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Fabrication and Evaluation of Thyroid Shield from Silicone Rubber-Cooper and its Comparison to Tube Current Modulation in CT Examination

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Abstract:- This study aimed to fabricate thyroid shields made from Silicone Rubber (SR)-Cooper (Cu) material, analyze the effectiveness of SR-Cu shields in reducing radiation dose, and compare them with tube current modulation (TCM) in computed tomography (CT) examination. Thyroid shields were made from SR-Cu with Cu percentages of 0, 5, 10, 15, and 20%. The thyroid shields were positioned over the neck of the anthropomorphic phantom. Scanning was performed using a GE 128-slice CT scanner with fixed tube current of 150 mA and tube current modulation (TCM). The elatiscity of thyroid shields was tested using an universal testing machine (UTM). The ability of thyroid shields for dose reduction was measured using a 10X6-3CT Radcal detector, and quality of the resulted images was characterized with metric of signal-to-noise ratio (SNR) at the anterior, posterior, and lateral areas of the neck area of anthropomorphic phantom. It is found that the elasticity of the thyroid shields increased from 0.09 to 0.12 N/mm^2 for Cu percentages from 0 to 20%. The measured dose decreased as the percentage of Cu increased. 20% of SR-Cu was able to reduce the dose by 32.4% for the fix tube current. In comparison, the TCM technique reduced the dose by 44.5%. Therefore, dose reduction using the developed shields is lower than using TCM approach. It is also found that implementation of the thyroid shields did not reduce image quality significantly. It is found that there were no apparent artifacts in the images. The highest SNR was found in the image with 20% SR-Cu, which was 3.84. In comparison, the SNR using the TCM approach was 3.59. In conclusion SR-Cu shields were successfully developed and they reduced dose with relatively consistent of image quality.

Keywords:- *SR-Cu Thyroid Shielding, Tube Current Modulation, Dose Absorption, Image Quality, CT.*

I. INTRODUCTION

Computed tomography (CT) scanner is a medical imaging modality widely used in health services for many purposes, such as diagnostic radiology and treatment planning systems [1]. CT uses ionizing radiation of X-rays. The CT radiation dose is relatively high compared to other medical imaging modalities. When radiation penetrates the body during CT examination, the beam of X-rays is partially absorbed by the tissues and organs. If more energy is absorbed by an organ, then the organ will receive higher radiation dose. Each organ has a specific sensitivity [2]. It is reported that organs susceptible to ionizing radiation include the thyroid, gonads, eye lens, and breast [2]. These organs are sensitive organs so they have a higher risk of developing cancer in the future [3]. The International Commission on Radiological Protection (ICRP), for instance, has identified the thyroid has a tissue weighting factor (WT) of 0.04. It means that it has a high risk [4]. Therefore, it is essential to reduce the dose received by the thyroid without compromising the image quality for specific medical purposes.

In neck CT examinations, efforts have been made to reduce the radiation dose, such as by lowering the tube current [5]. This procedure can reduce the dose by 10-30%, but lowering the tube current can produce higher image noise level and compromise diagnostic performance [6]. Another common approach to reduce the radiation dose is by tube current modulation (TCM). TCM is an approach to dynamically set the tube current during the scan based on the attenuation of the scanned objects to achieve the desired image quality [7]. The principle of TCM is to produce several constant noises in body images of different sizes and attenuations using dynamic currents within a predetermined minimum and maximum range [8]. Another method to reduce the dose of organs is by applying an organ shield. One of the basic materials used as a shield is Silicone Rubber (SR) with additional materials having high effective atomic number with certain percentage [9].

