the highest was 0.71 µSv/hour. This shows that the exposure recorded by the PSP dosimeter with a web camera reader can detect radiation that is small below the recommendations set by the Nklir Power management agency which recommends the Dose Limit value (NBD) in 1 year is less than 20 mSv / year, if reduced per hour is less than (< 0.12 µSv / hour. This shows that the PSP dosimeter is sensitive to detect up to hourly time derivatives, this also shows the accuracy of the PSP dosimeter model for monitoring radiation.

Rosberry-based PSP Dosimeter Reading Information System with web camera reader

The PSP dosimeter works to display the dose through the exposure index reading system displayed on the radiography computer modality (CR) monitor, this was chosen because most radiology services already have CR modalities for image processing. If PSP dosimetry is developed, then there is no difficulty for radiographers to know the dose received while working in the radiation field. This is in line with the regulation of the Nuclear Energy Regulatory Agency (215) that in order to limit the limitation of radiation dose values received by workers, nuclear installation employers are required to provide personal dosimetry monitors.

The advantages of this PSP dosimeter according to the dosimetry monitor requirements (35) include aspects of Efficiency, Speed, resolution and consistency. The PSP dosimeter is declared efficient, because by using one PSP detector plate, it can be used alternately by several employees in the hospital by entering the identity account of each employee before reading the exposure index. PSP allows for reuse in accordance with (121,35) that the PSP plate after exposure to radiation (exposure), there is a change in its electron trap, because it experiences excitation, this electron transfer when read by the sensor reader on the CR by laser light will be captured and converted into a digital signal which is converted into the Exposure Index (IE) value displayed on the monitor screen. This IE magnitude is captured by the PSP dosimeter model which is read by the Ropberry PI3 camera into characters that will be converted to the dose value, and after the EI is displayed, the PSP detector plate will be empty again so that it can be used again. When compared to commonly used detectors such as Film Badge, TLD which each personnel must have one by one, then this PSP dosimeter becomes more efficient.

The advantage of the PSP dosimeter from the aspect of speed is seen from the dose reading time. The digitally connected PSP dosimeter with a web-based information system allows each time after the PSP is read by the CR reader automatically through the radiation monitoring system application that has been developed, the average reading time lag is only about 1-3 seconds depending on the existing network service. This is in accordance with (35,121), that radiation monitoring can be done quickly as much as possible so that preventive action can be taken to prevent biological effects that occur. When compared to the commonly used dosimeters, namely film badges and TLDs whose readings according to Perba (215) are carried out by accredited institutions, generally the readings are obtained every 3 months and are cumulative, then this PSP dosimeter becomes faster for monitoring radiation doses.

Resolution requirements required by dosimeters in accordance with (35) Resolution aspects, PSP dosimeters are developed using the principle of digitisation and developed with a recognition pattern with programming

to obtain a data sheet of values processed using goggle colab where a computerised system has carried out an analysis of the equation of the numbers displayed on the monitor and those detecked by the webcameraraspbery PI 3 are all the same, so that the value converted into a dose in the information system accuracy can be guaranteed. In this study, the accuracy of capturing the value after image processing guarantee with google colab of miising annotation/value is 0.0, out of 37 images meaning that out of 37 captured images all are detected in the PSP dosimeter information system meaning that all exposure index values are detected correctly(Dianasari&Koesyanto, 2017).
Another advantage of the PSP dosimeter according to requirement (35) is the construction. In terms of PSP dosimeter construction, there are 3 important things from the aspect of the shape of the PSP dosimeter and the aspect of the shape of the capture camera and the developed dose information system. The aspect of the PSP dosimeter shape with a simple badge model 4x5 cm in size, very simple so that it is easy to use, equipped with a cocart strap or cocart pin allows this dosimeter plate to be easily used by radiation workers. The aspect of reading, this tool is enough to use the Radpberry PI 3 webcam camera in construction there is no difficulty, the worker after reading the PSP dosimeter just captures and the reading results are automatically connected in the information system so that the construction does not require a special system as the Film dosimeter model or TLD, which requires a special reader by comparing with a calibrated device. From the aspect of dose recording, with the database system developed in the radiation monitoring system with the PSP dosimeter, the data recorded in the PSP will automatically become a database according to the account entered, making it easier for radiation protection officers in charge of recapitulating the results of individual dose monitors(Fan et al., 2019).
This is in accordance with Bapeten regulation no 4 of 2020 (215) that nuclear installations in the context of limitation are required to routinely record radiation worker doses and report Bapeten. The existence of the developed information system model is very helpful for radiation protection officers to carry out radiation safety quality assurance. With the implementation of this information system, collecting and monitoring the Exposure Index value becomes more efficient and accurate. This makes it possible to maintain the work safety of radiographers by minimising the risk of excessive radiation exposure through continuous monitoring and data analysis(Indrati R, 2017).
The designed information system acts as a tool for monitoring and managing radiation exposure received by radiographers through the utilisation of IoT technology and integrated computing. The system incorporates the use of an IoT-based camera device connected to a Raspberry Pi to capture Exposure Index (EI) values that are displayed on the CR console screen. The periodically captured EI data is then read by the Raspberry Pi and sent to the information system server via a secure and reliable data communication network. The information system server is responsible for receiving, storing and processing the EI data, including the conversion of EI values into estimated radiation dose in millisievert (mSv), and storing the conversion results in a centralised database(Dehaghi BF, 2017).
The output of this information system includes a recapitulation of radiation exposure data received by each radiographer in the form of figures and diagrams of radiation exposure trends. This data can be accessed by individual users (radiographers) and system administrators through a specially designed user interface. This interface allows users to monitor daily EI values, total radiation dose received, as well as view historical analyses and trends of increasing radiation exposure. Thus, this information system not only assists in automatic and accurate data collection but also in the analysis and continuous monitoring of radiation exposure, ensuring the safety and health of radiographers in the long term. This is in accordance with Bapeten Regulation No. 4 of 2020 that to ensure that the Dose Limit Value (NBD) of workers is not exceeded, the permit holder (Nukir installation employer) must conduct dose monitoring. The dose reading information system developed can function to monitor the dose actively (directly), because the dose acquisition can be directly seen every day after finishing work. This is in accordance with bepaten regulation no 4 of 2020 article 33 where personal dose monitoring must be carried out using an active dosimeter. With the development of the PSP dosimeter monitor, it is hoped that it can help nuclear installation employers to monitor the dose of worker personnel. In accordance with the provisions of the regulation, article 34 explains that the use of active dosimeters must be recorded after interventional radiological services(Dwi Nanda et al., 2021). This PSP dose reading information system in addition to reading the dose recorded in personal dosimeters, also helps

computer-based recording, thus it is expected to help nuclear installation employers to monitor radiation safety in their respective work areas, so that efforts can be made to prevent radiation accidents in their respective work areas. This is in accordance with Bapeten's provisions that nuclear installation employers must ensure radiation safety by monitoring the safety of personnel working with radiation (125)(Parikh et al., 2017).

Although this PSP Dosimeter model has been designed as much as possible, there are some limitations, including the media for transferring PSP readings for service institutions that do not have a small CR reader, it is necessary to anticipate the reading by attaching the PSP to the size of the image plate size available at the health service institution, this requires training. Further research can be developed to design a reader holder according to the size of the PSP. This tool needs to be developed by adding a sensor if a dose is detected that exceeds the limit value (NBD) set by the Nuclear Energy Regulatory Agency.

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