FULL PAPER

RESEARCH PROJECT

# Investigation of Barium-Resin Composition for Radiation Protection in Diagnostic Radiology

BY

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## Abstract

The radiological diagnostic unit explores the patient's internal anatomy and lesion by using an x-ray, which is a non-invasion diagnostic. However, in some parts of the body which is the same type of tissue and cavitation, the lesion cannot be determined clearly. Therefore, medical chemicals have to be used to increase the difference in the area that is called contrast media such as barium sulfate compound ($BaSO_4$) that is used to investigate the Gastrointestinal system. Sometimes, barium sulfate is expired and cannot be used for clinical examination. They must also be disposed of in a standardized way to reduce their impact on the environment, which is very costly and budgetary that the hospital or medical service center has to bear. In this way, the research team has the idea to waste barium sulfate that cannot be used in medicine but is still intact. Developed as the main material for repairing such damage, barium has the properties of reducing radiation by mixing it with a resin that has restorative properties which makes the barium-resin composite material. The research team has determined the suitability of barium-resin proportions that are 70:30 (30 pieces), 60:40 (30 pieces) and 50:50 (29 pieces) and those are measured to find composited material density ($\rho_{material}$) are 2.21993 g/cm$^3$, 1.95568 g/cm$^3$ and 1.72655 g/cm$^3$ respectively. Moreover, all composites were taken to measure

the radiation attenuation values ($\mu_{Linear}$) at different X-ray energy at the Office of Atoms for Peace of Thailand. The $\mu_{Linear}$ of 70:30 proportion are 3.367 and 2.785 by using 100 kV 6 mA and 120 kV 9 mA respectively and 60:40 proportion are 3.261 and 2.555 by using 100 kV 6 mA and 120 kV 9 mA respectively and 50:50 proportion are 3.921, 2.651 and 2.076 by using 80 kV 4 mA, 100 kV 6 mA and 120 kV 9 mA respectively. In conclusion, the $\rho_{material}$ and the $\mu_{Linear}$ will increase when barium proportion is more than resin proportion which is considered under the same x-ray energy or setting parameter technique (for the $\mu_{Linear}$). However, the $\mu_{Linear}$ of 70:30 and 60:40 unable to detect at 80 kV 4 mA because that x-ray energy cannot penetrate the composited material to the radiation detector. So, the $\mu_{Linear}$ of 70:30 and 60:40 at 80 kV 4 mA cannot be calculated. However, in practice, the proper Barium-Resin proportions that can be easily mixed and used is 60:40.

## Acknowledgments

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Thanaphat Chongsan

Principle investigator

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# LIST OF ABBREVIATIONS

| Abbreviation | Term |
|---|---|
| HVL | The Half Value Layer |
| $I$ | The intensity at depth of x cm |
| $I_0$ | The original intensity |
| ICRP | The International Commission on Radiological Protection |
| M | The mass |
| V | The volume |
| x | The distance |
| $\mu$ | The attenuation coefficient of the medium |
| $\mu/\rho$ | The mass - linear attenuation coefficient |
| $\rho$ | The density of the medium |

# Chapter 1
# Introduction

## Importance and Background of Research Problems

Radiology is an integral part of medicine. For diagnostic unit, it explores patient's internal anatomy and lesion by using x-ray, which is non-invasion diagnostic. However, in some part of the body which is the same type of tissue and cavitation, the lesion cannot be determined clearly. Therefore, medical chemicals have to be used to increase the difference in the area.

These medical chemicals are called contrast media (Krestan C., 2019), which are available intravenously in the form of iodinated contrast media and oral intake (Nin, CS, et al, 2013) or rectal enema (Ferrucci JT, 2006) as a barium sulfate compound ($BaSO_4$) that is used to investigate the digestive system and intestines (Gastrointestinal). In general, a hospital or medical service center that has barium sulfate testing is often ordered and stored in a medical device warehouse to support the examination. However, at certain times, the drawdown may not be as expected, and barium sulfate is expired and cannot be used for clinical examination. They must also be disposed of in a standardized way to reduce their impact on the environment, which is very costly and budgetary that the hospital or medical service center has to bear.

The terrain and climate of Thailand, which is located in the Southeast Asian region, which is characterized by a tropical climate. Heavy rainfall and high temperatures (The ASEAN Secretariat, 2020) often affect the structure of the radiography chamber in the diagnostic radiology department located on the $1^{st}$ floor and [9] basement floor, which is affected by the process of dehumidification to the structure. This may result in damage and fail to meet the National Council on Radiation Protection and Measurements No. 147 (Archer, BR et al, 2005) standards. The research team found that such structures are prone to cracks or crevices such as walls, wooden door edges, and moisture swelling, which may reduce radiation safety standards. There may be a leakage of radiation to the outside resulting in harm to patient and unrelated staffs. However, rebuilding repairs can be difficult due to budgetary restrictions. The agency is responsible for repairing such leaks or fissures pending approval of the main budget. However, there have not been any researches conducted on whether the materials used for repairing are suitable or not.

In this way, the research team has the idea to waste barium sulfate that cannot be used in medicine but still intact. Developed as the main material for repairing such damage, barium has the properties of reducing radiation (T. Atichatkul et al, 2017) by mixing it with a resin that has no restorative properties (Chemical Retrieval on the Web (CROW), 2020), which makes the barium-resins composite material can cure such leaks and crevices to be more durable. However, the research team will be working to determine the suitability of barium-resin proportions that can lead to practical applications, together with necessary information that will be useful to those who apply.

**Research Objectives**

To study the suitable ratio of barium-resin that can be used for protection from radiation in diagnostic radiology as a standard. And create a database to distribute to those who are interested.

To verify the test results with Monte Carlo technical simulation and examining interactions that may arise from the simulation but could not be detected in the experiment.

**Research Delimitation**

The research team will be working to determine the suitability of barium-resin proportions that can lead to practical applications, together with necessary information that will be useful to those who apply.



**Expected Output and Expected Outcome**

It can reduce the risk of radiation that may be leaked from the radiography room and can reduce the cost of repairing the radiography room while waiting for the main budget. It also helps to reduce environmental problems from the problem of medical waste chemicals and reduce the cost of disposal of medical chemicals in hospitals.

It is expected to be able to create a timely solution to the problem of radiation leakage from the radiography room in case of wall cracks and hospitals can save budgets from eliminating medical waste chemicals.

# Chapter 2
# Literature Review

## Related Theories

The principles for the design of diagnostic radiography rooms are currently in use. Based on the guidelines recommended by the National Council on Radiation Prevention and Measurement, Issue 147 (Benjamin R. Archer et al, 2004), it focuses on the issue of radiation leaks from controlled areas in relation to the materials used for radiation shielding that were used by the equivalent lead thickness as a comparison under the requirements that the material must meet the standards set.

In general, radiation protection is determined by the radiation dose after it has passed through a medium or a radiation shielding wall. Using the Lambert-Beer law (Kocsis L et al, 2006), which has important variables in the calculation, which are the attenuation coefficient of the medium ($\mu$), the thickness of the medium (Thickness: X) and is also related to the density of the medium ($\rho$). The Lambert-Beer law were also able to determine the Half Value Layer (HVL) thickness, which is an important factor for radiological safety (Archer, BR et al, 2005).

In addition to the Lambert-Beer law, in practical, for the prevention of radiation hazards, it is also necessary to consider the amount of radiation to person exposed from the operations and the living surrounding area where the radiation is applied. The design of the radiation shielding wall must also be considered on this point, which has requirements from the International Commission on Radiological Protection (ICRP) No. 118 (Stewart, F. A. et al, 2012).



Which materials are able to protect from radiation hazards. Important physical properties must be taken into account, such as the atomic number that should be a high atomic number. This will affect the K absorption edge that is an important factor in the absorption of diagnostic radiological energy (McCaffrey, JP et al, 2007). The researchers chose to use barium sulfate. With barium as the main basic component, its atomic number is high at 56, its density is 3.5 g/cm$^3$ and its K absorption edge is 37.4 keV.

Currently, in-depth researches in radiation are often adopted computer techniques to provide more detailed research studies and to find interactions that are not possible in experimental research. The Monte Carlo technique (Sechopoulos, I. et al, 2018) is one of the most popular techniques used in this type of research because the factors can be adjusted in detail. This is very useful when studying potential trends. Moreover, Monte Carlo technique can also be used to verify the results of the experiment. And be used for further research. Through this second phase study, the researchers plan to use the PHITS Code (Yosuke Iwamoto, et al, 2017), a Monte Carlo-based technique created by researchers in Japan that is popular internationally.

**Related Studies**

Barium-sulphate was developed as radiation shielding material in difference images such fabric coating, glass, sheet or film. They were evaluated radiation shielding property with the value of linear attenuation coefficient ($\mu$) or mass - linear attenuation coefficient ($\mu/\rho$) by both measurement and simulation.