Susanto et al. [10] developed and evaluated a combination of SR-Aluminum (Al) as a radiation shield to reduce a superficial organ dose. It was found that a 10% Al of SR-Al shield is optimal for dose optimization [10]. However, Al is only effective in absorbing low-energy X-rays and is not as effective in absorbing high-energy radiation [10]. Another study was conducted by Sutanto et al. [11] which made a thyroid shield made from SR-Lead (Pb) with 0-5% percentages of Pb and they found that the thyroid dose on the surface decreased by 34% at a 5% percentage of Pb. The limitation of their study is that it only examined and evaluated the image quality quantitatively [11]. In addition, Pb has disadvantages. One of them is that it has high toxicity if it is absorbed by the body [12].

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Therefore, implementation of other material (i.e., Copper (Cu)) mixed with SR for radiation shield is important. The addition of Cu element in SR shield is expected to improve dose reduction because Cu has high density, high effective atomic number, and high mass absorption coefficient. However, combination of SR-Cu for thyroid shields is not comprehensively investigated yet. In addition, to the best of our knowledge, there are no studies compare the results of implementation of the SR-Cu shields to those from the TCM. Therefore, this study aimed to fabricate thyroid shields made from SR-Cu material, analyze the effectiveness of SR-Cu shields in reducing radiation dose and mantaining the image quality, and compare them with TCM in CT examination.

