(REFEREED RESEARCH)

A RESEARCH ON THE GAMMA RADIATION SHIELDING EFFECTIVENESS OF DICED WOVEN FABRICS

ZAR ÖRGÜLÜ KUMAŞLARIN GAMA RADYASYONU KALKANLAMA ETKİNLİĞİ ÜZERİNE BİR ARAŞTIRMA

Berkay CAMGÖZ[1], Hakan ÖZDEMİR[2]

[1]Ege University, Institute of Nuclear Sciences, İzmir, Turkey
[2]Dokuz Eylül University, Department of Textile Engineering, İzmir, Turkey

Received: 17.01.2017 Accepted: 14.12.2017

ABSTRACT

Lead aprons are used for personal protection of physicians and patients from X-ray (gamma) radiation during medical operations, though lead has environmental disadvantages, with high toxicity. Therefore, the aim of this research was to produce an environmentally friendly and flexible textile-based radiation shielding material. In this work, 1/3 twill and certain diced woven fabrics were manufactured with conductive core yarns, and gamma radiation shielding effectiveness of these diced woven fabrics were investigated and compared with that of the 1/3 twill woven fabric, which are commonly used as uniforms and were not studied previously in the literature. The effects of fabric structural characteristics such as weave, fabric thickness, porosity and conductive weft yarn density on these properties were analyzed by the physics of gamma radiation shielding and statistics. Experimental results are compatible with the physics of gamma radiation shielding. It is observed that with indenting and protruding structure diced woven fabrics performed better gamma radiation shielding performance than the 1/3 twill woven fabrics did. The samples E1 and B1, woven with diced weave 4 and 1, have the highest gamma radiation shielding effectiveness, thanks to the highest fabric thickness and to the lowest porosity. In addition, the increases of conductive core yarn density improved these gamma radiation shielding effectiveness of woven fabrics.

Keywords: Diced weave, twill weave, woven fabrics, gamma radiation, gamma radiation shielding effectiveness, conductive core yarn

ÖZET

Kurşun kalkanlayıcı ürün olan kurşun önlükler, kurşunun zehirli olması gibi çeveresel dezavantaja sahip olmasına rağmen, genellikle tıbbi işlemler esnasında doktorların ve hastaların kişisel korunmasında kullanılmaktadırlar. Bu nedenle, bu çalışmanın amacı çevre dostu ve esnek olan tekstil esaslı radrasyon kalkanlayıcı materyal üretmektir. Bu çalışmada iletken özlü iplikler ile 1/3 dimi ve zar örgülü kumaşlar üretilmiş olup, zar örgülü kumaşların gama radyasyonu kalkanlama etkinliği araştırılmış ve üniformalarda çok kullanılan ve literatürde daha önce çalışılmamış olan 1/3 dimi örgülü kumaşların kalkanlama etkinliği ile karşılaştırılmıştır. Örgü, kumaş kalınlığı, gözeneklilik ve iletken atkı ipliği sıklığı gibi kumaş yapısal özelliklerinin gama radyasyonu kalkanlama etkinliği üzerine etkisi gama radyasyonu kalkanlama fiziği ve istatistiklerle analiz edilmiştir. Deneysel sonuçlar gama radyasyonu kalkanlama fiziği ile uyum göstermektedirler. Girintili ve çıkıntılı yapıları ile zar örgülü kumaşların 1/3 dimi örgülü kumaşlardan daha iyi gama radyasyonu kalkanlama etkinliği gösterdiği gözlenmiştir. Zar örgü 4 ve 1 ile dokunan E1 ve B1 numuneleri kalın oldukları ve düşük gözenekliliğe sahip oldukları için en yüksek gama radyasyonu kalkanlama etkinliğine sahiptirler. Ek olarak, iletken özlü ipliğin sıklığının artırılması, dokuma kumaşların gama radyasyonu kalkanlama etkinliğini artırmıştır.

Anahtar Kelimeler: Zar örgü, dimi örgü, dokuma kumaşlar, gama radyasyonu, gama radyasyonu kalkanlama etkinliği, iletken özlü iplik

Corresponding Author: Hakan Özdemir, h.ozdemir@deu.edu.tr.

1. INTRODUCTION

As a generalized notion, the radiation is propagation of electromagnetic or particle energy which are two portions of radiation concept. However, the radiation is the general name of different characteristic energies. Different energized radiations realize the radiation spectrum. Many of radiation energies are known such as light, heat, radio waves, ultra violet rays (UV) and microwaves but people don't care those are radiation. All radiation types of electromagnetic energy are consisting of the same essence which is just electric and magnetic field coupling in different frequencies. Visible region is the frontier in the large electromagnetic (EM) radiation spectrum for health care. As energy value, under the light the radiations cannot damage the matter although it makes a specific interaction. Over the light (visible radiation) energy (Figure 1) the radiation has a name: ionizing radiation and nuclear radiation. Ultraviolet (UV) photons in region of electromagnetic spectrum that can damage the materials by separating its orbital electrons (2).