In 2012, Seon-Chil Kim, Kyung-Rae Dong and Woon-Kwan Chung evaluated medical radiation, region of diagnosis or 40-80 keV of effective energy photon, shielding effect by composition of barium compound. Barium compound was found to have excellent shielding effect for a general range of medical radiation as shown in Figure 1. However, one major problem in manufacturing barium compound sheet is the reproduction of the appropriated particle packing.



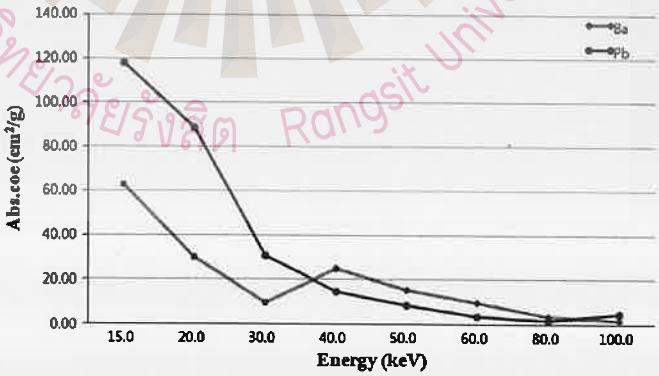



*Figure 1 the comparison of the radiation shielding sheet (in comparison of shielding ability between barium and lead in the medical radiation region for diagnosis or 40-80 keV, x-ray absorption of barium was higher than that of lead.) (Seon-Chil Kim et al., 2012)*

In 2016, Huda Ahmed Maghrabi et al. evaluated x-ray radiation shielding performance of Barium Sulphate-coating fabrics: pilot study. The motivation of this pilot study is manufacturing new fabric for radiation shielding apron without environment toxicity. Transmission of 3 types of coating formular, such as $BaSO_4$ 20 g + PVC 100 g, $BaSO_4$ 40 g + PVC 100 g and $BaSO_4$ 30 g + $Bi_2O_3$ 20 g + PVC 100 g, were investigated. Additionally, this pilot research used 80 kVp 12 mAs form general x-ray machine. Results showed higher percentage of x-ray transmitted than lead-rubber compound for all formular (60-80 %) shown as Figure 2.

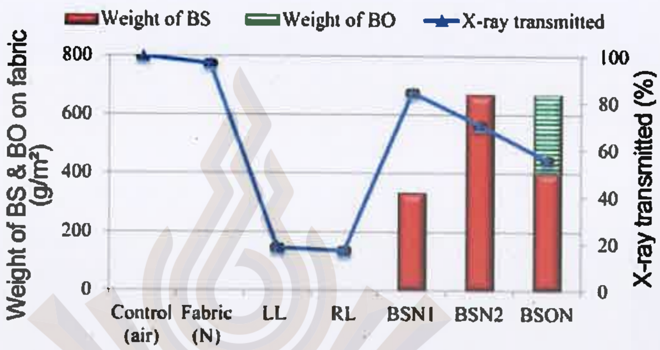



*Figure 2 the comparison of the amount of x-ray transmission (%) of control (air), uncoated Nylon 6,6 fabric (N), standard lead samples (lite Lead: LL & regular Lead: RL) and coated samples against the weight of $BaSO_4$(BS) and $Bi_2O_3$(BO) (Huda Ahmed Maghrabi et al., 2016)*

In Figure 2 shown about 16.5 % of transmitted decreasing while increased 2 times of $BaSO_4$ thickness. More quantity of $BaSO_4$ was required for radiation shielding apron to achieve standard level of shielding ability, which might be case of over-weight of radiation shielding apron. Therefore, $BaSO_4$ should be mixed with more amount of other material (such as $Bi_2O_3$) to keep suitable weight and smaller x-ray transmission.

In 2017, T. Atichatkul et al. investigated to fabricate an unleaded X-ray attenuation composite sheet to obtain and elastic sheet is composited with PU/$BaSO_4$. Studies have shown that percentage of attenuation depends on the amount of $BaSo_4$ as seen Figure 3 and the latter coefficient is used to determine the weight of composite materials for preparing the sheet with the desired attenuation levels.

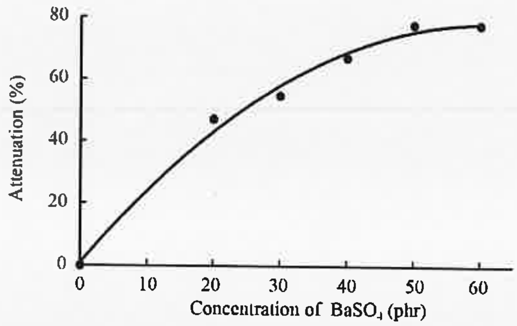



*Figure 3 the percentage of attenuation depends on the amount of $BaSo_4$ (T. Atichatkul et al, 2017)*

In 2019 Seon-Chil Kim and Sung-Hyoun Cho analyzed the correlation of porosity, tensile strength and shielding performance. The compound of $BaSo_4$ (65%) and polyethylene resin (35%) is one of specimens in this study. It was found that the correlation between the porosity and the shielding ration showed a decreasing trend. However, the strength increased referred to increasing of shielding ratio, as seen Figure 4.

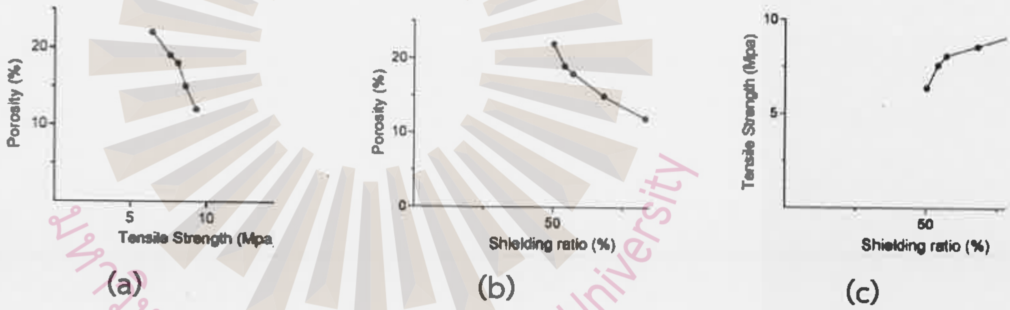



*Figure 4 the correlation between porosity, tensile strength, and radiation shielding ratio (barium sulphate). (a) comparison of tensile strength and porosity; (b) comparison of shielding performance and porosity; (c) comparison of shielding performance and tensile strength. (Seon-Chil Kim et al, 2019)*



In this study, porosity and tensile strength were other key point of photon shielding performance, not only linear attenuation coefficient and thickness. Especially powder base material, blending and cast method may affect to photon shielding performance because they difficult to manufacturing homogeneous shielding.

In 2020, M.S. Al-Buriahi et al. investigated of 5 barium borate glasses (Barium quantities were varied as 0, 10, 20, 30, 35 mol%) for radiation shielding applications. The simulated Mass-attenuation coefficient ($\mu/\rho$) in photon energy range of 356 keV to 2.51 MeV have been reported. The values of $\mu/\rho$ were obtained using PHITS code then they were verified by comparison with from both of FLUKA code and XCOM program. the results showed the highest mol% barium glass was the best photon shielding property in this study. which mean this property depend on quantity of Barium in the glasses.

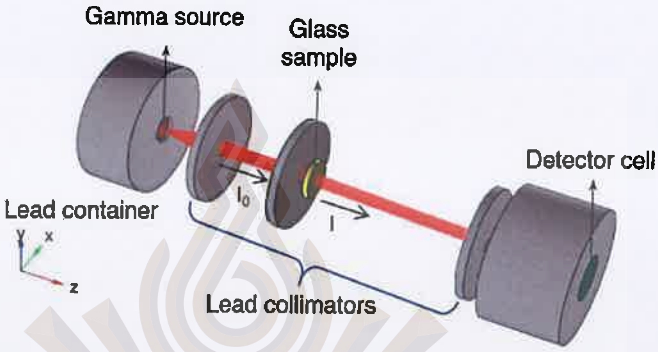



*Figure 5 A total 3 D view of the designed simulation geometry by using PHITS code (M.S. Al-Buriahi et al, 2020)*

# Chapter 3
# Research Methodology

## Research Design

1. Supply expired barium sulfate powder products or waste from the hospital is displayed in figure 6(B), but still form in a dry powder, not moist, and supply quality resin that does not keep its shape too quickly and air bubble release agent, surfactant agent (propylene glycol) and hardener agent is displayed in figure 6(A).

A B

*Figure 6 (A) the resin with air bubble release agent, surfactant agent (propylene glycol) and hardener agent and (B) the expired barium sulfate powder.*

2. Finding the resin combination between resin, air bubble release agent, surfactant agent (propylene glycol) and hardener agent.
3. Different proportions of barium and resin are mixed in a slow blending process to reduce internal air bubbles and allow the two to be blended together by mixing in the ratio of barium-resin as follows (Unit: gram – g)
   - Barium: Resin – 50: 50 Repeat 10 sets
   - Barium: Resin – 60: 40 Repeat 10 sets
   - Barium: Resin – 70: 30 Repeat 10 sets

   At this stage, there are 30 batches of barium-resin mixed liquids, all of which must be set aside to remove the air bubbles inside are displayed in figure 7.