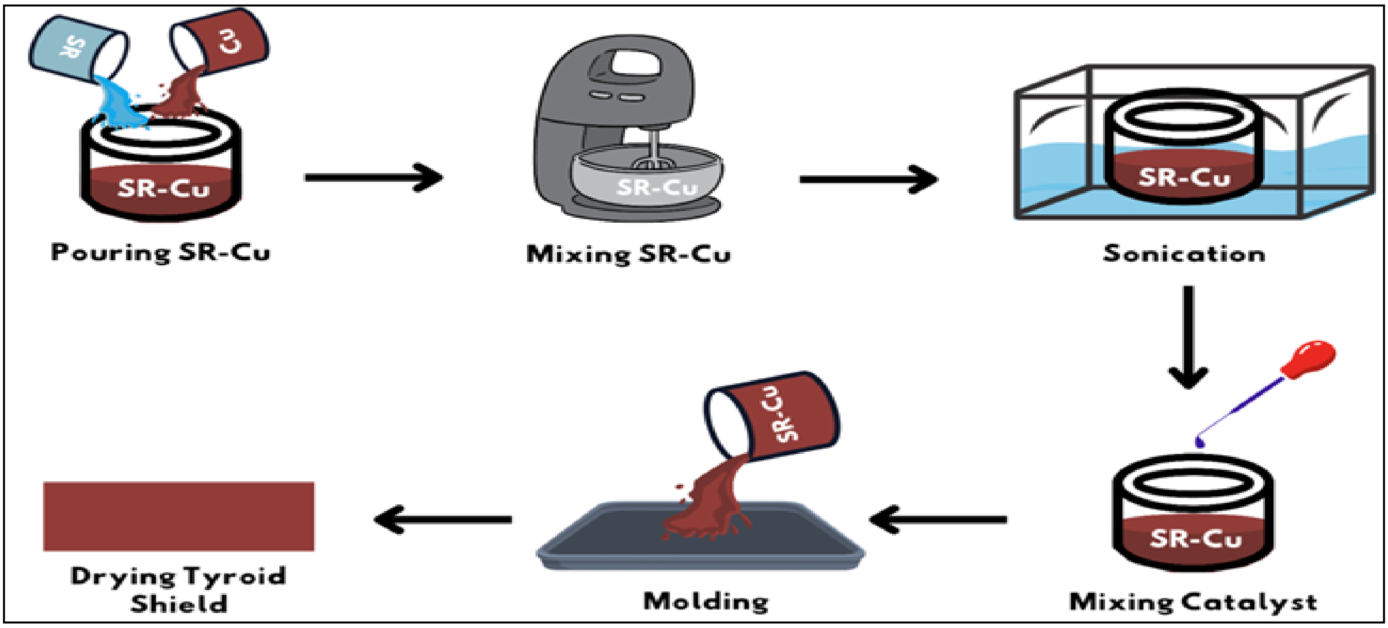

Fig 1 Procedure of SR-Cu thyroid Shield Synthesis

II. METHODS

A. *Synthesis procedure of SR-Cu shield*

SR-Cu thyroid shield was synthesized from SR material mixed with Cu. The synthesis procedure is shown in Figure 1. The SR was mixtured with different Cu percentages of 0, 5, 10, 15, and 20% for 30 minutes. Sonication with an ultrasonic bath to improve the homogeneity of SR-Cu was performed. The drying process of the thyroid shield was accelerated using the vulcanization technique. The dried thyroid shield was eventually moulded to a size of 15 × 7 × 1 cm^3.

B. *Elasticity test of SR-Cu Shield*

Young's modulus (E) in GPa indicates the degree of rigidity of a material [13]. Elasticity of the shield is an important to be tested due to it will be placed on the irregular shape of the neck surface of the anthropomorphic phantom. The elasticity test produces a stress-strain diagram, which is used to determine the tensile modulus. Young's modulus was measured using a universal testing machine (UTM) with ASTM D3039 standard. Young's modulus was calculated using equation (1).

$$E = \frac{\sigma}{\varepsilon} \quad (1)$$

Where σ is stress (GPa) and ε is strain. The lower Young's modulus value indicates that material has more elasticity, and in turn, it is good for folllowing the contour of the neck [13].

C. *Dose Measurement*

The dose absorbed by the thyroid with and without SR-Cu shields was measured using a 10X6-3CT Radcal detector (Radcal Corporation, Monrovia, California, USA). The detector was positioned on the neck surface of the anthropomorphic phantom as shown in Figure 2(a), and the SR-Cu shield was placed above the detector as shown in Figure 2(b).

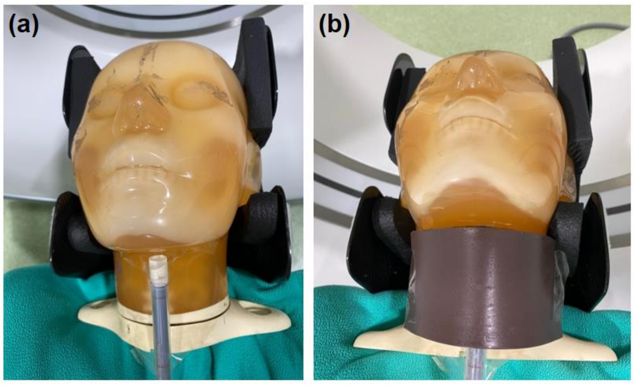

Fig 2 Position of Detector for Measuring the Radiation Dose on Surface of the Neck of Anthropomorphic Phantom: (a) Without SR-Cu Shield and (b) With SR-Cu shield.

CT used for this test was a 128 slice GE CT scanner. The scanning input parameters are tabulated in Table 1. Organ dose measurements were performed with fixed tube current of 150 mA and the TCM approach. Dose measurements were repeated three times for each parameter.

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Table 1 CT Scanning Input Parameters

Parameters	1st examination	2nd examination
Tube Voltage	120 kV	120 kV
Tube Current	150 mA	TCM
Rotation Time	0.75 s	0.75 s
Slice Thickness	5 mm	5 mm
Field of View (FOV)	320 mm	320 mm
Pitch	1.375	1.375

D. Image Quality Evaluation

The image quality obtained with and without thyroid shields was compared. In quantitative analysis, quality of image was evaluated by creating four circular region of interests (ROIs) in the anterior, lateral soft tissue, and posterior areas. The location of the four ROIs in the image is shown in Figure 3. This measurement was to determine the CT number (HU) and image noise level (HU). The signal-to-noise ratio (SNR) was then calculated. A higher SNR indicates better image quality. SNR was calculated with equation (2).