While the frequency increases the energy of the radiation increases. Visible region has several eV (electron volt, 1eV=1.6xE-19 Joule) unit energy but UV region begins from several keV (kilo eV) in EM spectrum. 13.6eV energy is required to separate an electron from hydrogen atom that is simplest and first element in periodical table, but visible and other regions that have energy under UV, has not enough energy. To compare UV with higher energies, it should be known that, X-rays has several ten keV to several MeV energies (2).

The electromagnetic radiation is not unique radiation type; the radiation that consist of particles with mass has completely effect of ionization on materials at each energy amount. These particles come from atomic nuclei of radioactive materials, outer space, nuclear interactions and scientific-industrial facilities. Alpha, beta and neutron are well known particles in many of particle types. Particle radiation can be shielded easily and cannot be faced in people life. However, electromagnetic-ionizing radiation cannot be easily stopped. Therefore, it is important to care ionizing radiation for organism because ionizing radiation definitely damages the DNA and life components. The DNA damages are commonly repaired by the organism but always there are permanent DNA damage risks. Coincidently the risk turns into reality of cancer or genetically mutations. Humans live in Ionizing/non-ionizing radiation sea. Natural earth materials and the sun are main radiation source for organisms in health hazard concept. Also, humans can be exposed by the ionizing radiation artificially via medical applications (2).

People have a care to protect their self against all the radiation types as degree of their acknowledge radiation. Although protection from particle radiation is not required remarkable effort, electromagnetic radiation, the ionizing region of the EM spectrum has wide research and job area in radioprotection. Mainly, medical physics brunch is almost interested with ionizing or nuclear radiation applications (2). The people who are except radiation workers is named the public in ionizing radiation mentioning. Radiation workers have to obey more widen tolerance protocols than public because of their controlled conditions and work times. However, the conditions are not controlled in radiation protection for the public. There are many products that put forwarding a protection for radiation shielding. Nevertheless, many of them are useless and out of scientific realities. Despite these, the people should protect their self from negative effects of the ionizing radiation. Annual radiation dose that comes from cosmic and terrestrial radiation has been reported as 2.4mSv meanly for worldwide (4-6) and this exposure value is higher than a single lung Rontgen exposure (7). Also, continuous protection shielding instead of heavy lead is necessary for radiation workers during daily medical jobs out of specific radiation treatments and applications in medical and industrial areas.

User friendly and light weight fabrics or materials have been always important the subject of radiation protection in different scales from high school's projects to specialized scientific researches. Therefore, researchers applied chemical treatments to increase the gamma radiation shielding effectiveness of fabrics:

Maghrabi et al. (8) coated 100% polyester and nylon plain woven fabrics with bismuth oxide. They found that coated polyester fabrics with over 50% Bi_2O_3 showed enhanced shielding ability for transmitted X-rays. Aral, Nergis and Candan (9) coated the cotton fabrics with silicone rubber that contains tungsten, bismuth or barium sulfate powders in equal weight fractions. The results showed that, at 60% weight ratio, 1.55 mm bismuth embedded coating could attenuate 90% of X-ray photons at the 100 kV level, while the required thickness of a tungsten embedded coating was 1.73 mm for the same protection level. Qu et al. (10) fabricated a series of X-ray radiation-resistant fibers via a primarily industrialized wet-spinning trail, and knitted the resultant fibers into fabrics by knitting loom. The X-ray attenuation ratio of the sample tended to increase with increasing barium sulfate content and finally reached a dose of a 0.1 mm thick lead equivalent.

In a recent study, Özdemir and Camgöz (2) developed conductive cellular and 3/1 twill woven fabrics and investigated gamma radiation shielding effectiveness of these fabrics. They found that cellular woven fabrics performed better gamma radiation shielding performance than the 3/1 twill woven fabrics did.

