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Optimization Of Sr-W Radiation Shield On Radiation Dose Absorption And Radiographic Image Quality In Abdominal Ct Scan Examination

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Abstract—This study aims to explore the potential use of tungsten silicon rubber composite (SR-W) with percentages of 100-0, 97-3, 91-9, 88-12, 85-15 wt% as a radiation shield on abdominal CT scans, to reduce the radiation dose of gonadal organs (ovaries and testes) without significantly degrading image quality. SR-W materials are characterized through homogeneity measurements to determine the uniformity of particle distribution in the polymer matrix. Furthermore, tests were conducted to assess radiation dose reduction using anthropomorphic phantoms, either without or with the addition of SR-W, at tube voltage variations of 80, 100, 120, and 140 kVp. Image quality evaluation was conducted by comparing the areas covered and those not covered by SR-W. The results showed that SR-W with a composition of 94-6 wt% had homogeneity and the most optimal image quality compared to other composition variations. Although the highest radiation dose reduction was achieved at an 86-15 wt% composition, SR-W at 94-6 wt% provided the best balance between dose reduction, noise reduction, and image contrast enhancement on CT Scan examinations. The results of this study have the potential to be applied clinically to optimize dose and image quality in abdominal CT Scan procedures.

Keywords— CT Scan Abdominal, Silicone Rubber-Tungsten, Dose Reduction, Image Quality

I. Introduction

Abdominal and pelvic CT scans are widely used in clinical settings, as they can clearly display anatomical structures and support diagnosis; however, the large and multi-phase scanning area raises concerns regarding the high dose of ionizing radiation, as the gonadal organs receive a greater dose value than other organs [1]. Because the weight factor of the gonadal tissue is greater than that of other organs [2]. A decrease in radiation dose results in an increase in the noise level in the image, thereby reducing image quality and reducing the accuracy of diagnosis [3]. Considering both aspects, namely the dose of irradiation and image quality, a radiation shield is needed that does not significantly compromise the image quality, but can still function as a radiation shield in the field of radiodiagnostics [4].

In general, the materials used for protective materials consist of elements with high atomic numbers, such as copper (Cu), lead (Pb), tungsten (W), and bismuth (Bi [5],[6]. Alternative materials such as Tungsten (*tungsten*), a non-toxic material, have a large mass density (19.3 g/cm^3 for tungsten and 11.34 g/cm^3 for lead) as well as the ability to protect against radiation in excess of lead [7]. Although effective in inhibiting radiation, the material is less elastic, so it cannot follow the contours of the patient's body when examined with X-rays. As a solution, silicone rubber is used because it has flexible properties and easily adjusts to the shape of the body [4]. Silicone rubber has been researched for use in breast radiation shields and CT Scan Thorax examinations, with a

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material composition of SR-Pb 94-6 wt%. It is stated that the radiation shield with this composition is optimal because it can reduce the dose by 25% and the resulting image does not contain artifacts [8].

Although various studies related to radiation shielding materials have been conducted, studies that specifically examine the protective performance of Silicon Rubber-Tungsten (SR-W) are still rare, especially when it comes to varying the percentage of tungsten applied to the composite. Based on this background, the use of SR-W composite is the focus of research to evaluate its effect on the effectiveness of reducing radiation dose while maintaining the quality of radiography images at an optimal diagnostic level, and becoming another alternative material to be used as a radiation shield that is expected to be able to protect the gonadal organs in abdominal CT-Scan examinations.