$$SNR = \frac{signal}{noise} \tag{2}$$

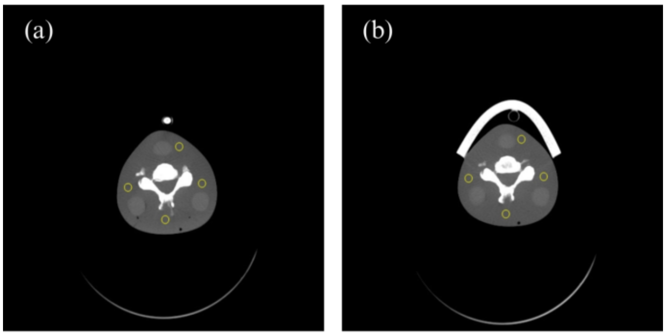

Fig 3 Location of Four ROIs on the Images: (a) Without SR-Cu Shield and (b) With SR-Cu Shield.

III. RESULT AND DISCUSSION

E. Elasticity of the Shields

The Young's modulus measured for SR-Cu shields with various percentages of Cu is shown in Figure 4. It can be seen that increasing percentage of Cu causes an increase in Young's modulus and a decrease in strain values. The elasticity increases from 0.09 to 0.12 N/mm^2 with increasing Cu percentage from 0 to 20%. It is also seen that the percentage of strain decreases as the percentage of Cu increases from 248.13 to 126.55%. The impact of the Cu on the elasticity due to the cross-linking interaction between Cu and SR as a matrix that restricts the movement of polymer chains [15-17]. The Young's modulus of the shield with 20% Cu is 0.12 N/mm^2 or equivalent to 0.00123 GPa.

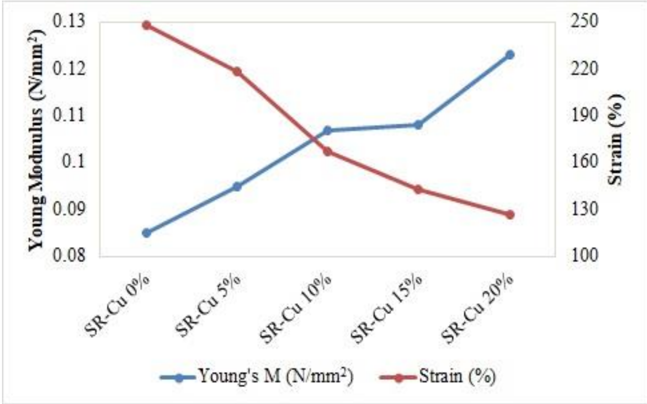

Fig 4 Young's Modulus and Strain Values of SR-Cu Thyroid Shields for Various Cu Percentages.

F. Effect of the Shields on Dose Reduction

The doses measured on the surface neck of the anthopomorphic phantom with and without shields for fix tube curret and TCM are shown in Table 2. The dose without SR-Cu shields for fix tube current is 12.21 mGy, and this dose is considered as reference for dose reduction. It is clear that the dose decreases with increasing percentage of Cu. The dose for 20% Cu is 8.24 mGy. It means that the dose decreases 32.4%. Meanwhile the implementation of TCM reduces more dose compared to the implementation of the shields, i.e., 44.5%.

G. Effect of Thyroid Shield on Image Quality

The images of the neck anthropomorphic phantom without SR-Cu thyroid shields scanned with fix tube current and TCM approach are shown in Figure 5. Image obtained with TCM is similar to image obtained with fixed tube current. The images of the neck anthropomorphic phantom scanned with SR-Cu thyroid shields having different Cu percentages of 0, 5, 10, 15, and 20% for fixed tube current of 150 mA are shown in Figure 6. It is seen that there are no obvious artifacts in the images with SR-Cu thyroid shields. Images with SR-Cu are still similar to images without SR-Cu. However, at the top region of the phantom (close to the shields), artifacts are faintly visible marked by a slightly white image. This phenomenon is increasingly obvious when the Cu percentage increases.