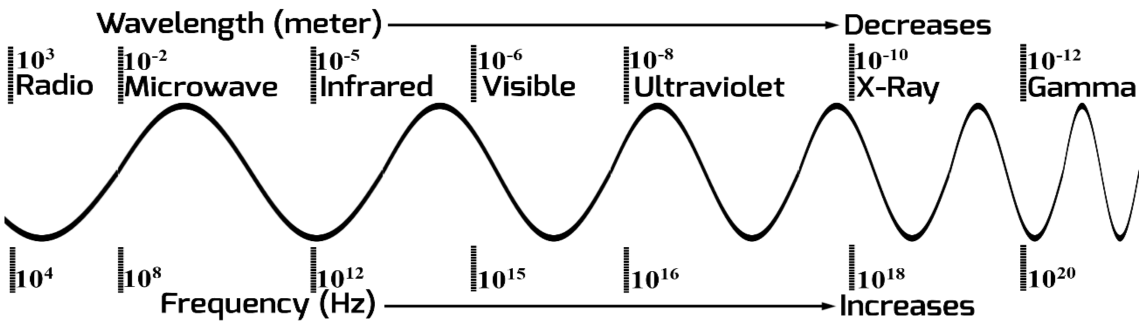


Figure 1. Electromagnetic radiation spectrum

Ionizing radiation is absorbed in different ratios by different element media. While atomic number of absorbing element increase, absorption fraction increase. Reason of lead usage for shielding is its high atomic number. Manufacturing technology of a material or its composition cannot affect the absorption ratios however atomic number or effective atomic number of material is dominant factor. Mechanism of radiation interactions are directly dependent on atomic properties and initial radiation energy. So the shielding (radioprotection) realized by lead has common usage and indispensable still despite improved technology, because the lead atoms have heavy and wide nuclei independently from macro features of materials. This should be remarked to develop efficient radiation absorbers. The basic method is inserting material with heavier atom into the fabric to have a mentionable radioprotection level (2).

The studies in literature focused on chemical treatment of plain woven fabrics. However gamma radiation shielding effectiveness of diced and 1/3 twill woven fabrics produced with conductive core yarns have not been investigated. If a fabric is required to be radiation shielded, firstly it should include bigger atomic number material in its pattern. Commonly fabrics were manufactured with organic or synthetic materials which do not contain bigger atom then themselves. Usual fabrics behave, as there is nothing in front of the initial radiation. Metals are most suitable matters for radiation protection to combine with flexible and woven (or composite) materials. In this study stainless steel, contributed fabric was investigated. Steel is consisting of mostly iron and rarely carbon atoms. Carbon fraction determines quality and firmness of the steel. Industrial quality and hardness of steel is being better by increasing carbon doping. Carbon has 6 atomic number but Iron has 26 atomic number, so carbon amount should be kept at optimum to supply effective atomic number around the Iron. Effective atomic number of Carbon-Iron atom combinations bigger than number of common fabric material atoms. There are bigger atom than steel but industrially treatments has limitation for other element. Steel is user friendly to dope into a fabric, economic and non-toxic (2).

The aim of this study was to investigate the effects of fabric structural parameters, which are weave, conductive weft yarn density, fabric thickness and porosity on gamma radiation shielding effectiveness of the certain diced woven fabrics, whose thickness are bigger than basic weaves, and to compare this property with those of 1/3 twill woven fabric. In this regard, an experimental study has been carried out and then, the effects of the parameters were detected firstly by graphics formed by obtained data and secondly by analysis of variance.

1.1. Physics of Gamma Radiation Shielding

Gamma or X rays which take place on ionizing radiation part of the electromagnetic spectrum, interact with matter by three main ways: Photo electric event, Compton scattering and pair production. Pair production is possible when the radiation (photon) energy is greater than two rest mass of electron (1.022 MeV). So under the 1.022MeV energies two interactions are effective. Photons (radiation) lose its energy in the matter or during passing through the matter by those ways. In process of photoelectric event, photon disappears by transferring its all energy to atomic electron of the absorbing mass (Figure 2) however in the Compton scattering, the photon hits to a semi-free electron in the mass, electron and photon scatters with their own angles comparatively direction of initial photon (Figure 3). Scattered photon has less energy than initial situation, electron of matter and photon share the initial energy.

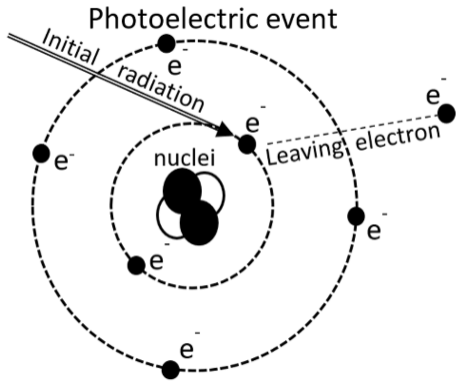


Figure 2. Photoelectric process in absorbing material.

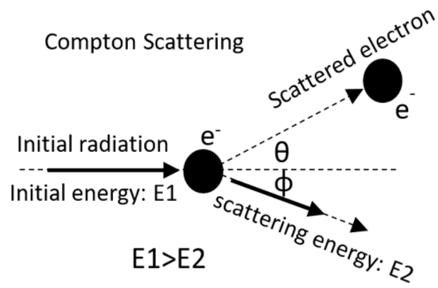


Figure 3. Compton Scattering in absorbing material.