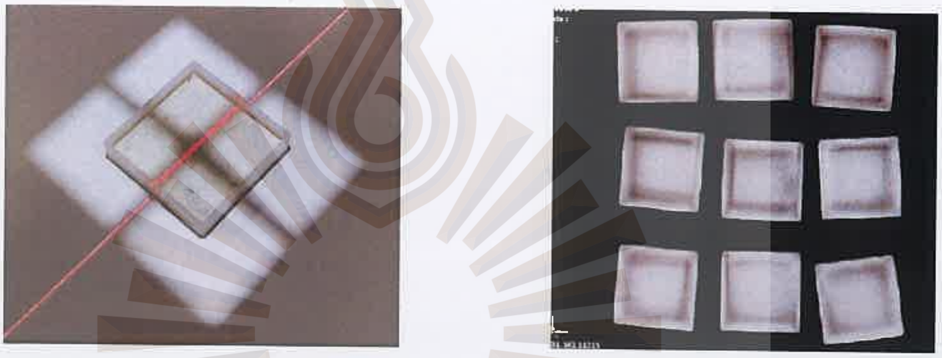
*Figure 7 Mixing barium sulfate with resin by over-head stirrer.*

4. Pour the two ingredients (resin combination and barium power) into a 10x10x1 cm mold by casting 3 components per 1 mixing ratio, carefully smoothing the surface of the material by using a sanding machine to reduce the effect of uneven radiation attenuation when radiation hits the surface of the composite material at this stage, a total of 90 pieces of casting materials are obtained are displayed in figure 8.



*Figure 8 Pouring liquid composited material into a 10x10x1 cm mold.*

5. Wait for the mixture to dry completely to room temperature without exposing them to the sun or receiving heat, as this may cause the material to dry quickly and cause cracking or cracks in the composite material.
6. The finished mixture is taken to weigh with a balance that has been calibrated with a standard metrological method. The size was measured again to find the volume of every workpiece, and the data was then used to find the density of the composite material using the density equation.
7. All composites were taken radiography for checking fracture and inhomogeneity inside barium – resin composite specimens are displayed in figure 9.



A B

*Figure 9 Taking radiography to find air cavity in solid composited material.*



8. All composites were taken to measure the radiation attenuation values at different X-ray energy values. The Accredited Radiological Metrology Agency in this case is the Nuclear and Radiation Measurement Standards Group, System Development and Security Supervision Division, Office of Atoms for Peace and the resulting values were used to find both linear and mass radiation attenuation coefficients are displayed in figure 10.

A

B

*Figure 10 (A) Placing solid composited specimen in front of the aperture of radiation generator and (B) the free-air ionization chamber (radiation detector) was used for detecting transmitted radiation.*

9. Data from 6 and 8 were drawn to graph the relationship between the linear attenuation coefficient of the barium-resin proportion in this experiment. And create a data table to be a database for those interested and can use Interpolation. The graphs and tables provided were obtained to determine the radiation attenuation coefficient in cases where the barium-resin ratio differs from the data provided by the research team. And the research user was able to substitute the radiation attenuation coefficient in Lambert – Beer law to find the appropriate thickness for use.
10. Statistical tests were performed to determine the difference of barium-resin proportions on both linear and mass radiation attenuation coefficients.

A schematic diagram of research design is shown in Chart 1.

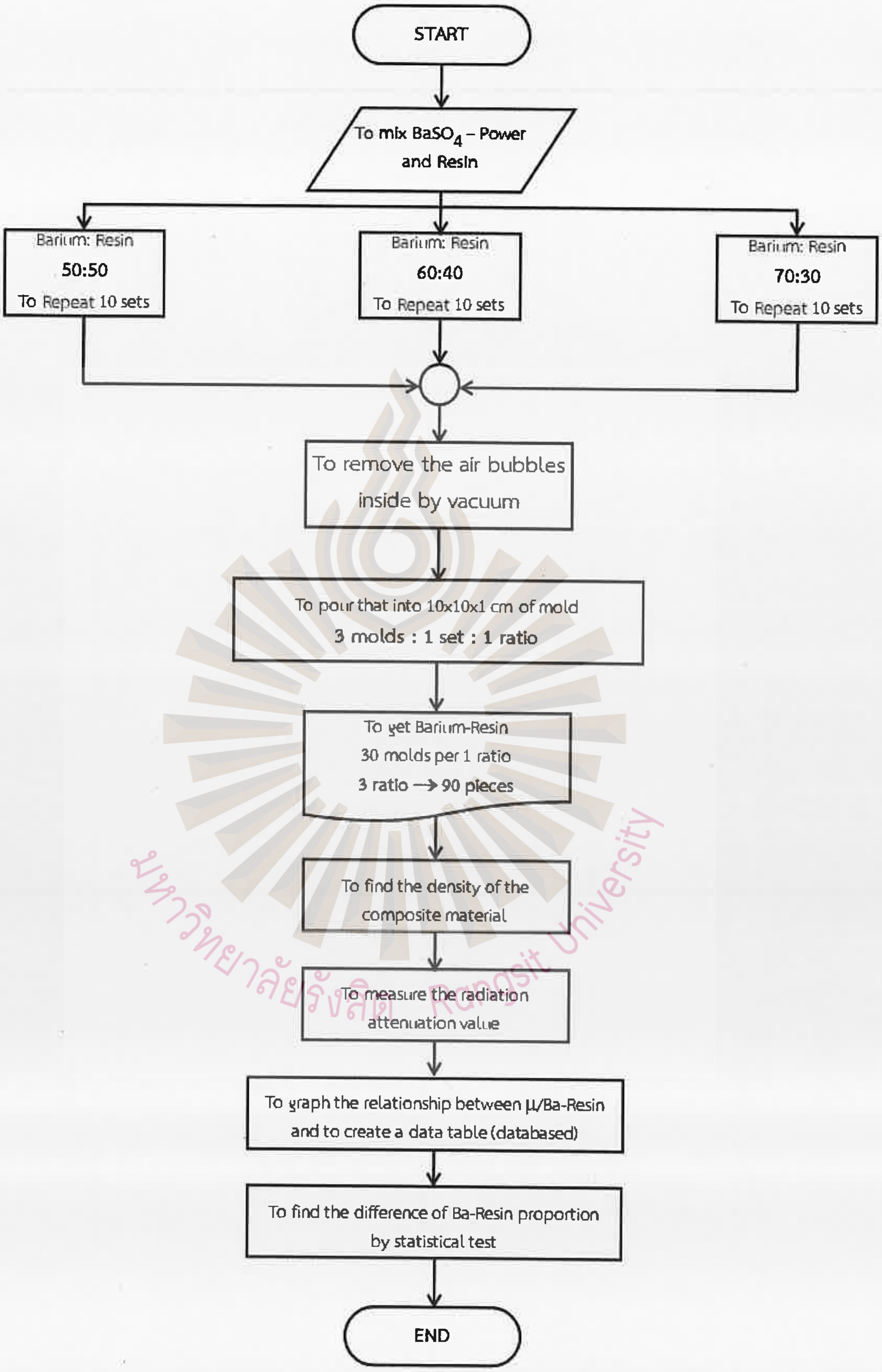



*Chart 1 A schematic diagram of research design*

**Materials and Equipment**

1. Barium sulfate powder used in medicine that has expired but still intact.


*Figure 11 Barium sulfate power*

2. Water-based resin, clear color

*Figure 12 Water based resin*



3. Air bubble release agent

*Figure 13 Air bubble release agent*

4. Surfactant (Propylene glycol)


*Figure 14 Propylene glycol agent*

5. Hardener agent


*Figure 15 Hardener agent*

6. Silicone mold size 10x10x1 cm

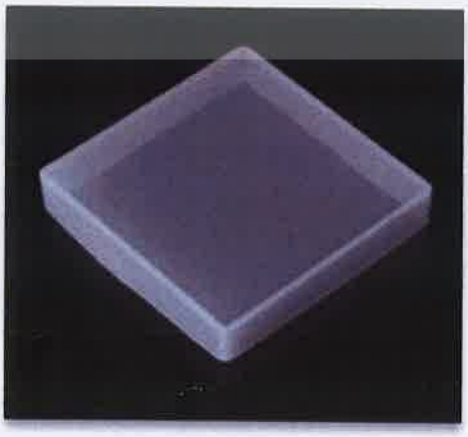


*Figure 16 Square silicone mold 10x10x1 cm*

7. Over-head stirrer

*Figure 17 Over-head stirrer machine*

8. Sanding machine


*Figure 18 Sanding machine*



9. Digital weighing scales that have been calibrated by metrological methods

*Figure 19 Calibrated digital weighing machine*

10. Ruler or any other dimensioning device that has been calibrated for metrological scaling standards.

*Figure 20 Calibrated ruler*

11. Kilovolt-energy radiation generators used in diagnostic radiology (Fujifilm Global Fuji FDR Smart GXR-S Series) that have been calibrated by radiological metrology

*Figure 21 Fujifilm Global Fuji FDR Smart GXR-S Series*



12. Gamma – Calibrator Buchler QB 85-BA used in radiation quality assurance

*Figure 22 Calibrated x-ray generator*

13. A free-air ionization chamber (radiation detector) is used as the primary standard instrument for absolute measurement of air kerma for of X-ray beams.

