Apart from three basic weaves namely plain, twill and sateen weaves, there are derivative of these weaves. The idea behind developing these weaves is to obtain physical and aesthetic characteristics in the fabric somewhat different than those obtained with the basic weaves. In derivative weaves properties intermediary between these main groups are obtained. This is achieved by rearranging the basic weave structures by the application of certain methods to give the desired result [1].

Many of radiation kinds are known by the people such as visible light, heat, radio waves, ultra violet waves (UV) and micro waves but not know they are radiation. All radiation types of electromagnetic energy are made by the same thing which is just electric and magnetic field coupling but different frequencies. Visible region is the frontier in the large electromagnetic radiation spectrum. As energy value, under the light all kinds of radiations cannot damage the matter although make a specific interaction. After light energy (figure 1) the radiation has a name: ionizing radiation and nuclear radiation. UV region starts to damage the matter by separating the electrons. While the frequency increases the energy of the radiation decreases. Visible region has several eV (electronvolt, 1 eV = 1.6 × 10⁻¹⁹ Joule) unit energy but...
UV region has several keV (kilo eV). 13.6 eV energy is needed to separate an electron from hydrogen atom but visible and other regions under UV have not enough such energy. X-ray regions have energies several ten keV to several MeV. Secondly, after the electromagnetic radiation, there is particle radiation that has completely effect of ionizing. These particles come from atomic nuclei of radioactive materials, outer space and scientific facilities. Alpha, beta and neutrons are commonly used and known in many of particle type. Particle radiation can be easily shielded and there cannot be faced in people life. On the other hand, electromagnetic-ionizing radiation cannot be easily stopped. So it is important to care ionizing radiation for alive organism because ionizing radiation definitely damages the DNA. The DNA damages are commonly repaired by the organism but always there are permanent DNA damage risks. Sometime the risk turns into reality of cancer or genetically mutation. In practical life, we live in Ionizing Radiation Sea additionally other non-ionizing radiations. Natural earth materials and the sun are main radiation source for us. Also, humans can face the ionizing radiation artificially by medical applications which include diagnostic and therapy treatments.

Humans try to avoid all the radiation types as degree of their information about radiation concept. Although protection of particle radiation does not need remarkable effort, electromagnetic radiation, also particularly the ionizing region of the electromagnetic spectrum has wide research and job area in radiation protection. Especially, medical physics area almost consists of ionizing or nuclear radiation applications. The people that are except radiation workers are named the public in ionizing radiation application. Radiation workers have more wider tolerance protocols than public because of their controlled conditions. However, the conditions are not controlled in radiation protection in the practical life of the public. Commercially, there are many products which put forwarding a protection for radiation shielding. Many of them are useless and out of scientific realities. Despite these, it is needed to protect the people from ionizing radiation. Annual radiation dose that comes from cosmic and terrestrial radiation is 2.4 mSv meanly [3–5] and this value is higher than a single lung Rontgen exposure [6]. Also, radiation workers need continuous protection shielding instead of heavy lead during daily medical jobs out of specific radiation treatments.

User friendly and light wearing fabrics or materials have been always important the subject of radiation protection in scale from high school's projects to specialized scientific researches. Therefore researchers applied chemical treatments to enhance the gamma radiation shielding effectiveness of fabrics: Maghrabi et al. coated 100 % polyester and nylon plain woven fabrics with bismuth oxide [7]. They found that coated polyester fabrics with over 50% Bi₂O₃ showed enhanced shielding ability for transmitted X-rays. Aral, Nergis and Candan coated the cotton fabrics with silicone rubber that contains tungsten, bismuth or barium sulphate powders in equal weight fractions [8]. 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. fabricated a series of X-ray radiation-resistant fibres via a primarily industrialized wet-spinning trail, and knitted the resultant fibres into fabrics by knitting loom [9]. The X-ray attenuation ratio of the sample tended to increase with increasing barium sulphate content and finally reached a dose of a 0.1 mm thick lead equivalent.