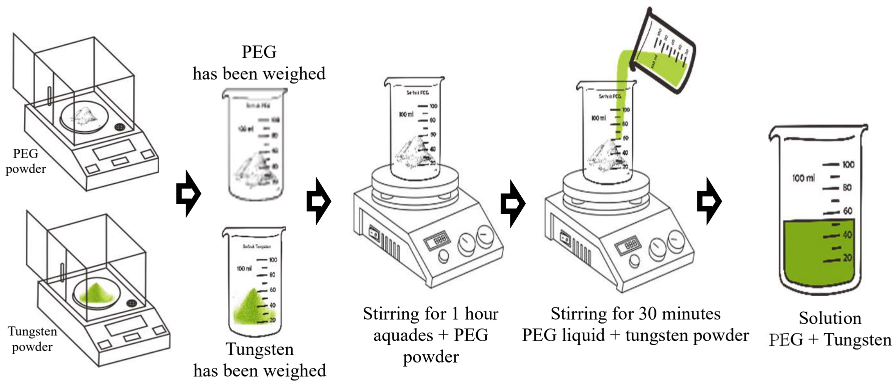
II. Research Procedure

2.1. Materials

The materials used in this study consist of silicone rubber (RTV-52) as the main matrix, tungsten powder (W) as the filler, Polyethylene glycol (PEG4000) as the binding agent, Aquadest as a PEG solvent, Bluesil catalyst to accelerate the polymerization process, and silicone oil as the mold coating material. The equipment used includes a digital balance to weigh the mass of the material, a hot plate stirrer to dissolve PEG, a mechanical mixer for the mixing process, an ultrasonic bath used in the sonication stage to increase the homogeneity of the mixture, a measuring cup to control the volume of liquid materials, and an acrylic mold that has been coated with silicone oil so that the sample can be released easily after the printing process.

2.2. SR-W Composite Synthesis

The first process of making the PEG-W solution is to dissolve 20 g PEG into 10 ml of aquades on a hot plate stirrup at 60 ºC 500 rpm for 60 minutes, stirred continuously at room temperature of 500 rpm for 30 minutes while slowly inserting W powder with variations in composition (3, 6, 9, 12, and 15 wt%) gradually, after the PEG-aquades solution-W is mixed and then sonicated to homogenize the composite. The first process for making PEG and tungsten solutions is illustrated in Figure 1.



Picture 1. First Process of Making PEG and Tungsten Solution

The second process involves making an SR-W composite by stirring the SR solution for 15 minutes and then mixing the PEG+W solution according to the specified composition for 30 minutes. The tungsten concentration variations are 3, 6, 9, 12, and 15 wt%. Then, the mixture is placed in an ultrasonic bath for 30 minutes to accelerate homogeneity and prevent settling. Next, the RTV-blue catalyst (comprising up to 2% of the total mass) was mixed for 10 minutes, and the resulting mixture was poured into an acrylic mold that had been coated with silicon oil. The mold was then allowed to dry. The second process for making SR-W composites is illustrated in Figure 2.

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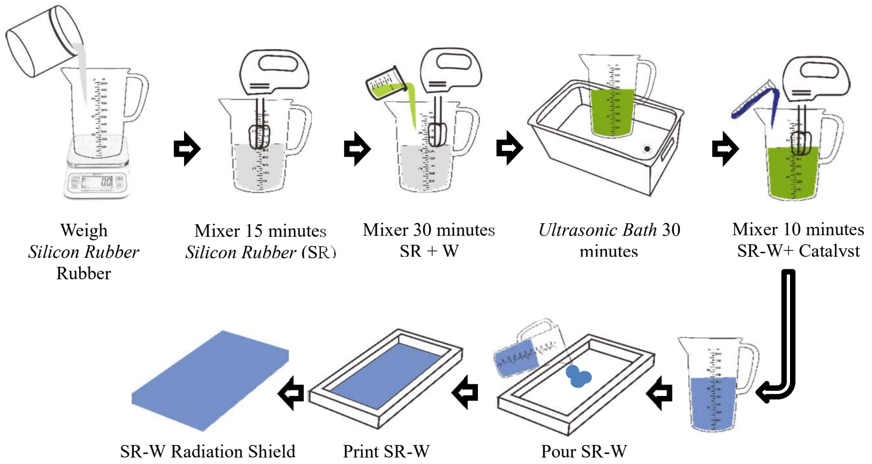


Figure 2. Second Process of SR-W Composite Manufacturing

2.3 SR-W Material Homogeneity Test

The evaluation of the radiation shield was conducted by observing the Hounsfield unit (HU) values in the radiation shield image, in order to assess the homogeneity level of the composite [9]. The purpose of this analysis was to determine the homogeneity of the SR-W composite material in terms of its ability to absorb radiation in the gonadal organs on the examination of the abdominal CT scan. Figure 3 shows the position of the region of interest (ROI) to determine the HU value of the image used in the homogeneity calculation. The homogeneity calculation was calculated according to equation (1).

