Assessment of Annual Effective dose and radiological hazards associated with radioactivity on workers in Physics Laboratory

Abstract:

Radioactive materials and X-rays are among the common causes of cancer. Determining the Excess Lifetime Cancer Risk (ELCR) and Annual Effective Dose Equivalent (AEDE) due to ionizing radiation that affects the faculty and students working in the Nuclear and solid-state Undergraduate Laboratories, College of Science, Salahaddin University -Erbil was the objective of this study. In this study, it was used two separate portable nuclear radiation detectors; the (INSPECTXUSB) and (DKG-21) Geiger counter nuclear radiation detectors. For every radioactive source (Am^{241}, Cs^{137}, Co^{60}, Na^{22} and Sr^{90}), X-rays were radiated in three separate devices, and the *in-situ* Equivalent Dose Rate (DER) and Absorbed Dose Rate (ADR) values (in μSv/h) were measured. The results were compared with the values listed in the UNSCEAR 2008 and ICRP world safety recommendations. The results indicated that the students experienced no substantial health risks, and the exposure doses are within the permissible limit. Moreover, the hot spots of X-ray and Sr^{90} should be closely monitored. Since the staff personnel spend more time in the lab than students, they are more likely to be exposed to radiation and contamination.

Keywords: *Radioactive sources, X-ray devices, excess lifetime cancer risk, annual effective dose equivalent*

Introduction:

Ionizing radiation refers to electromagnetic radiation containing adequate energy for removing electrons from the atoms and molecules and transforming them into electrically-charged ions. Ionizing radiation mostly consists of Gamma rays, X-rays, Alpha, and Beta particles. They can ionize matter, and cause chemical modifications that could modify the DNA or even kill the cell (Abojassim et al., 2016). The environment will always contain some level of radiation; humans inhabit a world where they are continuously exposed to radiation and cosmic rays from the environment (i.e., from soil, construction materials, water, and air). People are exposed to man-made radiation through various activities such as radiation therapy (cancer treatment), medical imaging (radiology and nuclear medicine studies), and research activities in laboratories in universities where the characteristics and applications of radioactive materials are investigated (Ismail, 2016, Bushberg et al., 2007). Humans are exposed to a global average dose of radiation of 0.274 μSv/h, with 80% of the radiation emitted from natural sources, while the remaining 20% of the radiation was emitted from artificial sources (UNSCEAR, 2008).

The radioactive materials and forms exhibit variable air and tissue penetrance; however, alpha particles travel short distances (<0.1 mm) and pose a risk when the alpha-emitting radionuclides are consumed, inhaled, or infect the wound. Beta particles, on the other hand, travel up to 10 m through the air and 1 cm through soft tissues. Thus, most beta-emitting radioactive elements can harm the skin if they are left on the skin for a long time. Internally deposited beta-emitting pollutants may be dangerous. Many radioactive substances release gamma and X-rays, which can penetrate the biological tissues (a few cm deep) and many meters through the air. To protect against gamma and X-rays, dense layers of different materials, like lead, are frequently utilized. Some gamma and beta emitters include Cesium-137 (Cs^{137}), Iridium-192 (Ir^{192}), Strontium-90 (Sr^{90}), Cobalt-60 (Co^{60}), and Iodine-131 (I^{131}), while alpha emitters include Americium-241 (Am^{241}), and Californium-252 (Cf^{252}) (Bushberg et al., 2007).

In radiation physics laboratories, solid, sealed, un-calibrated sources are the most common type of radioactive material. In general, manufacturers offer warranties for affordable radioactive sources (Peralta, 2004). The likelihood of negative health impacts is seen to increase with an increase in radiation exposure (Ozdemir et al., 2017). It is known that long-term ionizing radiation exposure results in non-leather mutations, which may raise the risk of cancer (Ugbede and Echeweozo, 2017).