Numerically, CT number, noise, and SNR at the anterior, posterior, left side, and right side regions of the images of the neck anthropomorphic phantom are tabulated in Table 3. In general, there is no apparent increase in CT number values in all ROIs, including at the posterior area for the use of SR-Cu at all Cu percentages. Likewise, there is no obvious increase in noise values in all ROIs for the use of SR-Cu shields. The same results are also obtained for the SNR value. There is no obvious change of SNR value.

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Table 2 Mean Surface Dose Values with and without Shield Dose and its Comparison with the TCM Approach.

No	SR-Cu with different Cu percentage	Tube current (mA)	Measured dose (mGy)	Dose reduction (%)
1	Without shield	150	12.21 ± 0.12	-
2	0%	150	10.80 ± 0.07	13.1
3	5%	150	10.24 ± 0.06	16.1
4	10%	150	9.40 ± 0.06	23.0
5	15%	150	8.93 ± 0.12	26.8
6	20%	150	8.24 ± 0.20	32.4
7	Without shield	TCM	6.78 ± 0.04	44.5

Table 3 HU Values and Standard Deviations with and Without Thyroid Shields at Four ROI Areas.

SR-Cu with different Cu percentage	Tube current (mA)	Position of ROIs											
		Anterior			Right side			Left side			Posterior		
		CT # (HU)	Noise (HU)	SNR	CT # (HU)	Noise (HU)	SNR	CT # (HU)	Noise (HU)	SNR	CT # (HU)	Noise (HU)	SNR
Without Shield	150	20.18	8.58	2.35	15.19	5.58	2.72	14.48	3.27	4.43	11.36	2.85	3.99
0%	150	13.61	4.97	2.74	15.71	3.82	4.11	10.57	3.29	3.21	14.61	3.30	4.43
5%	150	11.29	3.52	3.21	15.00	3.89	3.86	8.310	3.56	2.33	15.60	2.95	5.29
10%	150	12.41	3.71	3.35	12.35	3.94	3.13	11.74	3.08	3.81	14.81	3.61	4.10
15%	150	19.55	6.40	3.05	12.26	3.70	3.31	12.97	3.65	3.55	16.60	3.46	4.80
20%	150	23.35	7.52	3.09	14.98	4.32	3.47	17.24	4.57	3.77	15.77	3.13	5.04
Without Shield	TCM	15.63	8.75	1.79	14.05	3.88	3.62	17.54	3.69	4.75	13.68	3.25	4.21

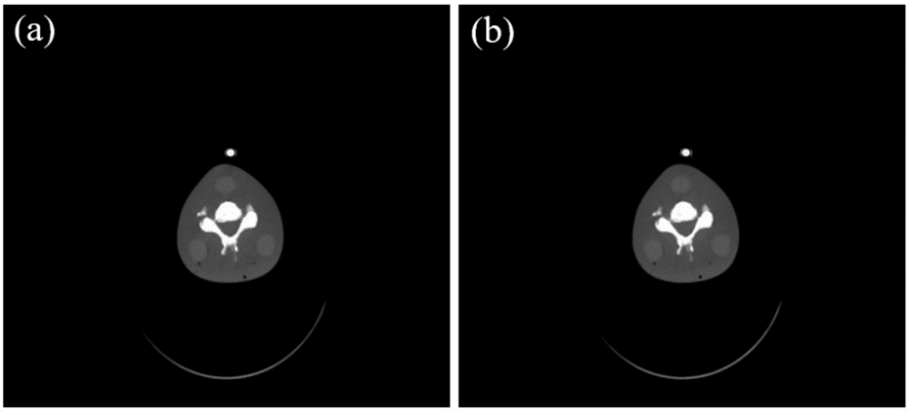

Fig 5 Images of the Neck of Anthropomorphic Phantom without SR-Cu Shield for Fixed Tube Current of 150 mA (a) and for TCM Approach (b).

