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# Dose Customized Apron Micro Functional Design Using Convergence Shielding Sheet

Seon-Chil Kim
Professor, Department of Biomedical Engineering, School of Medicine, Keimyung University

# 융합 차폐시트를 이용한 선량 맞춤형 에이프런 마이크로 기능성 디자인

김선칠
계명대학교 의용공학과 교수

**Abstract** Radiation shielding clothing for medical institutions is used based on lead equivalent of 0.25 mmPb. However, this study intends to study the shielding suit that can guarantee the user's activity while considering the sensitivity of each part of the body. By manufacturing based on eco-friendly shielding material, it was attempted to solve the weight problem and environmental problem of existing lead aprons, and to present the same shielding performance as lead equivalent in thickness. The fabric of the produced shielding sheet was manufactured through a calendar process that adjusts the thickness of the shielding sheet from lead equivalent 0.12 mmPb to 0.32 mmPb. In addition, the usability evaluation of the manufactured shielding clothes was conducted for the subjects who were workers in medical institutions. As a result, the activity became easier and the weight was reduced by 0.26 kg. In the future, it is thought that it is necessary to improve the shielding suit design considering the activity.

**Key Words :** Medical radiation, Apron, Tungsten, Convergence of shielding sheets, Bismuth oxide

**요 약** 본 의료기관에서 사용되는 방사선 차폐복은 납당량 0.25 mmPb를 기준으로 제시하고 있다. 그러나 신체 각 부위별 감수성을 고려하고 사용자의 활동성을 보장할 수 있는 동시에 정밀한 방어가 가능한 차폐복 제작에 대해 연구하고자 한다. 친환경 차폐 재료를 기반으로 제작하여 기존 납 Apron의 중량 문제와 환경 문제를 해결하는 동시에 두께로 납당량과 동일한 차폐성능을 제시하고자 하였다. 제작된 차폐시트의 원단은 납당량 0.12 mmPb부터 0.32 mmPb까지 차폐시트의 두께로 조절하는 카렌더 공정을 통해 제작하였다. 각 신체 부위별 감수성을 고려한 차폐복을 제작하여 의료기관에서 상시 착용하고 있는 대상자를 통해 사용성평가를 실시하였다. 차폐복을 착용한 후 활동성이 좀 더 증가하였다는 의견이 많았으며, 무게는 0.26kg을 줄였다. 향후에는 의료기관의 종사자의 활동성을 고려한 차폐복 디자인 개선 노력이 필요할 것으로 사료된다.

**주제어 :** 의료방사선, 에이프런, 텅스텐, 차폐, 산화비스무트

## 1. Introduction

Radiation shielding clothing in medical institutions uses a shielding suit with a lead equivalent of 0.5-0.25 mmPb, and the weight is about 3.2-4.2 kg, and it is produced in various ways depending on the shielding material

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*Corresponding Author : Seon-Chil Kim(chil@kmu.ac.kr)
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used[1-4]. The weight difference of the radiation shielding suit may vary depending on the shielding material, mixing, and manufacturing technology. Although the shielding performance of radiation shielding clothing is suggested based on lead equivalent, environmentally friendly materials such as tungsten, bismuth, and barium sulfate have recently been used instead of lead[5]. Therefore, the shielding performance of the lead-free shielding suit is presented based on the lead equivalent that can be compared to the standard lead. Eco-friendly materials used instead of lead are produced in the form of films, sheets, and fibers depending on their light weight, processability, and compatibility with other materials. Radiation protection apron used in medical institutions (IEC 61331-3:1998) must be checked for shielding performance according to KS A 4025 (Test method for lead equivalent of X-ray protection products) with a performance evaluation standard of 0.25 mmPb or more[6]. In addition, the size of the shielding garment should cover the entire body from the neck to the knees, including the sternum and the entire shoulder[7]. However, since the shielding performance of the shielding clothing is stipulated as lead equivalent of 0.25 mmPb, in fact, it is difficult to produce and sell customized production based on the dose standard because there is no demand from medical institutions. In addition, as the domestic regulations do not provide a standard for radiation shielding lead equivalent for patients, the reality is that medical personnel must use shielding suits for the main purpose of direct dose shielding for patients as needed. Therefore, in the case of manufacturing a customized shielding sheet for each shielding area or when manufacturing clothes for low-dose shielding such as scattered rays, the term radiation shielding cannot be used in accordance with related regulations, and the name of functional clothing is used[8,9].