The latent period, which can extend many years, refers to the interval between radiation exposure and the detection of cancer. The possibility that a person would get cancer over their lifetime is described as Excess Lifetime Cancer Risk (ELCR) (Emelue et al., 2014). An annual acceptable exposure limit for ionizing radiation is set by the International Commission on Radiation Protection (ICRP), the ICRP value that is defined for the general population is 1 mSv/yr. However, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) set an effective dose rate limit of 2.4 mSv/yr (Baraya et al., 2019, Waqar et al., 2022).

The annual effective dose and extra lifetime cancer risk of X-ray emitting instruments commonly used in solid-state laboratories and radioactive sources in nuclear laboratories for many years but not thoroughly examined are computed in this study. We examined the radioactive sources (Cs^{137}, Na^{22}, Co^{60}, Am^{241}, and Sr^{90}) used in X-ray machines and nuclear laboratories in the Solid-State undergraduate laboratories of the College of Science at Salahaddin University-Erbil.

Materials and Methods:

Radiation Absorbed dose rates (ADR) in the Laboratories were measured using a portable Inspector USB Handheld Digital Radiation Alert Detector (Model No. INSPECTXUSB). It was used to ascertain the low alpha and beta radiation levels for the radionuclides such as strontium-90 (Sr^{90}) and americium-241 (Am^{241}). X-ray individual Dose Equivalent Rate (DER) and gamma radiation for Sodium-22 (Na^{22}), Cesium-137 (Cs^{137}), and Cobalt-60 (Co^{60}) were measured using the Ecotest CARD (Personal Gamma Radiation Dosimeter, DKG-21). The CPU registers an electrical pulse as a count whenever radiation enters the Geiger tube. Alpha, Beta, and Gamma are all detected by Inspector USB Detects Alpha down to 2 MeV, Detects Beta down to 16 MeV, and Detects Gamma down to 10 KeV through the end window. To ensure that samples retained their original environmental features, the researchers used an *in-situ* estimation technique.

As indicated in Figure 1, according to the procedure reported in the literature with some modification (Etim et al., 2014), measurements were made at 2 cm to identify alpha particles facing the area under examination and at 10 cm to detect the β-particles, γ-rays, and *x*-rays from the source. More than ten measurements were taken for each radioactive source separately at 1-hour intervals and averaged to produce a single value as equivalent dose rate (DER) by Dosimeter DKG-21 and absorbed dose rate (ADR) in μSv/h by Inspector USB. The Geiger-Mueller (GM) survey meter is a very common tool used for determining the presence of radiation and radioactive substances (Karam, 2021)

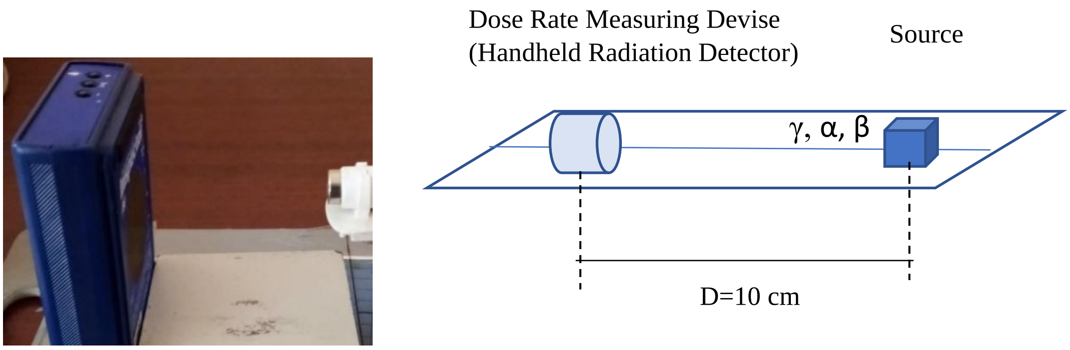

Figure 1: Handheld Radiation Alert Detector that was in direct contact with a radioactive source

To detect the X-rays emitted from three X-ray diffraction system equipment (Tel-X-Metre - Type 2580; Phywe Systeme GmbH & Co. KG XR 4.0 expert unit 35 kV, X-STRAHLUNG, KAT. - NR55461), the Eco test CARD (Personal Gamma Radiation Dosimeter DKG-21) was used.