*Figure 23 Free-air ionization chamber*

14. Electrometer


*Figure 24 Reading data display machine (electrometer)*

**Data Collection and Interpretation of Study Results**

1. After, Specimens were measured the volume of each specimen those were verified and calculated the material density by density equation (1).

$$\rho = \frac{M}{V} \qquad (1)$$

where...

| | | |
|---|---|---|
| $\rho$ | is | the density (g/cm$^3$) |
| M | is | the mass (g – gram) |
| V | is | the volume (cm$^3$ - cubic centimeter) |

The density value is importance for comparison of the strength of the specimens.

2. Next step, Specimens were measured the Linear attenuation coefficient ($\mu$) by the Gamma – Calibrator Buchler QB 85-BA and A free-air ionization chamber (radiation detector) at the Office of Atoms for Peace – OAP of Thailand. Those were verified and analyzed by equation (2)

$$I = I_0 e^{-\mu x} \qquad (2)$$

where...

| | | |
|---|---|---|
| I | is | the intensity at depth of x cm |
| $I_0$ | is | the original intensity |
| e | is | 2.71828 |
| $\mu$ | is | the linear attenuation coefficient |
| x | is | the distance (cm) |

3. When, the Linear attenuation coefficient ($\mu$) were calculated and verified. The Linear attenuation coefficient ($\mu$) were used to calculated HVL - Half Value Layer that is the width of a material required to reduce the air kerma of an x-ray or gamma ray to half its original value by equation (3)

$$HVL = \frac{0.693}{\mu} \tag{3}$$

HVL is importance to estimate appropriateness between radiation energy and material thickness.

# Chapter 4

# Results and Discussion

## Results

1. Resin composition

Table 1 Suitable barium sulfate and resin composition

| Resin X (Cobalt Naphthenate Agent 10%) | Air bubble release agent | Surfactant (Propylene glycol) | Hardener agent |
|---|---|---|---|
| 1 | 0.05 | 0.1 | 0.2 |

The researchers proceeded to find a suitable mixture of resin. To obtain a resin that can be used in this study under conditions that require timely hardening and mixing with barium sulfate. The conclusion of resin ratio (Resin X to Air bubble release agent to Surfactant and Hardener agent) was 1 to 0.5 to 0.1 and 0.2 respectively. The results are displayed in table 1.

2. Material density

Table 2 Material density values of composited specimen (Barium sulfate: Resin)

| Ratio of $BaSO_4$:Resin | Composited Material Density (Average) (g/cm$^3$) |
|---|---|
| 50:50 | 1.72655 |
| 60:40 | 1.95568 |
| 70:30 | 2.21993 |

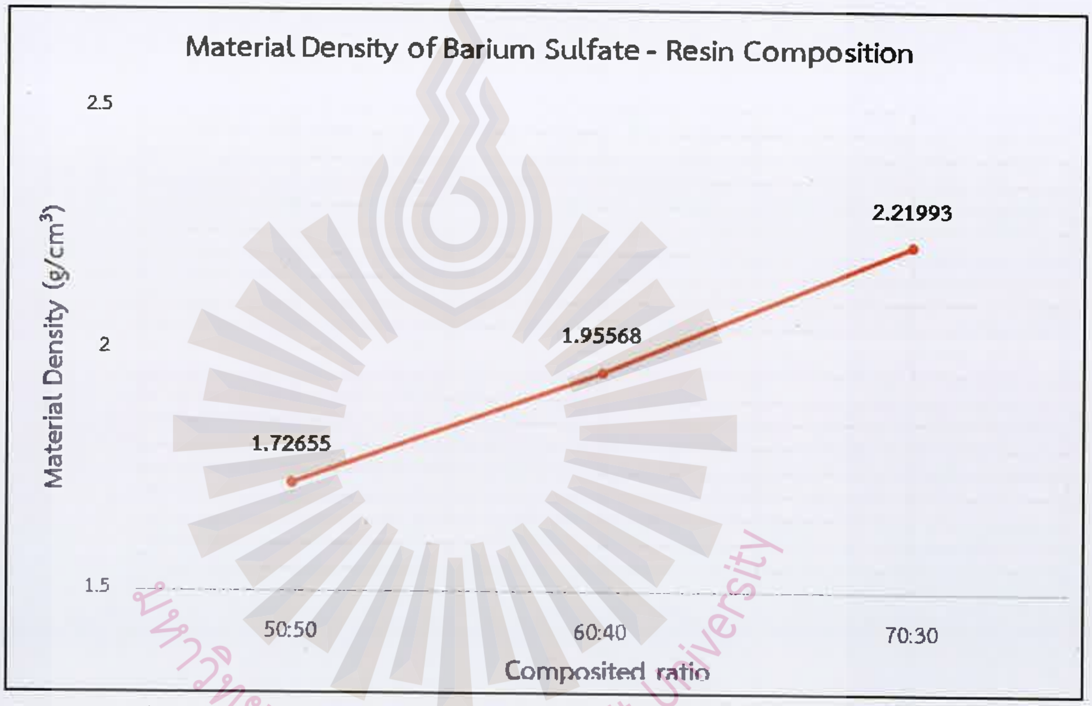



*Figure 25 the relationship of composited ratio (between barium sulfate and resin) with composited material density*



According to the result of Barium Sulfate – Resin composited material density, all composite material specimen were checked for volume and weight by standard methods to bring the obtained values to find the density according to equation 1. The results showed that when the amount of barium sulfate increases. This will result in a denser composite material and consistent with the results shown in figure 25. For more information of the material density values of all composited material are shown in the Appendix A.

3. Linear attenuation coefficient ($\mu_{Linear}$)

Table 3 Linear attenuation coefficient values ($\mu_{Linear}$) of composited specimen (Barium sulfate: Resin ratio) at 80 kV 4 mA (X-ray energy parameter setting)

| Barium sulfate: Resin ratio | Average of $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|
| 50:50 | 3.922934415 |
| 60:40 | N/A |
| 70:30 | N/A |

Table 4 Linear attenuation coefficient values ($\mu_{Linear}$) of composited specimen (Barium sulfate: Resin ratio) at 100 kV 6 mA (X-ray energy parameter setting)

| Barium sulfate: Resin ratio | Average of $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|
| 50:50 | 2.650953731 |
| 60:40 | 3.260866107 |
| 70:30 | 3.367385569 |

Table 5 Linear attenuation coefficient values ($\mu_{Linear}$) of composited specimen (Barium sulfate: Resin ratio) at 120 kV 9 mA (X-ray energy parameter setting)

| Barium sulfate: Resin ratio | Average of $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|
| 50:50 | 2.075785736 |
| 60:40 | 2.555498898 |
| 70:30 | 2.784867497 |



The Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 60:40 and 70:30 at 80 kV 4 mA could not be calculated because the radiation dosimeter could not detect transmitted radiation. as a result of the composited specimens were too thick when compare with the x-ray energy level.

The research set the composited material across the direction of the radiation beam that displayed the results in tables 3, 4 and 5. It found that when the X-ray energy value was maintained and the proportion of barium sulfate was increased, the radiation attenuation coefficient was increased. On the other hand, when maintaining the barium sulfate ratio and increasing the X-ray energy, the radiation attenuation coefficient was decreased. For more information of the linear attenuation coefficient value of all composited material are shown in the Appendix B.