Electromagnetic-ionizing radiation is absorbed in different percentages by different element media. While atomic number of element increases, absorption fraction increases so the lead has the heaviest number in periodic table as friendly usage. Material technology or composition cannot affect the absorption amount, just atomic number or effective atomic number (effective atomic number is defined for mixtures or compounds similar element numbers in nuclear science) of material elements. In consideration of fabric production techniques, technologies and science, radiation-mass interactions are not relevant with them. Mechanism of radiation interactions is directly dependent on mass atomic properties and initial radiation energy. So the shielding made by lead is popular and indispensable still despite improved technology of materials. This cannot be ignored to develop radiation shielding materials. The way is inserting material with heavy atom into the expected fabric for significant radioprotection. The studies in literature focused on chemical treatment of plain woven fabrics. However gamma radiation shielding effectiveness of fabrics woven with textured steel yarns has not been investigated. If a fabric is required to be radiation-shielded, firstly it should...
include bigger atomic number material in its pattern. Common fabrics were manufactured with organic or synthetic materials which do not contain bigger atom than themselves. Metals are most suitable matters for radiation protection so in this study stainless steel contributed fabric was investigated. Steel is consisting of mostly iron and rarely carbon. Carbon fraction determines the type of the steel. Iron has 26 atomic number. This is almost bigger than common fabric material atoms. There are bigger atoms than steel but industrial treatments have limitation for all elements. Steel is user-friendly to put it into a fabric, economic and non-toxic for an organism. 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 2/2 twill, 3/1 twill and certain derivative woven fabrics. In this regard, an experimental study has been carried out and then, the effects of the parameters have been detected firstly by graphics formed by obtained data and secondly by analysis of variance.

**MATERIAL AND METHODS**

**Material**

In this research 24 types of woven fabric samples (42×42 cm) were produced in Weaving Workshop of in-house by CCI automatic sample rapier loom (Evergreen 8900, Taiwan). 100% polyester yarns and textured stainless steel yarns, which have soft feeling and flexibility, required properties for fabrics, were used. The optical image of the textured steel yarn was taken by using Olympus BX 43 Microscopy as shown in figure 2. The specifications of yarns are given in table 1. Weave patterns are shown in figure 3. While the conductive steel yarns were inserted in certain intervals to obtain different open grid structures of conductive yarn within the fabrics, which resulted in different conductive weft yarn densities, the conductive and the polyester yarns were used in 1 to 4 orders as warp yarns. The characteristics of the conductive fabrics are shown in table 2. The open grid structures of the conductive yarns are represented with grey squares and letter of T, whereas the polyester yarns are represented with white squares and letter of P in figure 4. Both white and grey squares also represent intersection points between warp and weft yarns. Warp and weft settings of 24 kinds of woven fabric samples on the loom were 20 cm⁻¹, which was calculated for the loom state. And also reference samples were woven for all kinds of weaves with only 100% polyester warp and wefts.

| 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          | 2/2 Twill     | 20                              | 20                              | TP 1:1     | 1T4P × 1T1P                      |
| A2          |               |                                 |                                 | TP 1:2     | 1T4P × 1T2P                      |
| A3          |               |                                 |                                 | TP 1:4     | 1T4P × 1T4P                      |
| A4          |               |                                 |                                 | TP 1:8     | 1T4P × 1T8P                      |
| B1          | 3/1 Twill     | 20                              | 20                              | TP 1:1     | 1T4P × 1T1P                      |
| B2          |               |                                 |                                 | TP 1:2     | 1T4P × 1T2P                      |
| B3          |               |                                 |                                 | TP 1:4     | 1T4P × 1T4P                      |
| B4          |               |                                 |                                 | TP 1:8     | 1T4P × 1T8P                      |
| C1          | Herringbone   | 20                              | 20                              | TP 1:1     | 1T4P × 1T1P                      |
| C2          |               |                                 |                                 | TP 1:2     | 1T4P × 1T2P                      |
| C3          |               |                                 |                                 | TP 1:4     | 1T4P × 1T4P                      |
| C4          |               |                                 |                                 | TP 1:8     | 1T4P × 1T8P                      |
| D1          | Whipcord      | 20                              | 20                              | TP 1:1     | 1T4P × 1T1P                      |
| D2          |               |                                 |                                 | TP 1:2     | 1T4P × 1T2P                      |
| D3          |               |                                 |                                 | TP 1:4     | 1T4P × 1T4P                      |
| D4          |               |                                 |                                 | TP 1:8     | 1T4P × 1T8P                      |
| E1          | Barathea      | 20                              | 20                              | TP 1:1     | 1T4P × 1T1P                      |
| E2          |               |                                 |                                 | TP 1:2     | 1T4P × 1T2P                      |
| E3          |               |                                 |                                 | TP 1:4     | 1T4P × 1T4P                      |
| E4          |               |                                 |                                 | TP 1:8     | 1T4P × 1T8P                      |
| F1          | Crêpe         | 20                              | 20                              | TP 1:1     | 1T4P × 1T1P                      |
| F2          |               |                                 |                                 | TP 1:2     | 1T4P × 1T2P                      |
| F3          |               |                                 |                                 | TP 1:4     | 1T4P × 1T4P                      |
| F4          |               |                                 |                                 | TP 1:8     | 1T4P × 1T8P                      |

* T represents textured steel yarn, P represents polyester yarn
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.