The

$$H = \left(1 - \frac{|HU_{max} - HU_{min}|}{HU_{min}}\right) x100\% \quad (1)$$

homogeneity index (H) was calculated using eq. (1), where HUmax and HUmin represent the maximum and minimum CT numbers measured within the region of interest. A higher value of H indicates better uniformity of the material.

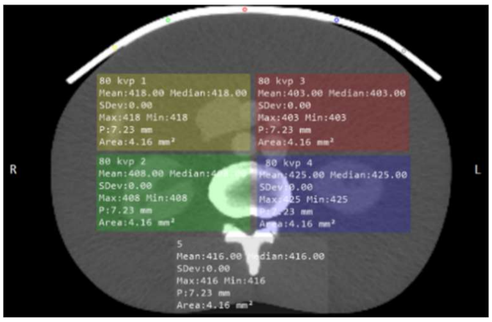


Figure 3. Location of ROI Size 3.27 mm^2 on Radiation Shield

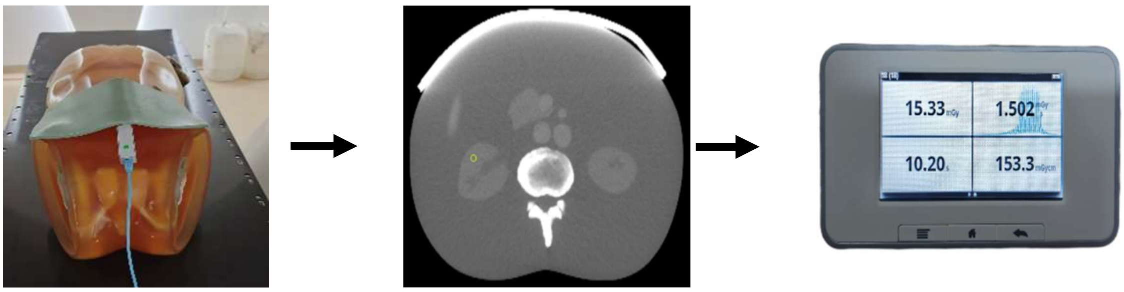
2.4 Dose Absorption Test

This study aims to evaluate the radiation dose on the surface of the gonadal organs during the abdominal CT Scan examination procedure using a GE Discovery RT CT Scan machine and a Raysafe X2 CT Sensor multimeter as a dosimetry instrument and phantom using a CT whole body phantom PBU-60. The CT sensor is placed precisely on the abdominal area of the anthropomorphic phantom to represent the anatomical position [10]. The Raysafe X2 CT Sensor device, which is equipped with a built-in electrometer, is connected to the X2 Base Unit via a USB cable to directly read and record the results of radiation dose measurements. Measurements were performed using scanning parameters as shown in Table 1.

Tabel 1 Parameter Pemindaian

No	Parameter	Input
1	Mode	Helical
2	kV	80, 100, 120, 140
3	mA	Auto mA
4	SFOV	Large
5	Slice thicknes	5 mm

Table 1 describes the scanning parameters used. The helical mode allows continuous data acquisition during gantry rotation, resulting in faster and more even volume coverage. Variation of tube voltage (kV) to evaluate the effect of changes in X-ray energy on image quality and the resulting radiation dose. Auto mA which automatically adjusts the current based on the thickness and density of the anatomy to optimize the balance between noise and dose. The width of the scanning field to ensure the phantom object coverage area is completely within the field of view. Meanwhile, the slice thickness is used to maintain image homogeneity and reduce noise, while maintaining the accuracy of CT number value measurements [11]. The radiation dose measurement flow is described in Figure 4.



(a) (b) (c)

Gambar 4. (a) Posisi perisai radiasi, (b) Hasil pemindaian, (c) Output dosis radiasi

Figure 4 explains the radiation dose measurement flow, namely, (a) shows the position of the SR-W radiation shield in relation to the phantom and detector, image (b) shows the CT Scan image results, and the right part is a display of the radiation dose output.