There is a difference in the extent to which radiation exposure to the human body is accepted for each body part according to the radiation sensitivity. Radiation susceptibility means that the degree of reaction varies according to body parts even when exposed to the same dose. Such radiation sensitivity appears high when the tissue's regenerative capacity is large, the cell division period is long, or the morphological undifferentiated stage[10,11]. In general, it is reported that the genital organs and the lens have high radiation sensitivity and low nerve cells[12]. Therefore, rather than manufacturing a product with a lead equivalent of 0.25 mmPb in a lump, it is possible to consider making an appropriate shield considering the tissue weighting factor based on human organs. This development and application is a new attempt to produce functional clothing for radiation defense, and it is advantageous in achieving a lightweight purpose that ensures the safe protection of body organs and the activity of medical personnel in radiation-producing areas.

In this study, functional clothing for radiation protection was designed and manufactured by changing the material and thickness of the shielding sheet based on the main organs by referring to the effective dose for each body part presented in the study related to radiation protection. The effective dose presented for each body part refers to the dose of a tissue or organ in consideration of the tissue weighting factor, which expresses the sensitivity of a specific part to radiation exposure[13]. Therefore, based on the current regulation of 0.25 mmPb, it is intended to perform reinforcing shielding in a specific range of the body at the same dose inside the imaging room.

In order to add functional elements that allow free medical activities to the radiation shielding suits of medical personnel in hospitals, it is necessary to improve the user-centered fundamental design. However, there is a limit to weight control to achieve the important function of radiation shielding. In order to design a shielding suit that satisfies the main shielding function and is not affected by activity, the type and location of the shielding sheet for each body part are selected and designed. Through this, this study was conducted to present a functional convergence design centered on shielding performance beyond the standardized radiation shielding standard.

## 2. Materials and Methods

Even if it is assumed that various parts of the body are uniformly affected within the radiation range in the radiation generating area, the relative risk of each tissue organ is different, so the tissue weighting factor is calculated by multiplying the equivalent dose($H_T$) for each organ. Table 1 shows the tissue weighting factor ($w_T$) according to the ICRP recommendations (ICRP Publication 103, 2007). Therefore, the effective dose($E$) is expressed as Equation 1[14].

$$E=\sum_T w_T \cdot H_T \quad \sum_T w_T = 1 \text{.............. Eq 1.}$$

**Table 1. Tissue weighting factor**

| Division | $w_T$ (ICRP 103) | Position |
|---|---|---|
| Colon, Lung, Stomach, Marrow | 0.12 | Upper abdomen |
| Sexual gland | 0.08 | Low abdomen |
| Bladder, Liver, Thyroid | 0.04 | |
| Salivary gland, Brain, Skin | 0.01 | - |

### 2.1 Lead equivalent of production Apron

The standard Apron single shielding fabric configuration was changed, and in order to increase the radiation defense ability of major body parts, the entire body part was divided into three grades, and the shielding performance suitable for the part was presented as a lead equivalent as shown in Fig. 1. In addition, additional shielding was provided to update the shielding performance while meeting the lead equivalent 0.25 mmPb standard. According to the current regulations, the lead equivalent of a shielding garment must meet the 0.25 mmPb standard, but the fabric design was reconstructed according to the tissue weighting factor recommendations in Table 1. Overall, the upper abdomen complied with 0.25 mmPb, and in the lower abdomen, the lead equivalent was lowered in consideration of the weight when moving. Therefore, it was designed as 0.23 mmPb by applying the same ratio of tissue weighting factor to the upper abdomen.

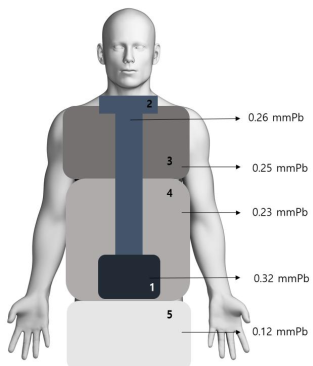


**Fig. 1. Design of shielding fabric according to shielding performance**

Based on the designed fabric, Apron, a shielding garment, was manufactured. In order to match the shielding performance of the lead equivalent, micro-sized tungsten powder (purity 99.9%) was mixed with polyurethane, a polymer material, to produce a shielding sheet. The shielding sheet was manufactured with a thickness of 1.5 mm through the calendar process in the same way and complied with the standard lead equivalent of 0.25 mmPb. Therefore, the sheet thickness that guarantees easy user activity was adjusted as shown in Table 2 to compose the lead equivalent. In addition, the shielding sheet on the thigh that complies with the lead equivalent of 0.12 mmPb was constructed by using bismuth to lower the weight.

**Table 2. Shielding sheet production by controlling lead equivalent**

| Lead equivalent (mmPb) | Thickness (mm) | Shielding material | Position |
|---|---|---|---|
| 0.12 | 0.65 | Bismuth | Abdomen |
| 0.23 | 1.18 | Tungsten | Abdomen |
| 0.25 | 1.50 | Tungsten | Lung |
| 0.26 | 1.72 | Tungsten | Spin |
| 0.32 | 2.58 | Tungsten | Sexual gland |

The adhesion of shielding sheets with different thicknesses was processed and designed as illustrated in Fig. 2 so that joints would not appear through bonding, and the outside was covered with flame-retardant and anti-fouling fabrics to finally manufacture an Apron for medical workers. In order to evaluate usability such as wearing comfort, the apron produced by 10 subjects, including doctors and radiologists, was evaluated.