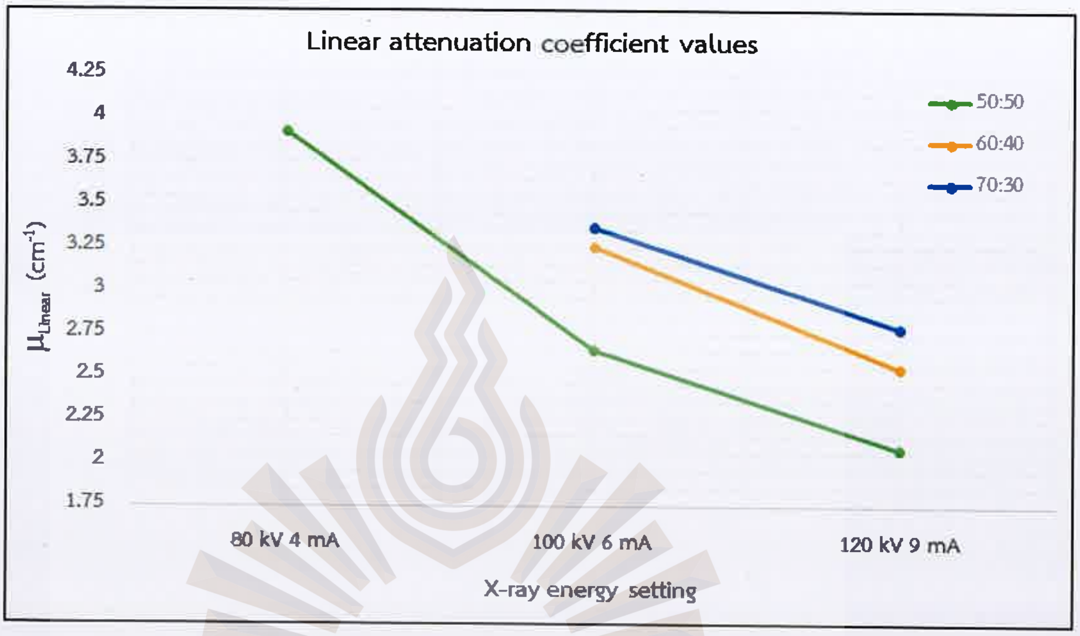



*Figure 26 the linear attenuation coefficient value comparison between composited material 50:50 (green line), 60:40 (yellow line) and 70:30 (blue line) at the same x-ray energy setting.*

**Discussion**

1. Material density

According to the result of the average density of Barium Sulfate – Resin composited material. The average value was obtained from the ratio of 70:30 of 30 pieces, 60:40 of 30 pieces and 50:50 of 29 pieces (1 piece broken) which are 2.21993, 1.95568 and 1.72655 g/cm$^3$ respectively, the results shown in table 2. This is consistent with the study by Amestoy, H., Diego., et al in 2021, the conclusion of the study is that increasing the amount of barium sulfate will increase the density of the object and result in increased radiation attenuation properties. This is in accordance with the theory and properties of barium sulfate.

2. Linear attenuation coefficient values of composited specimen

From the result, when considering the proportions of the same composite material, the radiation attenuation coefficient decreases as the X-ray energy increases. This is due to the greater penetrating power of X-rays. As shown in figure 26, it will result in more transmitted radiation to the detector in accordance with the theory that higher energy will decrease the radiation attenuation properties of the medium, consistent with the research of T. Atichatkul., et al in 2017. On another hand, considering the same level of X-ray energy and increasing the proportion of barium sulfate, it is found that the attenuation coefficient will increase. This is due to the higher barium sulfate content in the specimen, thus providing greater radiation attenuation capability. As shown in tables 3, 4 and 5, the test results are consistent with Elsafi, M., et al in 2021, and are consistent with the radiation attenuation properties of barium sulfate. Therefore, it is used to increase the differentiation of radiology examinations. which has been discussed in detail in the previous chapter.

## Chapter 5
## Conclusion and Suggestion

### Conclusion

In conclusion, the 70:30 Barium-Resin ratio specimens were the largest average linear attenuation coefficient for 100 and 120 keV photon beams. It was the largest barium ratio which was able to mix with resin uniformly.

The averaged linear attenuation coefficients ($\mu_{Linear}$) of 100 keV X-ray for 50:50, 60:40 and 70:30 Barium-Resin ratio specimens were 2.65 $\pm$ 0.3, 3.26 $\pm$ 0.36 and 3.37 $\pm$ 0.23 $cm^{-1}$, respectively. While 120 keV X-ray, the averaged linear attenuation coefficients for 50:50, 60:40 and 70:30 Barium-Resin ratio specimens were 2.08 $\pm$ 0.25, 2.56 $\pm$ 0.32 and 2.78 $\pm$ 0.24 $cm^{-1}$, respectively.

### Suggestion

For the evaluation of linear attenuation coefficients of 60:40 and 70:30 Barium-Resin ratio specimens for 80 keV x-ray, which were able to evaluate in this study, they should be repeat with thinner specimens. In practice, hospitals or healthcare facilities can use the results of this research to repair radiographic rooms for following the purposes of this research. The researchers suggest that if there is no mixing tool like the one used in the research, it is advisable to use a mixture of barium-resin 60:40, which is easy to mix for repairing wall cracks with can attenuate as standard. In the opinion of the researchers, it is sufficient to protect against radiation leakage.

## References


Archer, B. R., & Gray, J. E. (2005). Important changes in medical x-ray imaging facility shielding design methodology. A brief summary of recommendations in NCRP Report No. 147. *Medical physics*, *32*(12), 3599–3601. https://doi.org/10.1118/1.2124587

Amestoy, H., Diego, P., Meaurio, E., Muñoz, J., & Sarasua, J. R. (2021). Crystallization Behavior and Mechanical Properties of Poly(ε-caprolactone) Reinforced with Barium Sulfate Submicron Particles. *Materials (Basel, Switzerland)*, *14*(9), 2368. https://doi.org/10.3390/ma14092368

Chemical Retrieval on the Web (CROW) (2020). *Polymer Properties Database: PROPERTIES OF RESINS*. Retrieved 21 August 2020 from https://polymerdatabase.com/polymer%20classes/Intro%20Resins.html

Elsafi, M., Koraim, Y., Almurayshid, M., Almasoud, F. I., Sayyed, M. I., & Saleh, I. H. (2021). Investigation of Photon Radiation Attenuation Capability of Different Clay Materials. *Materials (Basel, Switzerland)*, *14*(21), 6702. https://doi.org/10.3390/ma14216702

Ferrucci J. T. (2006). Double-contrast barium enema: use in practice and implications for CT colonography. *AJR. American journal of roentgenology*, *187*(1), 170–173. https://doi.org/10.2214/AJR.05.0900

Huda Ahmed Maghrabi et al (2016). Evaluation of X-ray Radiation Shielding Performance of Barium Sulphate-Coated Fabrics. *Fibers and Polymers*, *17*(12), 2047-2054. https://doi.org/10.1007/s12221-016-5850-z

Krestan C. (2019). Kontrastmittel – Handlungsempfehlungen für die Praxis [Contrast media - Guidelines for practical use]. *Der Radiologe*, *59*(5), 444–453. https://doi.org/10.1007/s00117-019-0523-8

M. S. Al-Buriahi, C. Sriwunkum, Halil Arslan, Baris T. Tonguc & Mohamed A. Bourham. (2020). Investigation of barium borate glasses for radiation shielding applications. *Applied Physics A*, *126*, 68. https://doi.org/10.1007/s00339-019-3254-9

Nin, C. S., Marchiori, E., Irion, K. L., Paludo, A., Alves, G. R., Hochhegger, D. R., & Hochhegger, B. (2013). Barium swallow study in routine clinical practice: a prospective study in patients with chronic cough. *Jornal brasileiro de pneumologia : publicacao oficial da Sociedade Brasileira de Pneumologia e Tisilogia*, *39*(6), 686–691. https://doi.org/10.1590/S1806-37132013000600007

Seon-Chil Kim and Sung-Hyoun Cho. (2019). Analysis of the Correlation between Shielding Material Blending Characteristics and Porosity for Radiation Shielding Films. *Appl. Sci*, *9*, 1765. https://doi.org/10.3390/app9091765

Seon-Chil Kim, Kyung-RaeDong & Woon-Kwan Chung. (2012). Medical radiation shielding effect by composition of barium compounds. *Annals of Nuclear Energy*, *47*, 1–5. https://doi.org/10.1016/j.anucene.2012.04.014

T. Atichatkul N. Chanunpanich, V. Pungkun & C. Suwanboon (2017). X-ray attenuation coefficient of PU/BaSO4 composite sheet. *The Journal of KMUTNB*, *27*(1), 159-168. https://doi.org/10.14416/j.kmutnb.2016.03.001

The ASEAN Secretariat (2020). *ASEAN Guidelines on Green Meetings*. Jakarta:ASEAN Secretariat.