Some percent of initial radiation beam make interaction with matter by mentioned ways some percent of beam directly pass through the matter without any interaction. This situation is determined by the equation (1)

$$I(x) = I_0 e^{-\mu x} \tag{1}$$

While x is thickness of absorbing material I_0 is initial intensity of radiation beam and I(x) is detected beam after the matter. I(x) include non-interacted radiations and some scattered (Compton) radiations. μ is absorbing coefficient which is not constant and dependent on initial radiation energy and matter type (atom types). Radiation-matter interactions occur in atomic scale and interactions are directly statistical events. If there is an atom on propagation direction of the radiation they can interact else radiation pass through. Atomic radius is effective on interaction possibility. So if there is big atom (with big nuclei) such as Lead, interaction possibility is greater. Radius of the atom is determining coincidence probability to the initial radiation. Great interaction possibility is great absorption and also this means better shielding. Also μ is degree of interaction possibility. It is understood that manufacturing technology of any material is not important for radiation-matter interaction. Porosity or other effects of material can be effective but in atomic scale. For example, porosity: If there are air pores in solid material, the degree of interaction possibility will decrease, consequently solid material will shield worse. In a fabric there are yarn atoms and air pore. Technology just determine yarn material atom types and air amount by pore volume. There are steel yarns and pores which are naturally consisting of air.

As result, shielding quality or absorption percent increase while thickness of absorber material increases and total atomic numbers of atom types which the material is consisting of, increase: such as 10 cm thick cupper is better shield than 1 cm thick Lead but 1 cm thick cupper worse shield than 1 cm thick Lead because Lead atoms are bigger (2).

2. EXPERIMENTAL STUDY

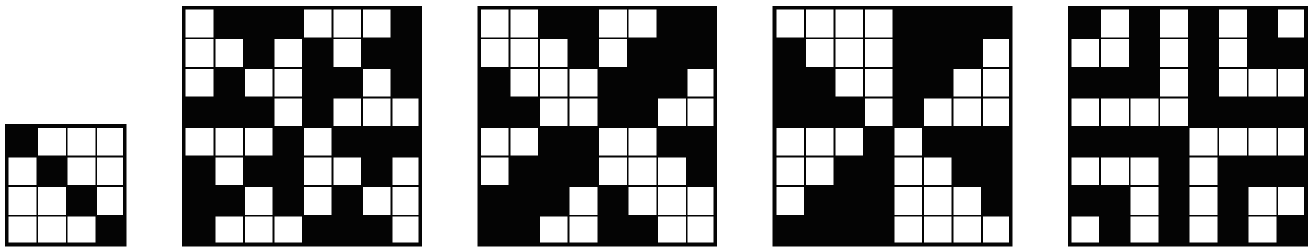
2.1. Production of Conductive Fabrics

In this research, 20 types of diced woven fabric samples and five types of 1/3 twill woven fabrics (35×35 cm) have been produced in Weaving Workshop of in-house by CCI automatic sample rapier loom (Evergreen 8900, Taiwan). 100% polyester and stainless steel core yarns with cotton fiber as sheath material have been used. The specifications of yarns are given in Table 1. Weave patterns are shown in Figure 4. The conductive yarns have been inserted in certain intervals to obtain different open grid structures of conductive yarn within the fabrics, which resulted in different yarn densities. The characteristics of the conductive fabrics are shown in Table 2. The open grid structures of the conductive yarns are represented in Figure 5. Warp and weft settings of 20 kinds of diced woven fabric samples on the loom have been 25 cm^{-1}, which have been equal to 1/3 twill weave settings, which has been calculated for the loom state, in order to compare these fabric samples with twill woven fabric sample. No finishing process has been applied on the fabric samples.

Table 1. The specifications of yarns

Material	Yarn count (dtex)	Diameter of wire (mm)	Conductivity $(\Omega.m)^{-1}$
Polyester yarn	300	0.02	10^{-14}
SS/Co core yarn	455	0.05	0.2×10^{7}

Fabric samples have been coded according to their weave pattern, warp and weft densities as in Table 2. The letter and number in each fabric code represent weave patterns and weft yarn arrangement respectively.



a b c d e

Figure 4. Weave patterns used in experimental: a- 1/3 twill; b- Diced weave 1; c- Diced weave 2; d- Diced weave 3; e- Diced weave 4