2.5 Image Quality Measurement

Signal-to-Noise Ratio (SNR) is a quantitative measure that compares the level of a signal (useful information) to the level of *Noise* (random interference) in the imaging system. SNR is a key indicator of signal quality commonly used in medical imaging [12]. Signal-to-noise ratio was calculated according to equation 2.

$$SNR = \frac{\mu_{signal}}{\sigma_{noise}} \qquad (2)$$

The signal-to-noise ratio (SNR) was calculated using eq.(2), where μ_{signal} is the mean CT number and σ_{noise} is the standard

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deviation of noise.

The Contrast-to-Noise Ratio (CNR) is a quantitative parameter in an imaging system that indicates the ability to distinguish an object from its background image, considering the level of interference or noise in the image [13]. Contras-to-noise ratio was calculated according to equation 3.

$$CNR = \frac{\mu_O - \mu_{Bg}}{\sqrt{\sigma_O^2 + \sigma_{Bg}^2}} \quad (3)$$

The contrast-to-noise ratio (CNR) was calculated using eq. (3), where μ_O and μ_{Bg} represent the mean CT numbers of the object and background regions, respectively, and σ_O^2 and σ_{Bg}^2 denote their corresponding noise standard deviations. Figure 5 shows the position of the ROI to determine the HU value of the image used in the calculation of SNR and CNR values.

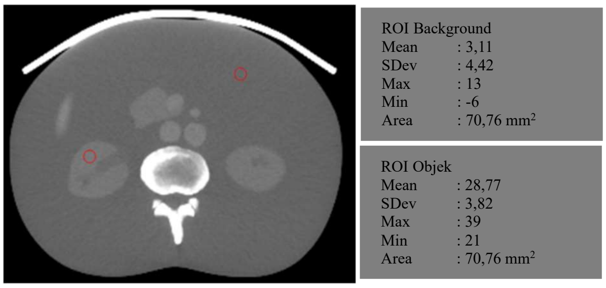

Figure 5. Region *of Interest* (ROI) Location

III. Results and discussion

The gonadal radiation shield, made of Silicon Rubber and Tungsten (W) composite with a thickness of 5 mm, a length of 27 cm, and a width of 14 cm, can be seen in Figure 6. Furthermore, this shield sheet was tested for its ability to withstand X-ray radiation of the gonadal organs on an abdominal CT scan. Photos of the gonadal radiation shield made of SR-W show that the color changes from light blue to dark green as the wt% W concentration increases from 0 to 15%, where the color difference is caused by variations in tungsten percentage. Visually, the shield surface is flat in the absence of empty cavities or air bubbles.

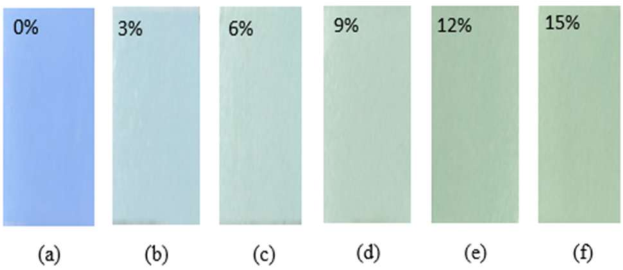

Figure 6. Shielding of gonadal radiation results from sites at SR-W percentage variations; (a) 100-0, (b) 97-3, (c) 94-6, (d) 91-9, (e) 88-12, dan (f) 85-15 wt%

3.3 Radiation Shield Homogeneity Test (SR-W)

The homogeneity of the Hounsfield unit (HU) value in the CT Scan image was determined by evaluating the uniformity of the HU value in the Region of Interest (ROI) placed at several different positions within the radiation shield [14]. Homogeneity is determined by the difference (difference) or standard deviation (standard deviation) of the HU value between the ROI. The smaller the difference in HU values between areas, the more homogeneous an image will be [15]. The results of the homogeneity calculation as shown in Table 2.