APPENDICES

## Appendix A

Table A.1 Material density values of composited specimen (Barium sulfate: Resin) 50:50

| No. | Thickness (cm) | Cross-sectional area ($cm^2$) | Volume ($cm^3$) | Weight (g) | Density ($g/cm^3$) |
|---|---|---|---|---|---|
| 1 | 1.45 | 100 | 145 | 240.9 | 1.66138 |
| 2 | 1.3 | 100 | 130 | 214.7 | 1.65154 |
| 3 | 1.4 | 100 | 140 | 240.0 | 1.71429 |
| 4 | 1.3 | 100 | 130 | 228.9 | 1.76077 |
| 5 | 1.4 | 100 | 140 | 240.7 | 1.71929 |
| 6 | 1.46 | 100 | 146 | 247.7 | 1.69658 |
| 7 | 1.2 | 100 | 120 | 198.9 | 1.65750 |
| 8 | 1.3 | 100 | 130 | 232.3 | 1.78692 |
| 9 | 1.15 | 100 | 115 | 202.0 | 1.75652 |
| 10 | 1.45 | 100 | 145 | 251.5 | 1.73448 |
| 11 | 1.4 | 100 | 140 | 247.8 | 1.77000 |
| 12 | 1.3 | 100 | 130 | 220.0 | 1.69231 |
| 13 | 1.4 | 100 | 140 | 244.2 | 1.74429 |
| 14 | 1.35 | 100 | 135 | 232.6 | 1.72296 |
| 15 | 1.5 | 100 | 150 | 257.8 | 1.71867 |
| 16 | 1.4 | 100 | 140 | 230.8 | 1.64857 |
| 17 | 1.5 | 100 | 150 | 256.6 | 1.71067 |
| 18 | 1.3 | 100 | 130 | 229.6 | 1.76615 |
| 19 | 1.45 | 100 | 145 | 245.7 | 1.69448 |
| 20 | 1.55 | 100 | 155 | 263.7 | 1.70129 |
| 21 | 1.45 | 100 | 145 | 252.5 | 1.74138 |
| 22 | 1.25 | 100 | 125 | 209.5 | 1.67600 |
| 23 | 1.3 | 100 | 130 | 234.7 | 1.80538 |
| 24 | 1.3 | 100 | 130 | 245.9 | 1.89154 |
| 25 | 1.4 | 100 | 140 | 243.9 | 1.74214 |
| 26 | 1.45 | 100 | 145 | 250.0 | 1.72414 |

Table A.1 Material density values of composited specimen (Barium sulfate: Resin) 50:50 (cont.)

| No. | Thickness (cm) | Cross-sectional area ($cm^2$) | Volume ($cm^3$) | Weight (g) | Density ($g/cm^3$) |
|---|---|---|---|---|---|
| 27 | 1.4 | 100 | 140 | 238.0 | 1.70000 |
| 28 | 1.4 | 100 | 140 | 236.2 | 1.68714 |
| 29 | 1.4 | 100 | 140 | 251.1 | 1.79357 |
| | | **Average of density of composited material 50:50** | | | 1.72655 |

Table A.2 Material density values of composited specimen (Barium sulfate: Resin) 60:40

| No. | Thickness (cm) | Cross-sectional area ($cm^2$) | Volume ($cm^3$) | Weight (g) | Density ($g/cm^3$) |
|---|---|---|---|---|---|
| 1 | 1.15 | 100 | 115 | 231.2 | 2.01043 |
| 2 | 1.3 | 100 | 130 | 258.4 | 1.98769 |
| 3 | 1.3 | 100 | 130 | 260.7 | 2.00538 |
| 4 | 1.1 | 100 | 110 | 238.7 | 2.17000 |
| 5 | 1.4 | 100 | 140 | 263.7 | 1.88357 |
| 6 | 1.35 | 100 | 135 | 254.3 | 1.88370 |
| 7 | 1.2 | 100 | 120 | 267.3 | 2.22750 |
| 8 | 1.2 | 100 | 120 | 223.2 | 1.86000 |
| 9 | 1.45 | 100 | 145 | 275.5 | 1.90000 |
| 10 | 1.4 | 100 | 140 | 269.3 | 1.92357 |
| 11 | 1.45 | 100 | 145 | 282.5 | 1.94828 |
| 12 | 1.35 | 100 | 135 | 260.3 | 1.92815 |
| 13 | 1.3 | 100 | 130 | 251.5 | 1.93462 |
| 14 | 1.45 | 100 | 145 | 283.0 | 1.95172 |
| 15 | 1.25 | 100 | 125 | 248.3 | 1.98640 |
| 16 | 1.35 | 100 | 135 | 271.9 | 2.01407 |
| 17 | 1.4 | 100 | 140 | 266.8 | 1.90571 |
| 18 | 1.5 | 100 | 150 | 287.4 | 1.91600 |

Table A.2 Material density values of composited specimen (Barium sulfate: Resin) 60:40 (cont.)

| No. | Thickness (cm) | Cross-sectional area ($cm^2$) | Volume ($cm^3$) | Weight (g) | Density ($g/cm^3$) |
|---|---|---|---|---|---|
| 19 | 1.4 | 100 | 140 | 266.9 | 1.90643 |
| 20 | 1.4 | 100 | 140 | 265.1 | 1.89357 |
| 21 | 1.2 | 100 | 120 | 224.9 | 1.87417 |
| 22 | 1.3 | 100 | 130 | 250.6 | 1.92769 |
| 23 | 1.45 | 100 | 145 | 284.2 | 1.96000 |
| 24 | 1.4 | 100 | 140 | 271.4 | 1.93857 |
| 25 | 1.5 | 100 | 150 | 289.6 | 1.93067 |
| 26 | 1.3 | 100 | 130 | 271.7 | 2.09000 |
| 27 | 1.3 | 100 | 130 | 255.6 | 1.96615 |
| 28 | 1.3 | 100 | 130 | 244.8 | 1.88308 |
| 29 | 1.5 | 100 | 150 | 288.5 | 1.92333 |
| 30 | 1.3 | 100 | 130 | 252.2 | 1.94000 |
| | | Average of density of composited material 60:40 | | | 1.95568 |

Table A.3 Material density values of composited specimen (Barium sulfate: Resin) 70:30

| No. | Thickness (cm) | Cross-sectional area ($cm^2$) | Volume ($cm^3$) | Weight (g) | Density ($g/cm^3$) |
|---|---|---|---|---|---|
| 1 | 1.2 | 100 | 120 | 268.7 | 2.23917 |
| 2 | 1.25 | 100 | 125 | 282.2 | 2.25760 |
| 3 | 1.15 | 100 | 115 | 257.5 | 2.23913 |
| 4 | 1.2 | 100 | 120 | 269.3 | 2.24417 |
| 5 | 1.2 | 100 | 120 | 266.3 | 2.21917 |
| 6 | 1.25 | 100 | 125 | 281.1 | 2.24880 |
| 7 | 1.25 | 100 | 125 | 278.4 | 2.22720 |
| 8 | 1.25 | 100 | 125 | 271.3 | 2.17040 |
| 9 | 1.25 | 100 | 125 | 279.9 | 2.23920 |
| 10 | 1.2 | 100 | 120 | 265.6 | 2.21333 |
| 11 | 1.3 | 100 | 130 | 287.0 | 2.20769 |

Table A.3 Material density values of composited specimen (Barium sulfate: Resin) 70:30 (cont.)

| No. | Thickness (cm) | Cross-sectional area ($cm^2$) | Volume ($cm^3$) | Weight (g) | Density ($g/cm^3$) |
|---|---|---|---|---|---|
| 12 | 1.25 | 100 | 125 | 284.0 | 2.27200 |
| 13 | 1.2 | 100 | 120 | 267.8 | 2.23167 |
| 14 | 1.35 | 100 | 135 | 288.5 | 2.13704 |
| 15 | 1.25 | 100 | 125 | 278.1 | 2.22480 |
| 16 | 1.2 | 100 | 120 | 258.6 | 2.15500 |
| 17 | 1.4 | 100 | 140 | 318.1 | 2.27214 |
| 18 | 1.25 | 100 | 125 | 280.0 | 2.24000 |
| 19 | 1.2 | 100 | 120 | 263.4 | 2.19500 |
| 20 | 1.25 | 100 | 125 | 270.6 | 2.16480 |
| 21 | 1.25 | 100 | 125 | 272.1 | 2.17680 |
| 22 | 1.2 | 100 | 120 | 266.6 | 2.22167 |
| 23 | 1.35 | 100 | 135 | 304.7 | 2.25704 |
| 24 | 1.35 | 100 | 135 | 300.0 | 2.22222 |
| 25 | 1.3 | 100 | 130 | 284.5 | 2.18846 |
| 26 | 1.2 | 100 | 120 | 270.0 | 2.25000 |
| 27 | 1.25 | 100 | 125 | 279.6 | 2.23680 |
| 28 | 1.3 | 100 | 130 | 294.1 | 2.26231 |
| 29 | 1.3 | 100 | 130 | 287.3 | 2.21000 |
| 30 | 1.2 | 100 | 120 | 260.9 | 2.17417 |
| | Average of density of composited material 70:30 | | | | 2.21993 |