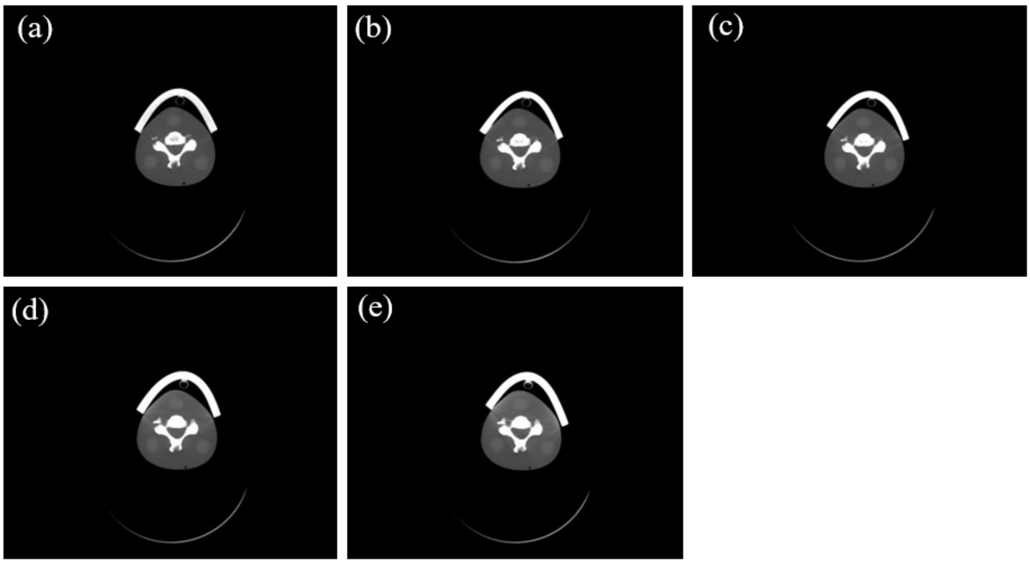

Figure 6. Images of the Neck of Anthropomorphic Phantom with SR-Cu Shields for Different Cu Percentages. (a) 0%, (b) 5%, (c) 10%, (d) 15%, and (e) 20%.

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The average of SNR values for images with SR-Cu shields scanned with fix tube current and TCM approach are shown in Figure 7. The average SNR value without SR-Cu shields for fix tube current is 3.37, the SNR values with SR-Cu shields are from 3.60 to 3.84, and the SNR value for TCM is 3.59. This indicates that the use of SR-Cu does not degrade the image. The same phenomenon is also seen in TCM application.

A simple method to reduce the surface dose on CT examination is achieved by reducing tube current. If the tube current is reduced by half, the dose will be reduced by around 50%. However, decreasing tube current increases noise in the image. At a certain level, noisy images cannot be used to make a diagnosis. Another effort to reduce dose while maintaining image quality is by implementation of TCM techniques. However, not all CT scanners are equipped with this feature.

Another simple approach to reduce the dose is by organ shields. The main problem in the use of organ shields is the appearance of artifacts on the image. The artifacts might disturb diagnosis [18, 6]. In the hope of avoiding artifacts, new thyroid shields as combination of SR-Cu with Cu percentages from 5 to 20% were developed in the current study. The effectiveness of SR-Cu shields were then evaluated from the aspect of dose reduction and resulting image quality. As a comparison, the effectiveness of SR-Cu shields were compared with other well-established techniques, namely the TCM technique.