Table 2. Homogeneity of gonadal radiation shields

Radiation Shield (wt%)	Hounsfield Unit						Homogeneity (%)
	Right Side	Right Center	Center	Left Center	Left Side	Average	
SR-W 100-0	418	408	403	425	416	414	94.7
SR-W 97-3	751	731	766	741	822	762	88.1
SR-W 94-6	1119	1102	1121	1167	1174	1137	93.7
SR-W 91-9	1481	1432	1586	1528	1639	1533	86.5
SR-W 88-12	2120	1903	1715	1987	2096	1964	79.4
SR-W 85-15	2365	2164	1874	2241	2366	2022	77.7

In Table 2, the homogeneity value of HU decreased from 94.7% in SR-W 100-0 to 77.7% in SR-W 85-15 wt%. This decrease indicates that the distribution of tungsten in the rubber silicon matrix becomes less uniform at higher W concentrations [16]. These results demonstrate that increased tungsten concentrations effectively enhance optical density and X-ray attenuation, but impact the internal uniformity of the material. Therefore, optimization of the composite mixing method is needed. Overall, the homogeneity test results stated that the homogeneity value of the radiation shield ranged from 77.7% to 94% which indicates that the entire sample had a fairly high level of homogeneity (>75%) for each percentage variation, and the optimal homogeneity of 93.7% was found in samples with the composition of SR-W 94-6 wt%.

3.4 Effect of SR-W Composition Variation and Tube Voltage Variation on Dose Absorption and Radiographic Image Quality.

3.4.1. Radiation Dose Absorption

The development of radiation shield materials continues to be pursued to reduce the radiation dose received by patients without compromising image quality. The evaluation of the shield's effectiveness was carried out by measuring the variation in absorption dose in the phantom when CT scans were performed at various tube tension values (kVp). The voltage of the tube plays a crucial role in determining the energy of X-ray photons. The higher the kVp value, the higher the energy of the photons produced, which in turn affects the level of radiation attenuation by the shield material. Therefore, tests were conducted on 4 kVp variations to obtain a comprehensive understanding of the performance of each ingredient under various clinical conditions. The results of the dose absorption test are shown in Table 3.

Table 3. Absorbed dose data with tube tension variation

Radiation Shield (wt%)	Absorbent Dose (mGy)				% Radiation Dose Reduction			
	80 kVp	100 kVp	120 kVp	140 kVp	80 kVp	100 kVp	120 kVp	140 kVp
No Sample	22.36	24.33	35.04	50.25	-	-	-	-
SR-W 100-0	19.74	22.24	32.68	47.08	11.72	8.59	6.74	6.31
SR-W 97-3	17.57	20.25	29.98	43.61	21.42	16.77	14.44	13.21
SR-W 94-6	15.86	18.48	27.63	40.67	29.07	24.04	21.15	19.06
SR-W 91-9	14.26	16.9	25.64	38.01	36.23	30.54	26.83	24.36
SR-W 88-12	13.32	16	24.45	36.27	40.43	34.24	30.22	27.82
SR-W 85-15	12.69	15.27	23.4	34.85	43.25	37.24	33.22	30.65

Based on the results shown in Table 3, it can be seen that all radiation shield materials show the ability to reduce absorbed doses compared to conditions without shields. The largest dose reduction percentage was observed in the SR-W 85-15 wt%composite for all tube tension variations, specifically 43.25%, 37.24%, 33.22%, and 30.65%. Overall, these results show a clear relationship between increased tungsten percentage and radiation absorption effectiveness. From these results, silicon rubber–tungsten composites can be used as radiation shielding materials, with efficiency that can be regulated through variations in the percentage of tungsten added. The pattern of radiation dose reduction, as indicated by the measurement results, is illustrated in Figure 7.