## Appendix B

Table B.1 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 50:50 at 80 kV 4 mA (X-ray energy parameter setting)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| Non attenuator | | **1.72221E-14** | - |
| 1 | 1.45 | 1.17395E-15 | 3.894442865 |
| 2 | 1.3 | 1.20768E-15 | 3.45473522 |
| 3 | 1.4 | 1.08333E-15 | 3.872610623 |
| 4 | 1.3 | 1.17944E-15 | 3.485494525 |
| 5 | 1.4 | 1.14222E-15 | 3.798504458 |
| 6 | 1.46 | 1.05444E-15 | 4.078041511 |
| 7 | 1.2 | 1.39167E-15 | 3.018829299 |
| 8 | 1.3 | 1.10056E-15 | 3.575491465 |
| 9 | 1.15 | 1.18389E-15 | 3.078996734 |
| 10 | 1.45 | 1.01389E-15 | 4.106979754 |
| 11 | 1.4 | 1.06944E-15 | 3.890675389 |
| 12 | 1.3 | 1.07611E-15 | 3.604691263 |
| 13 | 1.4 | 9.70556E-16 | 4.026511701 |
| 14 | 1.35 | 9.33333E-16 | 3.935501132 |
| 15 | 1.5 | 9.40000E-16 | 4.362102834 |
| 16 | 1.4 | 9.35000E-16 | 4.078762663 |
| 17 | 1.5 | 9.07222E-16 | 4.415341505 |
| 18 | 1.3 | 9.46111E-16 | 3.772064940 |
| 19 | 1.45 | 8.96667E-16 | 4.285133159 |
| 20 | 1.55 | 8.98889E-16 | 4.576822948 |
| 21 | 1.45 | 8.75556E-16 | 4.319680248 |
| 22 | 1.25 | 1.06722E-15 | 3.476417417 |
| 23 | 1.3 | 9.73889E-16 | 3.734446575 |
| 24 | 1.3 | 8.87222E-16 | 3.855608833 |
| 25 | 1.4 | 8.47778E-16 | 4.215861838 |

Table B.1 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 50:50 at 80 kV 4 mA (X-ray energy parameter setting) (cont.)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| 26 | 1.45 | 8.67778E-16 | 4.332618511 |
| 27 | 1.4 | 8.85556E-16 | 4.154826532 |
| 28 | 1.4 | 8.77778E-16 | 4.167176958 |
| 29 | 1.4 | 8.59444E-16 | 4.196727144 |
| Average of $\mu_{Linear}$ of composited material 50:50 at 80 kV 4 mA | | | 3.922934415 |

Table B.2 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 50:50 at 100 kV 6 mA (X-ray energy parameter setting)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| Non attenuator | | 1.24194E-14 | - |
| 1 | 1.45 | 1.77778E-15 | 2.818645596 |
| 2 | 1.3 | 2.00556E-15 | 2.370337517 |
| 3 | 1.4 | 1.89444E-15 | 2.632464846 |
| 4 | 1.3 | 2.02222E-15 | 2.359578835 |
| 5 | 1.4 | 1.83333E-15 | 2.678370598 |
| 6 | 1.46 | 1.73333E-15 | 2.875048531 |
| 7 | 1.2 | 2.47778E-15 | 1.934274670 |
| 8 | 1.3 | 1.89444E-15 | 2.444431643 |
| 9 | 1.15 | 2.33333E-15 | 1.922753769 |
| 10 | 1.45 | 1.73889E-15 | 2.850716413 |
| 11 | 1.4 | 1.82222E-15 | 2.686881262 |
| 12 | 1.3 | 1.96111E-15 | 2.399470389 |
| 13 | 1.4 | 1.79444E-15 | 2.708387062 |
| 14 | 1.35 | 1.68500E-15 | 2.696614329 |
| 15 | 1.5 | 1.65500E-15 | 3.023184976 |

Table B.2 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 50:50 at 100 kV 6 mA (X-ray energy parameter setting) (cont.)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| 16 | 1.4 | 1.75556E-15 | 2.739061215 |
| 17 | 1.5 | 1.66222E-15 | 3.016653396 |
| 18 | 1.3 | 1.76111E-15 | 2.539306557 |
| 19 | 1.45 | 1.77222E-15 | 2.823183941 |
| 20 | 1.55 | 1.54889E-15 | 3.226665738 |
| 21 | 1.45 | 1.64722E-15 | 2.929242573 |
| 22 | 1.25 | 2.21667E-15 | 2.154066367 |
| 23 | 1.3 | 1.82778E-15 | 2.491003787 |
| 24 | 1.3 | 1.54611E-15 | 2.708569294 |
| 25 | 1.4 | 1.71667E-15 | 2.770422527 |
| 26 | 1.45 | 1.71667E-15 | 2.869366188 |
| 27 | 1.4 | 1.78333E-15 | 2.717082742 |
| 28 | 1.4 | 1.77778E-15 | 2.721450920 |
| 29 | 1.4 | 1.71667E-15 | 2.770422527 |
| Average of $\mu_{Linear}$ of composited material 50:50 at 100 kV 6 mA | | | 2.650953731 |



Table B.3 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 50:50 at 120 kV 9 mA (X-ray energy parameter setting)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| Non attenuator | | **2.05992E-14** | - |
| 1 | 1.45 | 4.42222E-15 | 2.230984597 |
| 2 | 1.3 | 4.94444E-15 | 1.855084127 |
| 3 | 1.4 | 4.66667E-15 | 2.078730305 |
| 4 | 1.3 | 4.96667E-15 | 1.849254521 |

Table B.3 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 50:50 at 120 kV 9 mA (X-ray energy parameter setting) (cont.)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| 5 | 1.4 | 4.59444E-15 | 2.100566381 |
| 6 | 1.46 | 4.34444E-15 | 2.272277588 |
| 7 | 1.2 | 5.85556E-15 | 1.509433828 |
| 8 | 1.3 | 4.71667E-15 | 1.916395086 |
| 9 | 1.15 | 5.67222E-15 | 1.483122150 |
| 10 | 1.45 | 4.34444E-15 | 2.256714043 |
| 11 | 1.4 | 4.44444E-15 | 2.147036535 |
| 12 | 1.3 | 4.98333E-15 | 1.844899408 |
| 13 | 1.4 | 4.51111E-15 | 2.126192478 |
| 14 | 1.35 | 4.48333E-15 | 2.058595539 |
| 15 | 1.5 | 4.22222E-15 | 2.377336229 |
| 16 | 1.4 | 4.71111E-15 | 2.065460064 |
| 17 | 1.5 | 4.11111E-15 | 2.417338600 |
| 18 | 1.3 | 4.53333E-15 | 1.967933367 |
| 19 | 1.45 | 4.43889E-15 | 2.225530045 |
| 20 | 1.55 | 3.97778E-15 | 2.549020083 |
| 21 | 1.45 | 4.20000E-15 | 2.305743421 |
| 22 | 1.25 | 5.47222E-15 | 1.656959515 |
| 23 | 1.3 | 4.62778E-15 | 1.941128294 |
| 24 | 1.3 | 4.10556E-15 | 2.096784731 |
| 25 | 1.4 | 4.32778E-15 | 2.184277490 |
| 26 | 1.45 | 4.35556E-15 | 2.253010337 |
| 27 | 1.4 | 4.57778E-15 | 2.105654212 |
| 28 | 1.4 | 4.43889E-15 | 2.14878763 |
| 29 | 1.4 | 4.36111E-15 | 2.173535749 |
| Average of $\mu_{Linear}$ of composited material 50:50 at 120 kV 9 mA | | | 2.075785736 |

Table B.4 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 60:40 at 100 kV 6 mA (X-ray energy parameter setting)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| **Non attenuator** | | **1.34825E-14** | - |
| 1 | 1.15 | 1.35444E-15 | 2.642705041 |
| 2 | 1.3 | 1.19611E-15 | 3.149016255 |
| 3 | 1.3 | 1.19833E-15 | 3.146603262 |
| 4 | 1.1 | 1.30778E-15 | 2.566373047 |
| 5 | 1.4 | 1.16222E-15 | 3.431486616 |
| 6 | 1.35 | 1.24722E-15 | 3.213643806 |
| 7 | 1.2 | 1.38389E-15 | 2.731797814 |
| 8 | 1.2 | 1.46667E-15 | 2.662084197 |
| 9 | 1.45 | 1.11333E-15 | 3.616353986 |
| 10 | 1.4 | 1.18278E-15 | 3.406942040 |
| 11 | 1.45 | 1.07833E-15 | 3.662669710 |
| 12 | 1.35 | 1.16500E-15 | 3.305710795 |
| 13 | 1.3 | 1.26500E-15 | 3.076220716 |
| 14 | 1.45 | 1.09000E-15 | 3.647066178 |
| 15 | 1.25 | 1.23444E-15 | 2.988468404 |
| 16 | 1.35 | 1.16278E-15 | 3.308288361 |
| 17 | 1.4 | 1.14833E-15 | 3.448317788 |
| 18 | 1.5 | 1.08222E-15 | 3.783568814 |
| 19 | 1.4 | 1.13889E-15 | 3.459879670 |
| 20 | 1.4 | 1.15111E-15 | 3.444935327 |
| 21 | 1.2 | 1.38000E-15 | 2.735174701 |
| 22 | 1.3 | 1.21000E-15 | 3.134008007 |
| 23 | 1.45 | 1.07222E-15 | 3.670910497 |
| 24 | 1.4 | 1.15944E-15 | 3.434836701 |
| 25 | 1.5 | 1.02000E-15 | 3.872389684 |
| 26 | 1.3 | 1.11667E-15 | 3.238362001 |
| 27 | 1.3 | 1.21722E-15 | 3.126271660 |