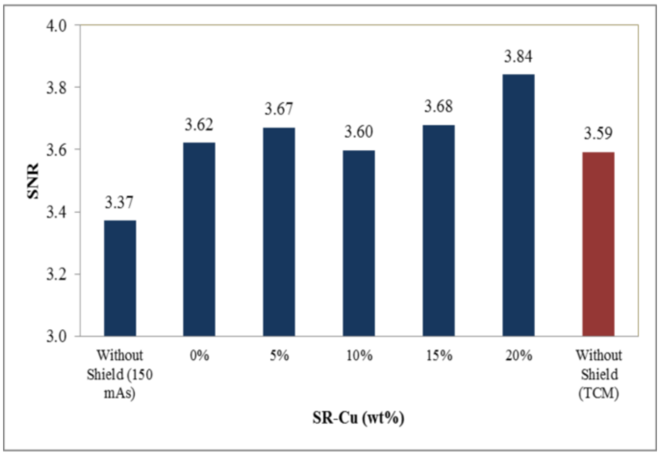

Fig 7 SNR Values of Images of the Neck of Anthropomorphic Phantom Scanned without SR-Cu, with SR-Cu for Various Cu Percentages, and its Comparison with SNR of Image Scanned with TCM Approach.

It is found that an increase in Cu percentage leads to a rise in thyroid surface dose reduction. A 20% Cu percentage in SR-Cu thyroid shields can reduce thyroid dose by up to 32.4%. However, the dose reduction using SR-Cu thyroid shields is slightly smaller than using SR-Pb thyroid shields, which is 34% [11]. It is because Pb is more effective to absorb the dose compared to Cu. Meanwhile, the TCM approach reduced the dose by 44.5%. Thus, TCM is more effective for dose reduction as previously reported [19, 20].

The use of SR-Cu thyroid shields only has a slight effect on the resulting image. The results showed that there are no significant increases in the CT number and noise in the images obtained using SR-Cu shields. In general, the SNR value obtained from SR-Cu shields is relatively the same as without SR-Cu shields. The same result is also obtained in the implementation of TCM. Thus, it can be said that the implementation of SR-Cu shield does not significantly reduce image quality as with the TCM technique.

This study has several limitations: First, the maximum Cu percentage is 20%. The impact of a Cu percentage above 20% needs to be further investigated. Second, this study only implements the SR-Cu shields on an anthropomorphic phantom. Although this phantom is similar to the patient, the effect of SR-Cu shields on the patient needs further evaluation. Third, the anthropomorphic phantom used only has one size. For neck anthropomorphic phantoms with different sizes, the dose reduction and resulting image quality may also be different. Four, in this study, the TCM used as a comparison only has one strength. When TCM with different strength levels is used, the results may also be different. Lastly, this study only performs evaluations of SR-Cu shields with one CT scanner. Evaluation of SR-Cu shields on different scanners may produce different results.

IV. CONCLUSIONS

The SR-Cu shields with different Cu percentages up to 20% were successfully developed and evaluated. The measured dose decreases as the percentage of Cu increases. 20% of SR-Cu is able to reduce the dose by 32.4%, while the TCM is able to reduce the dose by 44.5%. Therefore, dose reduction using the TCM is higher than the developed shields. It is interesting that implementation of the thyroid shields does not reduce image quality significantly as implementation of the TCM. In contrary, there is a tendency that the SNR value increases with an increase in the Cu percentage in the SR-Cu shields, which gives the impression that there is an increase in image quality. However, further evaluation of the use of SR-Cu shields needs to be carried out in future studies.

REFERENCES

[1]. Jawas, N. (2017). Segmentasi Bagian Paru-Paru di Citra 2D CT-Scan. *E-Proceedings KNS&I STIKOM Bali*, 803-808.

[2]. Lewis MA, Edyvean S. Patient dose reduction in CT. *Br J Radiol*. 2005;78(934):880-883.

[3]. Brenner DJ, Hall EJ. Computed tomography--an increasing source of radiation exposure. *N Engl J Med*. 2007;357(22):2277-2284.

[4]. Lawrence S and Seeram E. (2017). The current use and effectiveness of bismuth shields in computed tomography: a systematic review *Radiol. Open. J.* 2 7–16.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24AUG732

[5]. Franck, C., Smeets, P., Lapeire, L., Achten, E., & Bacher, K. (2018). Estimating the Patient-specific Dose to the Thyroid and Breasts and Overall Risk in Chest CT When Using Organ-based Tube Current Modulation. *Radiology*, *288*(1), 164–169.