**Method**

The thickness of fabrics was measured with Digital Thickness Gauge Meter. Five numbers of the samples were measured. The porosities of fabrics were calculated by \( \varepsilon = 1 - \frac{\rho_a}{\rho_b} \) (1)

where \( \rho_a \) is the fabric density (g/cm\(^3\)), \( \rho_b \) is the fibre density (g/cm\(^3\)) and \( \varepsilon \) is the porosity. Fabric density is calculated by dividing the fabric weight per unit area, by fabric thickness.

Radiation absorption measurements of prepared samples of fabric types were performed using Geiger Muller (GM) gas filled radiation detector in the geometry as shown with figure 5. 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 3 while there is no fabric sample between detector and the source. This mean value represents “I0” 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/I0. Each sample was measured five times.

Am-241 radionuclide was used as radiation source (point source geometry). Single source energy was used instead of 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 6) in scale of x-ray region and this region is comparable medical radiation energies.

While transferred part, \( T \), was calculated from equation (2), absorbed part, \( A \), was calculated from equation (3);

\[
T = \frac{I}{I_0} \times 100
\]

\[
A = 100 - T
\]

In this method it is not needed to calculate real intensity I0 because I/I0 rate does not change by calculating real (raw) counting rate in unit count/time.

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.

RESULTS AND DISCUSSIONS
The averages of thickness, porosities and gamma radiation measurements are given in table 3. Initial intensity was counted as 479 cpm (count per minute). It is seen from table 3 that if the fabric thickness increased and the porosity decreased the transferred intensity decreased.

| Fabric code | Thickness (mm) | Porosity | Transferred intensity (cpm) | Transferred/Initial Percent (%) |
|-------------|----------------|----------|----------------------------|---------------------------------|
| A1          | 0.66           | 0.16     | 338                        | 70.56                           |
| A2          | 0.64           | 0.17     | 341                        | 71.19                           |
| A3          | 0.63           | 0.19     | 345                        | 72.03                           |
| A4          | 0.62           | 0.21     | 348                        | 72.65                           |
| B1          | 0.69           | 0.15     | 334                        | 69.73                           |
| B2          | 0.68           | 0.16     | 337                        | 70.35                           |
| B3          | 0.66           | 0.18     | 341                        | 71.19                           |
| B4          | 0.65           | 0.20     | 345                        | 72.03                           |
| C1          | 0.72           | 0.14     | 329                        | 68.68                           |
| C2          | 0.71           | 0.15     | 333                        | 69.52                           |
| C3          | 0.69           | 0.17     | 337                        | 70.35                           |
| C4          | 0.68           | 0.19     | 340                        | 70.98                           |
| D1          | 0.76           | 0.13     | 325                        | 67.85                           |
| D2          | 0.74           | 0.14     | 328                        | 68.48                           |
| D3          | 0.72           | 0.16     | 332                        | 69.31                           |
| D4          | 0.71           | 0.18     | 336                        | 70.15                           |
| E1          | 0.79           | 0.12     | 320                        | 66.81                           |
| E2          | 0.77           | 0.13     | 323                        | 67.43                           |
| E3          | 0.75           | 0.15     | 327                        | 68.27                           |
| E4          | 0.74           | 0.17     | 331                        | 69.10                           |
| F1          | 0.82           | 0.11     | 316                        | 65.97                           |
| F2          | 0.80           | 0.12     | 319                        | 66.60                           |
| F3          | 0.79           | 0.14     | 322                        | 67.22                           |
| F4          | 0.78           | 0.16     | 325                        | 67.85                           |

While the samples F1-F5 and E1-E5, whose thicknesses are the biggest and porosities are the lowest, have the lowest transferred intensity, the samples A1-A5 and B1-B5, whose thicknesses are the lowest and porosities are the biggest, have the highest transferred intensity. Moreover, when the density of conductive weft yarn increased, the transferred intensity is increased as expected.

The transferred and absorbed parts of radiation for each fabric are shown in figure 7. It is observed from figure 6 that while absorbed part of radiation increased agreement with fabric thickness, transferred part of radiation decreased. The samples F1-F5 and E1-E5 have the lowest transferred part of radiation due to their highest fabric thicknesses, whereas samples A1-A5 and B1-B5 have the highest transferred part of radiation due to its lowest fabric thickness. The opposite is valid for the absorbed part of radiation. When the density of textured steel yarn decreased, transferred part of radiation increased, whereas; absorbed part of radiation decreased, as expected.

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 (0.021) and (0.013) respectively.

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 2/2 twill, 3/1 twill and certain derivative woven fabrics.

With the highest thicknesses and lowest porosities, Barathea and Crêpe woven fabrics performed better gamma radiation shielding efficiency than other woven fabrics. Thanks to the highest fabric thicknesses and lowest porosities, the sample F1 and E1, woven with Barathea and Crêpe, show the best gamma radiation shielding effectiveness, namely absorbed part, (34.03 and 33.19 %). When the conductive weft yarn density increased, gamma radiation shielding effectiveness of fabrics increased. 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.
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