### 2.2 Evaluation on wearing an apron

This study tried to provide objective data on the derivation of product-related problems by conducting usability evaluation on subjects who directly used the developed product. For the usability evaluation index developed in this study, evaluation items were written on a Likert 5-point scale (very much, yes, moderate, dissatisfied, very dissatisfied) so that the subjects did not have any difficulty in evaluating them[15]. Table 3 shows the main evaluation items and contents.

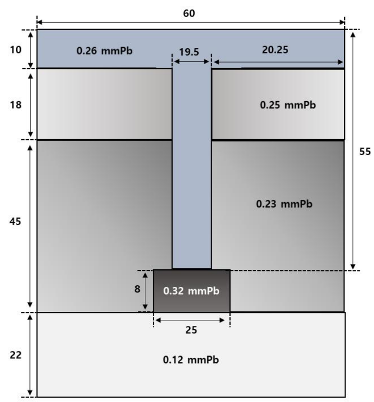


**Fig. 2. Distribution drawing of lead equivalent of shielding sheet (unit: cm)**

The content validity of the used indicator is evaluated on whether the indicator has the concept of generality and whether the concept to be measured is comprehensive. In this study, the content validity of the evaluation items was evaluated by asking the user to fill out a Likert 5-point scale (very reasonable, reasonable, moderate, insufficient, very insufficient) for the validity of the questionnaire questions of the usability evaluation index presented to the user. Content validity was analyzed as in Equation 2 based on the content validity ratio (CVR) suggested by Lawshe[16].

$$CVR = \frac{N_e - \frac{N}{2}}{\frac{N}{2}} \quad \text{............. Eq 2.}$$

$N_e$ = Number of opinions that an item is valid
$N$ = Total number of participants

**Table 3. Shielding sheet production by controlling lead equivalent**

| Domain | Attribute | Details |
|---|---|---|
| Safety | External safety | Is the shielding suit externally safe and sturdy |
| | Cohesion | Is the binding part to wear the shielding suit adhered well without dismantling |
| | Durability | Is the appearance of the shielding suit well-preserved without fear of deterioration or deformation |
| | Finishability | Are there no protruding parts on the outside and are there no parts that irritate the skin due to the finishing treatment |
| | Physical irritation | Does the material of the shielding suit not irritate the skin or body |
| Operability | Joint | Is it easy to combine and release the binding part of the product |
| | | Does the connection at the waist cause physical restraint when wearing a shielding suit |
| | Ease of wear | Is it easy to put on and take off the product |
| Satisfaction | Design | Are you satisfied with the material of the product |
| | | Is the appearance and size of the product appropriate |
| | Weight | Is there a feeling of weight in the shoulder or abdomen when wearing a shielding suit |
| | Activity | Is there any difficulty when moving up and down after wearing a shielding suit |
| | | Is there any difficulty when moving left and right after wearing a shielding suit |
| | | Are there any physical restrictions when moving after wearing a shielding suit |
| | Ease of storage | Is the product convenient for storage in the folded state |
| | Persistence of use | Can you recommend the same product to other users |
| | | Is it convenient enough to share the same shielding suit with others |

The evaluation was conducted through the Apron usability evaluation index derived through reliability verification. The most commonly accepted principle for calculating the number of usability evaluation subjects is described as the general Magic Number 5. In the user evaluation, if the number of subjects is 5, it is sufficient to discover the problems of the product[17]. With only 5 evaluators, the probability of finding a problem is more than 80%, and with 10 participants, it can be found up to 90%[18]. Therefore, in this study, 10 users evaluated.

## 3. Results

Fig. 3 shows the shielding sheet and Apron prototype with the thickness and lead equivalent controlled by the shielding material. The apron is designed to be worn from the neck to above the knee in accordance with IEC 61331-3:1998, and a sponge reinforcement is added to prevent the weight from being concentrated on the shoulder area. The composition of the shielding sheet cannot be observed from the outside due to the outer fabric, and when compared with the existing 0.25 mmPb Apron, the weight was reduced by 0.26 kg. Shielding sheets for each body part were customized. In order to ensure free movement of the lower body, a thin and light shielding sheet is attached to minimize restrictions on movement.