Table 2. The specifications of conductive fabrics

Fabric code	Weave pattern	Warp density on the reed (cm^{-1})	Weft density on the loom (cm^{-1})	Yarn type*	Fabric composition (warp × weft)
A1	1/3 Twill	25	25	CP	1C1P × C
A2				CP 1:1	1C1P × 1C1P
A3				CP 1:3	1C1P × 1C3P
A4				CP 1:7	1C1P × 1C7P
A5				CP 1:15	1C1P × 1C15P
B1	Diced weave 1	25	25	CP	1C1P × C
B2				CP 1:1	1C1P × 1C1P
B3				CP 1:3	1C1P × 1C3P
B4				CP 1:7	1C1P × 1C7P
B5				CP 1:15	1C1P × 1C15P
C1	Diced weave 2	25	25	CP	1C1P × C
C2				CP 1:1	1C1P × 1C1P
C3				CP 1:3	1C1P × 1C3P
C4				CP 1:7	1C1P × 1C7P
C5				CP 1:15	1C1P × 1C15P
D1	Diced weave 3	25	25	CP	1C1P × C
D2				CP 1:1	1C1P × 1C1P
D3				CP 1:3	1C1P × 1C3P
D4				CP 1:7	1C1P × 1C7P
D5				CP 1:15	1C1P × 1C15P
E1	Diced weave 4	25	25	CP	1C1P × C
E2				CP 1:1	1C1P × 1C1P
E3				CP 1:3	1C1P × 1C3P
E4				CP 1:7	1C1P × 1C7P
E5				CP 1:15	1C1P × 1C15P

*C represents stainless steel/cotton core yarn, P represents polyester yarn

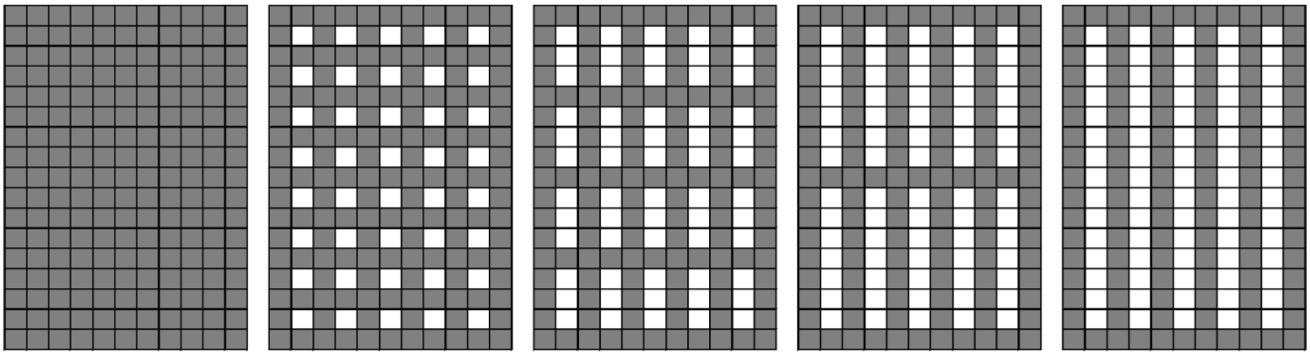


Figure 5. Schematic diagram of open-grid structures formed in the woven fabrics (gray squares: conductive core yarns; white squares: polyester yarns)

2.2. Measurement of Gamma Radiation Shielding Effectiveness

The thickness of fabrics was measured with Digital Thickness Gauge Meter. Five number of the samples were measured.

The porosity of fabrics were calculated by (11)

$$\varepsilon = 1 - \frac{\rho_a}{\rho_b} \qquad (2)$$

where ρ_a is the fabric density (g/cm^3), ρ_b is the fibre density (g/cm^3) and ε is the porosity. Fabric density is calculated by dividing the fabric weight per unit area, by fabric thickness.

Radiation absorption measurement of prepared samples of fabric types were performed using Geiger Muller (GM) gas filled radiation detector in the geometry as shown with Figure 6. Preferring cause of GM detector is detection efficiency for total gamma radiation energy instead of spectroscopic Scintillators of semi-conductor crystals. Also dose studies are commonly based on gas filled detectors (such as ionization chambers) for all type of radiation particles in dosimetry science.

Firstly, a background (absence of non-natural radiation source) radiation was counted to correct the main counting. In step one, americium (Am-241) gamma radiation was counted several times to get mean radiation rate in determined time in geometry of Figure 6 while there is no fabric sample between detector and the source. This mean value represents "I_0" initial intensity of radiation beams that reach to GM detector. In step two, radiation detection-counting was done while each sample is between source and GM detector. This value represents "I" transferred part of gamma radiation by the samples. Transfer and abruption rates of the samples were calculated by fractions of I/I_0. Each sample was measured five times.