Table B.4 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 60:40 at 100 kV 6 mA (X-ray energy parameter setting) (cont.)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| 28 | 1.3 | 1.30333E-15 | 3.037411864 |
| 29 | 1.5 | 1.05333E-15 | 3.824154016 |
| 30 | 1.3 | 1.28056E-15 | 3.060332260 |
| Average of $\mu_{Linear}$ of composited material 60:40 at 100 kV 6 mA | | | 3.260866107 |

Table B.5 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 60:40 at 120 kV 9 mA (X-ray energy parameter setting)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| Non attenuator | | **2.03686E-14** | - |
| 1 | 1.15 | 3.55556E-15 | 2.007306215 |
| 2 | 1.3 | 3.08333E-15 | 2.454378846 |
| 3 | 1.3 | 2.97778E-15 | 2.499662984 |
| 4 | 1.1 | 3.38889E-15 | 1.972842172 |
| 5 | 1.4 | 2.92778E-15 | 2.715651810 |
| 6 | 1.35 | 3.16667E-15 | 2.512775898 |
| 7 | 1.2 | 3.55000E-15 | 2.096456864 |
| 8 | 1.2 | 3.67222E-15 | 2.055837602 |
| 9 | 1.45 | 2.68333E-15 | 2.939056022 |
| 10 | 1.4 | 3.00000E-15 | 2.681535782 |
| 11 | 1.45 | 2.71111E-15 | 2.924122831 |
| 12 | 1.35 | 2.99444E-15 | 2.588268965 |
| 13 | 1.3 | 3.16667E-15 | 2.419710124 |
| 14 | 1.45 | 2.75556E-15 | 2.900545076 |
| 15 | 1.25 | 3.28889E-15 | 2.279306508 |
| 16 | 1.35 | 2.85556E-15 | 2.652383577 |

Table B.5 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 60:40 at 120 kV 9 mA (X-ray energy parameter setting) (cont.)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| 17 | 1.4 | 3.03889E-15 | 2.663504254 |
| 18 | 1.5 | 2.60556E-15 | 3.084523609 |
| 19 | 1.4 | 3.03889E-15 | 2.663504254 |
| 20 | 1.4 | 3.11667E-15 | 2.62812331 |
| 21 | 1.2 | 3.64444E-15 | 2.064949263 |
| 22 | 1.3 | 3.11111E-15 | 2.442719575 |
| 23 | 1.45 | 2.75556E-15 | 2.900545076 |
| 24 | 1.4 | 3.02222E-15 | 2.671203632 |
| 25 | 1.5 | 2.54444E-15 | 3.120123986 |
| 26 | 1.3 | 2.95556E-15 | 2.509400857 |
| 27 | 1.3 | 3.13889E-15 | 2.431163943 |
| 28 | 1.3 | 3.25000E-15 | 2.385941992 |
| 29 | 1.5 | 2.66111E-15 | 3.052876866 |
| 30 | 1.3 | 3.35000E-15 | 2.346545038 |
| Average of $\mu_{Linear}$ of composited material 60:40 at 120 kV 9 mA | | | 2.555498898 |



Table B.6 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 70:30 at 100 kV 6 mA (X-ray energy parameter setting)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| Non attenuator | | **1.32695E-14** | - |
| 1 | 1.2 | 9.08889E-16 | 3.217199433 |
| 2 | 1.25 | 8.98333E-16 | 3.365851482 |
| 3 | 1.15 | 9.81667E-16 | 2.994566159 |
| 4 | 1.2 | 9.61111E-16 | 3.150158829 |
| 5 | 1.2 | 9.86111E-16 | 3.119344012 |

Table B.6 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 70:30 at 100 kV 6 mA (X-ray energy parameter setting) (cont.)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| 6 | 1.25 | 9.17778E-16 | 3.339083864 |
| 7 | 1.25 | 9.01111E-16 | 3.361992263 |
| 8 | 1.25 | 9.05556E-16 | 3.355842189 |
| 9 | 1.25 | 9.21667E-16 | 3.333798443 |
| 10 | 1.2 | 9.31111E-16 | 3.188212517 |
| 11 | 1.3 | 8.77778E-16 | 3.530577595 |
| 12 | 1.25 | 8.90000E-16 | 3.377501147 |
| 13 | 1.2 | 9.27778E-16 | 3.192516167 |
| 14 | 1.35 | 8.87222E-16 | 3.651921311 |
| 15 | 1.25 | 8.82222E-16 | 3.388473004 |
| 16 | 1.2 | 1.01500E-15 | 3.084694186 |
| 17 | 1.4 | 7.62222E-16 | 3.999777931 |
| 18 | 1.25 | 9.12222E-16 | 3.346673444 |
| 19 | 1.2 | 9.02778E-16 | 3.225295140 |
| 20 | 1.25 | 9.18333E-16 | 3.338327434 |
| 21 | 1.25 | 8.91111E-16 | 3.375941571 |
| 21 | 1.2 | 9.68333E-16 | 3.141175199 |
| 23 | 1.35 | 8.33889E-16 | 3.735614988 |
| 24 | 1.35 | 8.34444E-16 | 3.734715887 |
| 25 | 1.3 | 8.70556E-16 | 3.541318043 |
| 26 | 1.2 | 9.23333E-16 | 3.198278483 |
| 27 | 1.25 | 8.90556E-16 | 3.376721115 |
| 28 | 1.3 | 8.07778E-16 | 3.638616003 |
| 29 | 1.3 | 8.51111E-16 | 3.570683603 |
| 30 | 1.2 | 9.63889E-16 | 3.146695623 |
| Average of $\mu_{Linear}$ of composited material 70:30 at 100 kV 6 mA | | | 3.367385569 |

Table B.7 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 70:30 at 120 kV 9 mA (X-ray energy parameter setting)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| Non attenuator | | **2.05319E-14** | - |
| 1 | 1.2 | 2.22778E-15 | 2.665169166 |
| 2 | 1.25 | 2.28333E-15 | 2.745428147 |
| 3 | 1.15 | 2.48333E-15 | 2.429233708 |
| 4 | 1.2 | 2.40000E-15 | 2.575812173 |
| 5 | 1.2 | 2.43889E-15 | 2.556523583 |
| 6 | 1.25 | 2.10556E-15 | 2.846749409 |
| 7 | 1.25 | 2.25000E-15 | 2.763810831 |
| 8 | 1.25 | 2.31111E-15 | 2.73031309 |
| 9 | 1.25 | 2.22222E-15 | 2.779338981 |
| 10 | 1.2 | 2.47222E-15 | 2.540233740 |
| 11 | 1.3 | 2.07222E-15 | 2.981364506 |
| 12 | 1.25 | 2.18333E-15 | 2.801407650 |
| 13 | 1.2 | 2.45000E-15 | 2.551069028 |
| 14 | 1.35 | 2.11111E-15 | 3.070932047 |
| 15 | 1.25 | 2.16111E-15 | 2.814195486 |
| 16 | 1.2 | 2.51111E-15 | 2.521504263 |
| 17 | 1.4 | 1.78333E-15 | 3.420892453 |
| 18 | 1.25 | 2.17222E-15 | 2.807785215 |
| 19 | 1.2 | 2.41111E-15 | 2.570269438 |
| 20 | 1.25 | 2.37222E-15 | 2.697689649 |
| 21 | 1.25 | 2.32222E-15 | 2.724317875 |
| 22 | 1.2 | 2.40556E-15 | 2.573037605 |
| 23 | 1.35 | 1.88333E-15 | 3.225063094 |
| 24 | 1.35 | 1.91667E-15 | 3.201378275 |
| 25 | 1.3 | 2.07778E-15 | 2.977883915 |
| 26 | 1.2 | 2.32778E-15 | 2.612477775 |
| 27 | 1.25 | 2.18889E-15 | 2.798231029 |

Table B.7 Linear attenuation coefficient values of composited specimen (Barium sulfate: Resin ratio) 70:30 at 120 kV 9 mA (X-ray energy parameter setting) (cont.)

| No. | Thickness (cm) | Reading of a dosimeter (Coulomb/sec) | $\mu_{Linear}$ ($cm^{-1}$) |
|---|---|---|---|
| 28 | 1.3 | 2.00000E-15 | 3.027481211 |
| 29 | 1.3 | 2.10556E-15 | 2.960619385 |
| 30 | 1.2 | 2.40000E-15 | 2.575812173 |
| Average of $\mu_{Linear}$ of composited material 70:30 at 120 kV 9 mA | | | 2.784867497 |

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| | |
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**Research field of Interest**

1. Radiation Protection
2. Monte Carlo simulation on radiation interaction
3. Quality control of Radiation Therapy