Fig. 3. Fabricated fabrics and shielding clothing

In this study, there were a total of 17 usability evaluation indicators of Apron, and how much they affected the user's activity while having the function of shielding medical radiation was evaluated as shown in Fig. 4. The content validity of the index items was reviewed for 5 people who wore them every day out of 10 subjects. In previous studies, the minimum ratio of item validity was suggested to be 0.56[19]. In this evaluation, it was found to be 0.60, and the items of the usability evaluation index were found to be reasonable.

In the usability evaluation of the manufactured shielding clothing, it received an evaluation of 4.24 on a 5-point scale, and there was a difficulty in the connection of the buckle part. There were many positive evaluations of the movement up and down, left and right. The weight, which is the most important factor, also received positive evaluations, but the evaluation of ease of storage was lacking, as in the case of conventional shielding suits. In addition, positive answers came out in the question of feeling constrained by body parts when worn.


**Fig. 4. Basic movements according to movement after wearing a shielding suit**

**Table 4. Usability evaluation index evaluation result**

| Domain | Attribute | Average |
|---|---|---|
| Safety | External safety | 4.2 |
| | Cohesion | 4.8 |
| | Durability | 4.4 |
| | Finishability | 4.4 |
| | Physical irritation | 4.6 |
| Operability | Joint | 4.2 |
| | | 4.2 |
| | Ease of wear | 3.8 |
| Satisfaction | Design | 4.4 |
| | | 4.0 |
| | Weight | 4.2 |
| | Activity | 4.6 |
| | | 4.6 |
| | | 4.8 |
| | Ease of storage | 3.8 |
| | Persistence of use | 4.6 |
| | | 4.4 |

## 4. Discussion

Most of the radiation shields used in medical institutions are made of lead. Recently, the danger of lead is known and due to environmental hazards during disposal, many eco-friendly shielding materials are selected and processed. Tungsten, a representative material, is the most used because it satisfies the condition of being lighter than lead products in the case of the same shielding performance. In this study, when an apron was manufactured based on the same lead equivalent of 0.25 mmPb, the lead-based apron weighed 3.15 kg, and the micro-designed apron using tungsten was reduced by 0.26 kg to 2.89 kg. Therefore, it can be seen that there is no significant difference in weight when eco-friendly materials are used as much as the psychological difference.

Shielding clothing used in medical institutions is a lightweight product and requires a product with small restrictions on medical activities. Through this study, it can be seen that these problems cannot be largely solved by changing the material, and it is thought that the weight reduction by up to 20% will be achieved through continuous research in the future[20]. In addition, as in this study, it is possible to manufacture a shielding suit while maintaining the shielding performance by reconfiguring the existing shielding sheet in various ways. Therefore, there is also a method to solve this problem in terms of the design of the shielding suit.

In this study, the shielding fabric was designed based on the tissue weighting factor, but it can be used in various fields such as distance and task. Therefore, it is possible to suggest a more stable Apron fit and activity to medical workers. In addition, if the shape of the Apron is made in the form of a jacket in the form of a jacket, the user's burden can be reduced when doing activities such as wearing and taking off. However, as in this study, there is a problem of reinforcing the shielding power of the seam, so more research is needed in the future.

As a limitation of this study, the current domestic standard suggests a legal factor of 0.25 mmPb lead equivalent, making it difficult to commercialize it. In addition, the thickness and weight of the shielding sheet can be actively reduced through the shielding sheet manufacturing process technology, but there is a limitation in that the shielding performance is presented as a lead equivalent according to the thickness in order to realize various shielding performances.

Among the contents evaluated through the produced Apron, from the user's point of view, the center of the Apron is well maintained, and there were many opinions that it can move more easily than the existing Apron if it moves back and forth. Most of the subjects who participated in the evaluation of this experiment submitted the opinion that the activity became easier. Therefore, although changes in shielding materials are important, it is believed that improving the design of shielding clothing will also play a sufficient role in increasing user satisfaction.

## 5. Conclusions

The radiation shielding clothing used in medical institutions was reinterpreted from the viewpoint of activity, and sheets with different shielding rates were fused to produce a functional shielding suit. Overall, the weight was reduced by 0.26Kg compared to the previous Apron, but in the activity part, an excellent evaluation of 4.2 on a 5-point scale was obtained through usability evaluation. Therefore, in the case of future shielding clothing production, it is considered that a convergence micro design based on the shielding function is more necessary than the existing shield-type design.

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김 선 칠(Seon-Chil Kim) [정회원]

· 2003년 2월 : 고려대학교 의료정보기기학과 (공학석사)
· 2009년 2월 : 경북대학교 의료정보학과 (의료정보학박사)
· 2003년 3월 ~ 2015년 8월 : 대구보건대학교 방사선과 교수
· 2015년 9월 ~ 현재 : 계명대학교 의용공학과 교수
· 관심분야 : 방사선 차폐, 의료기기, 의료정보
· E-Mail : chil@kmu.ac.kr