Am-241 radionuclide was used as radiation source (point source geometry). Single source energy was used instead variable energies because to use different energies the x-ray tube is needed and properly radioprotection shielding during experiment. Despite this situation Am-241 has gamma energy (Figure 7) in scale of x-ray region and this region is comparable medical radiation energies (2). Common usage of energy range is 10-20keV and up to 100 keV in medical physics. In addition, there is no certain range border in both physics and medical applications. Certain literature data cannot be mentioned for the x ray ad gamma ray separating. Generally, nuclear level photons are named as gamma rays. X-ray region of the electromagnetic spectrum is named in case of lower energized situation or source type of the photons.

On the other hand, it is extremely hard to represent material composition of the sample fabric (or unit fabric) in WinXCom or XCOM format/radiation absorption data set because to calculate or determine is almost impossible element weights and densities in fabric grid that includes air gaps within the fabric grid formed by organic and steel yarns. Although simple materials such as element, mixture and compound which have well known content even if types of tissues which are published by ICRU (*International Commission on Radiation Units & Measurements*) theoretical modelling of nuclear data calculations cannot represent correctly complex materials such as combined fabric.

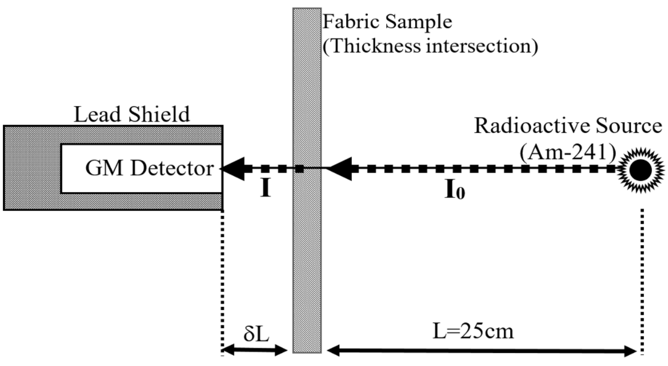


Figure 6. Illustration of radiation (nuclear) absorption experiment. 1) I_0 initial intensity was counted without a fabric sample in air media. 2) I intensity was counted while the sample is between detector and source

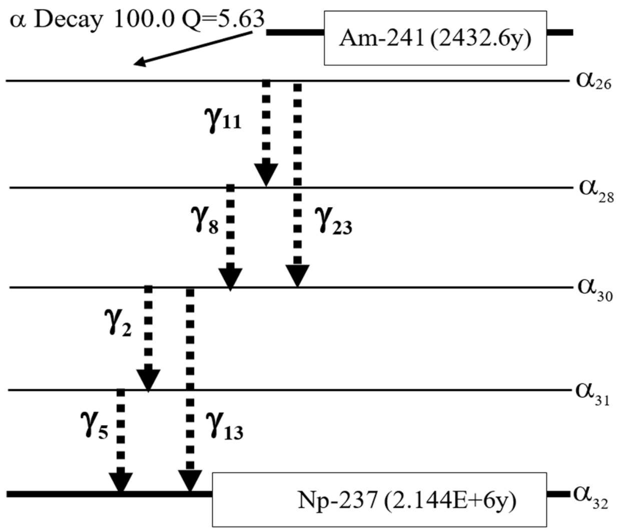


Figure 7. Decay Scheme of Am-241

While transferred part, T, was calculated from equation (3), absorbed part, A, was calculated from equation (4);

$$T = \frac{I}{I_0} \times 100 \quad (3)$$

where I_0 is initial intensity, namely gamma counting without absorber, I is transferred intensity, namely gamma counting with absorber.

$$A = 100 - T \quad (4)$$

In this method it is not needed to calculate real intensity I_0 because I/I_0 rate does not change by calculating real (raw) counting rate in unit count/time.

Mono energy was used in the study so there is no information energy dependence of attenuation. Really attenuation ratios changes by radiation energy even if material properties are fixed. However, usage of variables photon energies bu x-raj tube in an experiment causes some uncertainties such as buildup factors, additionaly x-ray tube usage has health hazard during long period studies.

Radiation absorption measurements were evaluated statistically by ANOVA according the General Linear Model with SPSS 15.0 software package. In order to analyze the effect of weave and conductive weft density, multivariate analysis was made. Significance degrees (p), which were obtained from ANOVA, were compared with significance level (α) of 0.05. The effect, whose significance degree was lower than 0.05, was interpreted as statistically important.

3. RESULTS AND DISCUSSIONS

The averages of thickness, porosity and gamma radiation measurements are given in Table 3. Initial intensity was counted as 479. It is seen from Table 3 that if the fabric thickness increased, the transferred intensity decreased. This can be explained by equation (1) in Physics of Gamma Radiation Shielding. Samples E1-E5 and B1-B5 have the highest transferred intensity because single warp and weft yarn floats in sections of diced weave 4 and 1 cause to increase the thickness of sample E1-E5 and B1-B5. On the other hand, sample C1-C5 and D1-D5 transferred approximately equal amount of radiation. This is due to the fact that warp and weft yarn floats come side by side in sections of sample diced weave 2 and 3. Besides, the sample A, whose thickness is the lowest, have the highest transferred intensity.