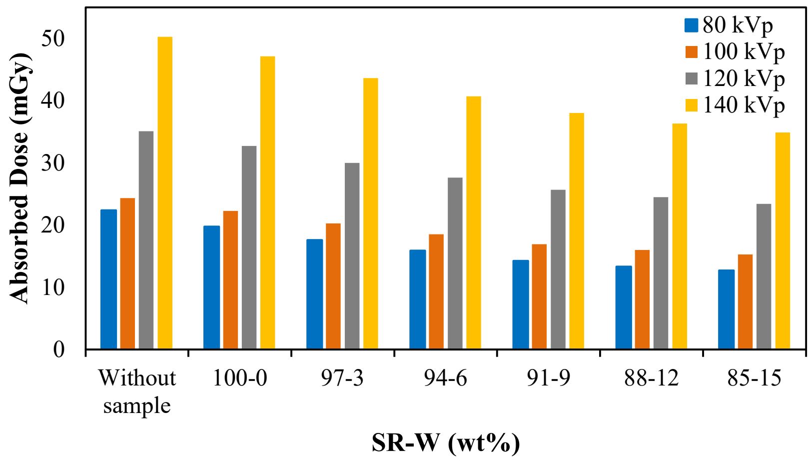

Figure 7. Graph of the relationship of tungsten concentration to radiation dose with tube voltage variation

Figure 7 illustrates a decrease in dose proportional to the increase in tungsten percentage, as tungsten has a high atomic number and density, enabling it to increase photoelectric interactions at low energies and Compton scattering at medium energies. Thus, the higher the tungsten concentration in a composite, the greater the material's ability to absorb radiation [17].

3.4.2 Image Quality

The image quality, as measured by the use of tube voltage ranging from 80 kVp to 140 kVp, exhibits an increasing trend in SNR and CNR values in most samples, indicating a decrease in relative noise and an improvement in signal stability, as shown in Table 4. The use of radiation shields made of SR-W composite has an impact on image quality, where the higher the percentage of tungsten, the lower the SNR and CNR values [18].

Table 4. SNR and CNR Values of Gonadal Radiation Shield SR-W

Radiation shield (wt%)	Tube Voltage Variations							
	80 kVp		100 kVp		120 kVp		140 kVp	
	SNR	CNR	SNR	CNR	SNR	CNR	SNR	CNR
No Sample	2.9	5.3	6.6	6.0	5.4	5.2	13.1	8.0
SR-W 100-0	3.7	6.2	4.9	4.4	6.4	5.4	11.8	8.0
SR-W 97-3	2.6	5.5	4.3	5.2	11.4	4.6	7.2	4.3
SR-W 94-6	3.8	6.1	8.7	7.0	15.7	6.5	11.1	4.8
SR-W 91-9	3.1	3.7	2.5	1.9	6.5	3.8	12.7	4.7
SR-W 88-12	2.5	3.1	3.9	2.4	9.3	4.6	10.5	3.7
SR-W 85-15	2.8	3.4	4.5	2.3	9.9	2.7	7.8	2.2

Based on Table 4, under conditions without and with the use of radiation shields. SNR values tend to fluctuate, and the highest value is observed at SR-W 94-6 wt%, as described in Figure 8. Based on Figure 8, the fluctuations in decline are due to variations in tungsten composition and several technical factors, namely changes in photon statistics, image reconstruction, and the use of auto mA during sample testing [19]. A CT scan system with auto-exposure (auto mA) has a decrease in intensity due to the radiation shield, but is compensated by an automatic increase in tube current, which can maintain and even increase the SNR as the system adjusts the noise.

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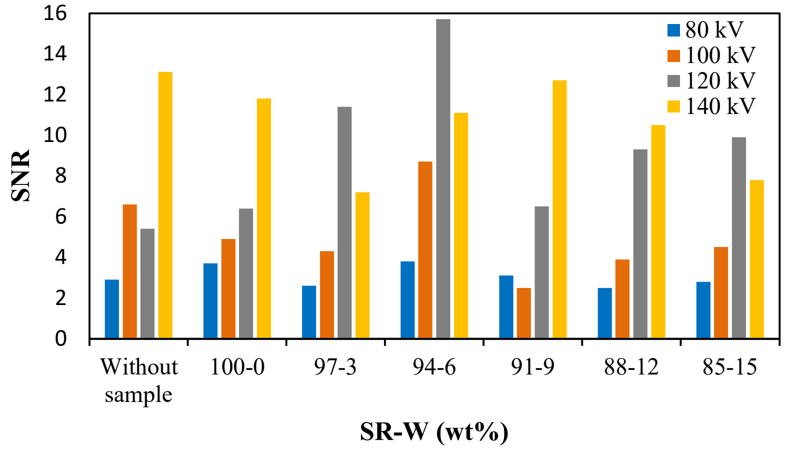