[6]. Riyanto, S., Budo, W.S., & Anam, C. (2019). Pengaruh Arus Tabung Terhadap Noise dan Kontras Citra pada Pesawat CT-Scan. *Berkala Fisika, 22(3),* 105-109.

[7]. Saeedi-Moghadam, Mahdi & Tayebi, Mansour & Chegeni, Nahid & Sina, Sedigheh & Kolayi, Tayebeh. (2020). Efficiency of non-lead and lead thyroid shields in radiation protection of CT examinations. *Radiation Physics and Chemistry*. 180. 109265.

[8]. Rego SL., Yu L., Bruesewitz MR., Vrieze TJ., et al. CARE Dose4D CT Automatic Exposure Control System : Physics Principles and Practical Hints. Radiol. Soc. North Am. 2007 Sci. Assem. Annu. Meet. 2007.

[9]. Haaga, J. R., Miraldi, F., MacIntyre, W., Lipuma, J. P., Bryan, P. J. and Wiesen, E., (1981). The effect of mAs variation upon computed tomography image quality as evaluated by in vivo and in vitro studies. *Radiology*, 138(2), 449-454.

[10]. Susanto, B. 2019. Fabrikasi Filter Radioprotektif Berbahan SR RTV 52-Al untuk Aplikasi Radiodiagnostik Menggunakan Digital Radiografi (DR). Universitas Diponegoro, Semarang.

[11]. Sutanto, H., Irdawati, Y., Anam, C., Fujibuchi, T., Dougherty, G., Hidayanto, E., Arifin, Z., Soedarsono, J. W., & Bahrudin (2020). An artifact-free thyroid shield in CT examination: a phantom study. *Biomedical physics & engineering express*, *6*(1), 015029.

[12]. Kessel, I dan O'Connor, J.T. (1997) Getting the Lead Out: The Complete Resource on How to Prevent and Cope with Lead Poisoning. Published by Plenum Trade, New York.

[13]. Halliday, D., Resnick, R. and Walker, J. (2014) Fundamental of Physics. 10th Edition, Wiley and Sons, New York.

[14]. Wijesinghe P, Kennedy BF, Sampson DD. Optical Elastography On The Microscale. *Tissue Elast. Imaging*. 2020; 185–229.

[15]. Araby, Sherif & Zhang, Liqun & Kuan, Hsu-Chiang & Dai, Jia-Bin & Majewski, Peter & MA, Jun. (2013). A novel approach to electrically and thermally conductive elastomers using graphene. *Polymer*. 54. 3663-3670.

[16]. Kang H, Zuo K, Wang Z, Zhang L, Liu L and Guo B 2014 Using a green method to develop graphene oxide/elastomers nanocomposites with combination of high barrier and mechanical performance. *Compos. Sci. Technol*. 92 1–8.

[17]. Yang, Heng & Yao, XueFeng & Zheng, Zhong & Gong, LingHui & Yuan, Li & Yuan, Yanan & Liu, YingHua. (2018). Highly sensitive and stretchable graphene-silicone rubber composites for strain sensing. *Composites Science and Technology*. 167.

[18]. Lee YH, Park ET, Cho PK, et al. Comparative analysis of radiation dose and image quality between thyroid shields and unshields during CT examination of the neck. *AJR Am J Roentgenol*. 2011;196(3):611-615.

[19]. Matsubara K, Sugai M, Toyoda A, et al. Assessment of an organ-based tube current modulation in thoracic computed tomography. *J Appl Clin Med Phys*. 2012;13(2):3731.

[20]. Kalra MK, Maher MM, Toth TL, et al. Techniques and applications of automatic tube current modulation for CT. *Radiology*. 2004;233(3):649-657.