Table 3. The thickness and transferred intensity of conductive fabrics

Fabric code	Thickness (mm)	Porosity	Transferred Intensity (cpm)	Transferred/initial Percent (%)
A1	0.58	0.22	326	67
A2	0.56	0.25	330	68
A3	0.54	0.27	335	69
A4	0.51	0.30	341	71
A5	0.49	0.33	347	72
B1	0.76	0.14	300	63
B2	0.74	0.17	305	64
B3	0.72	0.19	309	65
B4	0.7	0.22	314	66
B5	0.68	0.25	320	67
C1	0.65	0.19	313	65
C2	0.63	0.21	317	66
C3	0.61	0.23	322	67
C4	0.59	0.26	327	68
C5	0.56	0.29	331	70
D1	0.67	0.17	311	65
D2	0.65	0.20	315	66
D3	0.63	0.22	320	66
D4	0.6	0.25	325	68
D5	0.58	0.28	329	69
E1	0.78	0.13	297	62
E2	0.76	0.16	302	63
E3	0.74	0.18	306	64
E4	0.71	0.21	311	65
E5	0.68	0.24	316	66

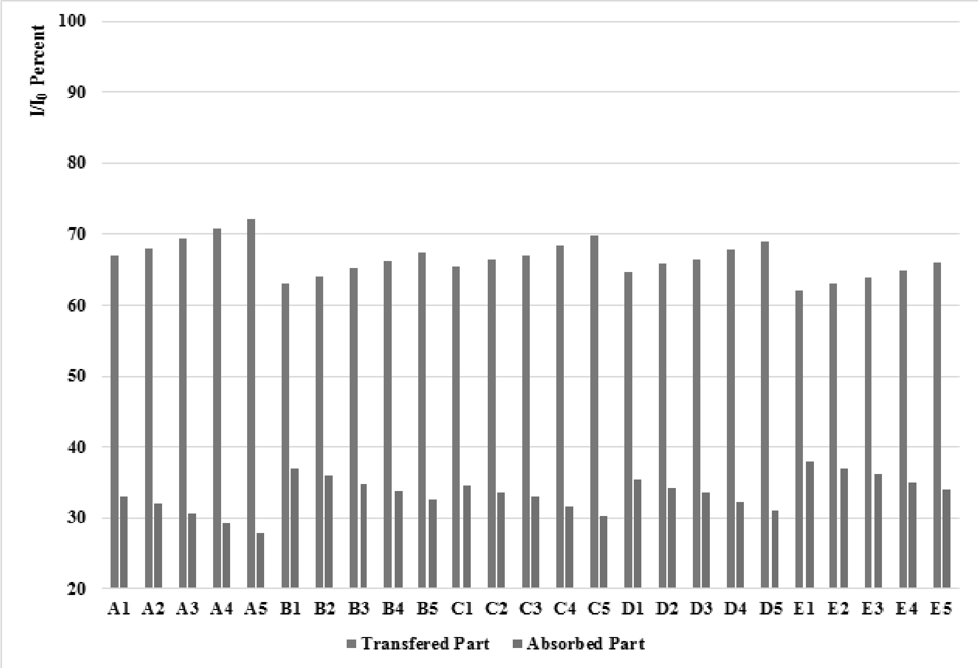


Figure 8. Absorption and transferring rates of initial radiation activity from fabric volume