Figure 8. Graph of the signal value to noise ratio (SNR) of the SR-W radiation shield

The CNR parameter is used as the primary indicator of image quality because it describes the imaging system's ability to distinguish low-contrast objects from noise. Thus, the change in the CNR value at each variation in the percentage of SR-W and the variation in kVp give an idea of the extent to which the use of the SR-W shield affects the overall image quality. Based on Table 3, the CNR value tends to decrease and fluctuate, and the highest value is at SR-W 94-6 wt%.

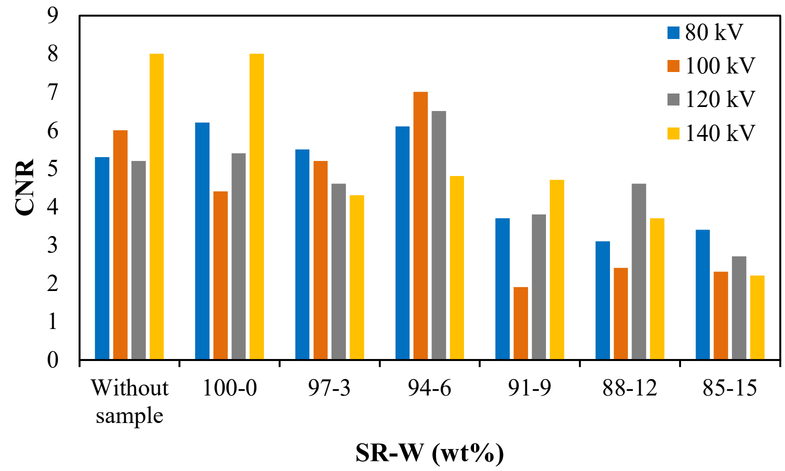

Figure 9. Graph of the contrast value of the noise ratio (CNR) of the SR-W radiation shield

Figure 9 shows a graph of CNR values on various SR-W compositions. It can be seen that there is a fluctuation in the CNR value due to variations in tungsten composition and several technical factors, namely changes in photon statistics, image reconstruction, and the use of auto mA during sample testing [20]. The use of a radiation shield made of elastic SR-W composite is able to disperse secondary radiation subtly, thereby reducing the streak of artifacts or noise mottles, and stabilizing the contrast between tissues, as indicated by the increase in CNR values.

This study used material testing with auto mA scanning parameters, which raised concerns about the use of patient shielding in CT due to potential interference with the automatic exposure control (AEC) system and quality degradation. Several studies have shown that shielding remains effective when combined with Automatic Exposure Control (AEC) technology, as long as the shield is placed after scout view acquisition. This position prevents the Tube Current Modulation system from reading the shield as increased attenuation, thus preventing compensatory increases in mA during tube rotation [21]. There are studies that show that bismuth shielding can be beneficial in clinical practice using the latest MDCT scanners. Bismuth shielding has been shown to be useful, especially when combined with other dose reduction methods, such as AEC and OBTCM [22].

IV. Conclusion

Radiation shields made of SR-W composite have been successfully made. The optimal homogeneity test result of 93.7% was at the SR-W composition of 94-6 wt%. Dose absorption testing at various tube voltage variations showed a maximum dose absorption percentage at SR-W composition of 85-15 wt%. The optimal image quality at the highest SNR and CNR values is at the SR-W percentage of 94-6 wt%. Although the greatest radiation dose reduction is found at 85-15 wt%, the SR-W of 94-6 wt% provides optimal performance between attenuation, noise reduction, and CT Scan image contrast. Based on the overall test results, it is demonstrated that the SR-W composite material can be utilized as a gonadal radiation shield during abdominal CT scan examinations.

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