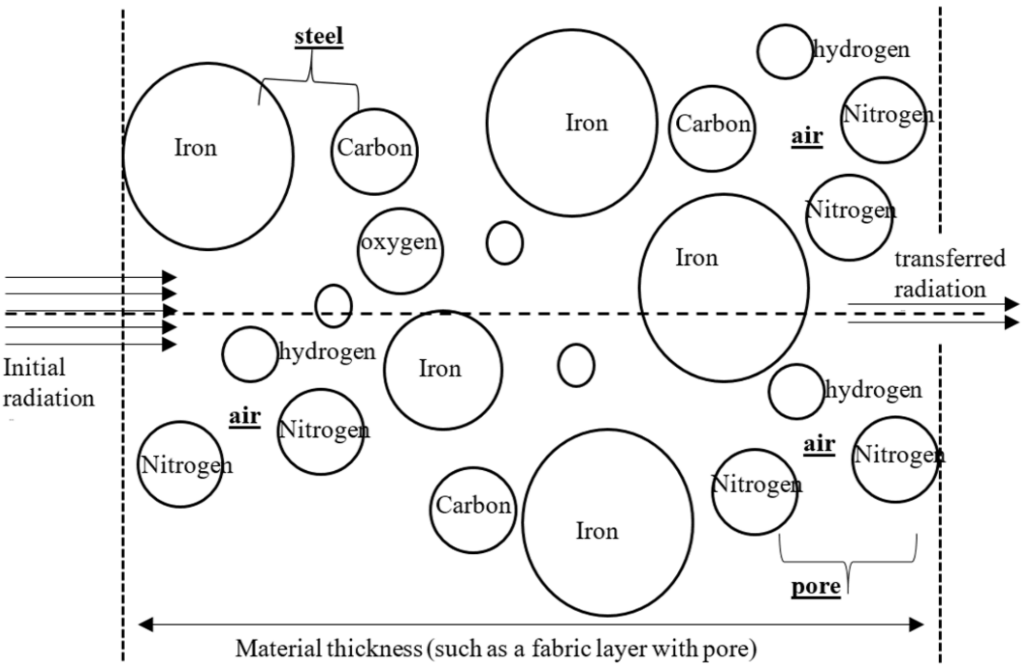


Figure 9. An illustration of fabric-radiation interaction in atomic scale. The figure is hypothetical material information that was derived from basic physics of the mass-radiation interactions. Elements H, N, O and C are organic material components, and iron is steel material, air is gaps of the fabric.

The transferred and absorbed parts of radiation for each fabric are shown in Figure 8. It is observed from Figure 8 that while absorbed part of radiation increased agreement with fabric thickness, transferred part of radiation decreased. The samples E1-E5 and B1-B5 have the lowest transferred part of radiation due to their highest fabric thicknesses, whereas; samples A1-A5 have the highest transferred part of radiation due to its lowest fabric thickness. Because; shielding quality or absorption percent increase while thickness of fabric increases and total atomic numbers of atom types which the material is consisting of, increase, namely the degree of interaction possibility, explained in Physics of Gamma Radiation Shielding, increase. Therefore, fabric which is thicker shields better. Fabric-radiation interaction in atomic scale is illustrated in Figure 9. The opposite is valid for the absorbed part of radiation.

In addition, the samples E1-E5 and B1-B5, whose porosities are the lowest, have the lowest transferred intensity, namely the highest absorbed intensity, the samples A1-A5, whose porosities are the biggest, have the highest transferred intensity, namely the lowest absorbed intensity. In a fabric there are yarn atoms and air pore. With regard to the physics of gamma radiation shielding, if there are air pores in fabric, the degree of interaction possibility will decrease, namely fabric will shield worse.

Moreover, when the density of conductive weft yarn increased, the transferred intensity is decreased as expected. Since conductive core yarn has high bending rigidity, fabric thickness become big. So; the increase in fabric thickness resulted from the increase in conductive yarn density.

The variance analysis showed that both the effects of weave and conductive weft density on gamma radiation shielding effectiveness of conductive fabrics are statistically significant, getting the p-values of (0.022) and (0.043) respectively.

4. CONCLUSION

The main aim of this study was to develop lead-free, fabrics for gamma radiation shielding, focusing on the attenuation properties. Therefore, experimental study was performed within the scope of this study to determine the effects of weave and fabric thickness, which are fabric structural parameters, on the gamma radiation shielding effectiveness of certain diced woven fabrics in comparison with 1/3 twill woven fabric.

It is observed that experimental results are coherent with the physics of gamma radiation shielding. According to the physics of gamma radiation shielding, porosity and thickness of material effect the degree of interaction possibility and correspondingly effect the gamma radiation shielding effectiveness of material.

With the indenting and protruding structures, diced woven fabrics performed better gamma radiation shielding efficiency than 1/3 twill woven fabrics. Thanks to the highest fabric thicknesses and lowest porosities, the sample E1-E5 and B1-B5, woven with diced weave 4 and 1, show the best gamma radiation shielding effectiveness, namely absorbed part, (38 and 37.37 %). Additionally, fabrics woven with diced weave 2 and 3 have higher thickness and lower porosity than 1/3 twill woven fabrics, these fabrics have higher gamma radiation shielding effectiveness, than 1/3 twill woven fabrics. If the conductive weft yarn density increases, gamma radiation shielding effectiveness of fabrics will decrease. Theoretically synthetic or organic materials are not affective on remarkable radiation absorption as it was mentioned in the introduction section but the metal components in the yarn composition of the fabric is dominant on the effective radiation shielding. Metal (steel) density in unit surface of the fabric is deterministic factor for absorption/transfer fraction.

Practically none of the materials is not more efficient than the lead for ionizing radiation protection because of its atomic number/effective atomic number. This study do not put the fabric instead of the lead however material such as steel combined fabrics can be alternative in some situation of radiation protection.

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