The dose equivalent for beta, X-ray, and gamma radiation is equal to the absorbed dose. Since W_R=1 is the radiation weighting factor for X-, ß-, and γ- radiation, the radiation meter's LCD screen was used to directly record the DER values (µSv/h). The values were converted to milli-Sieverts per year (mSv/y). The following formula was used to determine the Annual Effective dose rate (AEDR) that was received by the staff and lab students:

$$AEDE\ (\mu Sv/y) = DER \times T \times OF \times 10^{-3} \quad (1)$$

Where T = total time in h per year (8760); OF = Occupancy factor. Here, this factor was used (indoor = 0.8) (UNSCEAR, 2008).

The Excess Lifetime Cancer Risk (ELCR), which is based on AEDE values, considers the likelihood of contracting cancer throughout a lifetime for a specific exposure life. ELCR was assessed by:

$$ELCR\ (mSv/yr) = AEDE \times DL \times RF \quad (2)$$

Where: DL=average life duration (70 years); RF= risk factor (Sv^{-1}), i.e., fatal cancer risk per sievert. For the stochastic effects, ICRP 103 proposed a value of 0.05 for public exposure (ICRP, 2007).

Results and Discussion:

Table 1 presents the DERs that are received by the staff at Nuclear and solid-state laboratories, Salahaddin University-Erbil, and the values ranged between 11.88±0.540 and 1164±1.852 µSv/h. The staff spends around 12 h every week in the labs. Hence, their DER values are seen to be slightly higher compared to those noted for the students who spend 2 h/week in the labs (ranging between 1.98±0.088 and 194.00±0.583 µSv/h), as described in Table 2. As shown in Figure 2, the AEDRs that were calculated for the staff ranged between 83.255±3.784 and 8157.312±12.976 µSv/y, while the AEDE for students ranged between 13.876±0.617 and 1359.552±4.082 µSv/y (Figure 3).

Table 1: AEDE and ELCR for the different dose equivalent rates received by the Laboratory staff [Mean ±SD].

Ionizing Radiation	DER-µSv/h	AEDE-µSv/y	ELCR-mSv/y
Cs^{137}	134.4±1.235	941.875±8.656	3.297±0.030
Na^{22}	24.6±0.719	172.4±5.040	0.603±0.018
Co^{60}	11.88±0.540	83.255±3.784	0.291±0.013
St^{90}	651.84±10.645	4568.095±74.602	15.988±0.261
Am^{241}	67.2±0.578	470.938±4.052	1.648±0.014
X-ray (Phywe Systeme)	1164±1.852	8157.312±12.976	28.551±0.045
X-ray (Tel-X-Ometer)	64.8±0.817	454.118±5.724	1.589±0.020
X-ray (X-STRAHLUNG)	40.68±0.347	285.085±2.430	0.998±0.009

Table 2: AEDE and ELCR due to dose equivalent rates received by the student [Mean ±SD].

Ionizing Radiation	DER-μSv/h	AEDE-μSv/y	ELCR-mSv/y
Cs^{137}	22.40±0.972	156.979±6.815	0.549±0.024
Na^{22}	2.10±0.093	14.717±0.649	0.052±0.002
Co^{60}	1.98±0.088	13.876±0.617	0.049±0.002
St^{90}	108.64±1.774	761.349±12.434	2.665±0.044
Am^{241}	11.20±0.508	78.490±3.564	0.275±0.012
X-ray (Phywe Systeme)	194.00±0.583	1359.552±4.082	4.758±0.014
X-ray (Tel-X-Ometer)	10.80±0.189	75.686±1.324	0.265±0.005
X-ray (X-STRAHLUNG)	6.78±0.191	47.514±1.342	0.166±0.005

Figures 4 and 5 illustrate that the ELCR values were seen to be above the standard global permissible values (the ICRP's suggested limit of 1 mSv/y and UNSCEAR's permissible limit of 2.4 mSv/y) for Cs^{137} (3.297±0.030 mSv/y), St^{90} (15.988±0.261 mSv/y), and X-ray (28.551±0.045 mSv/y), emitted from Phywe Systeme.

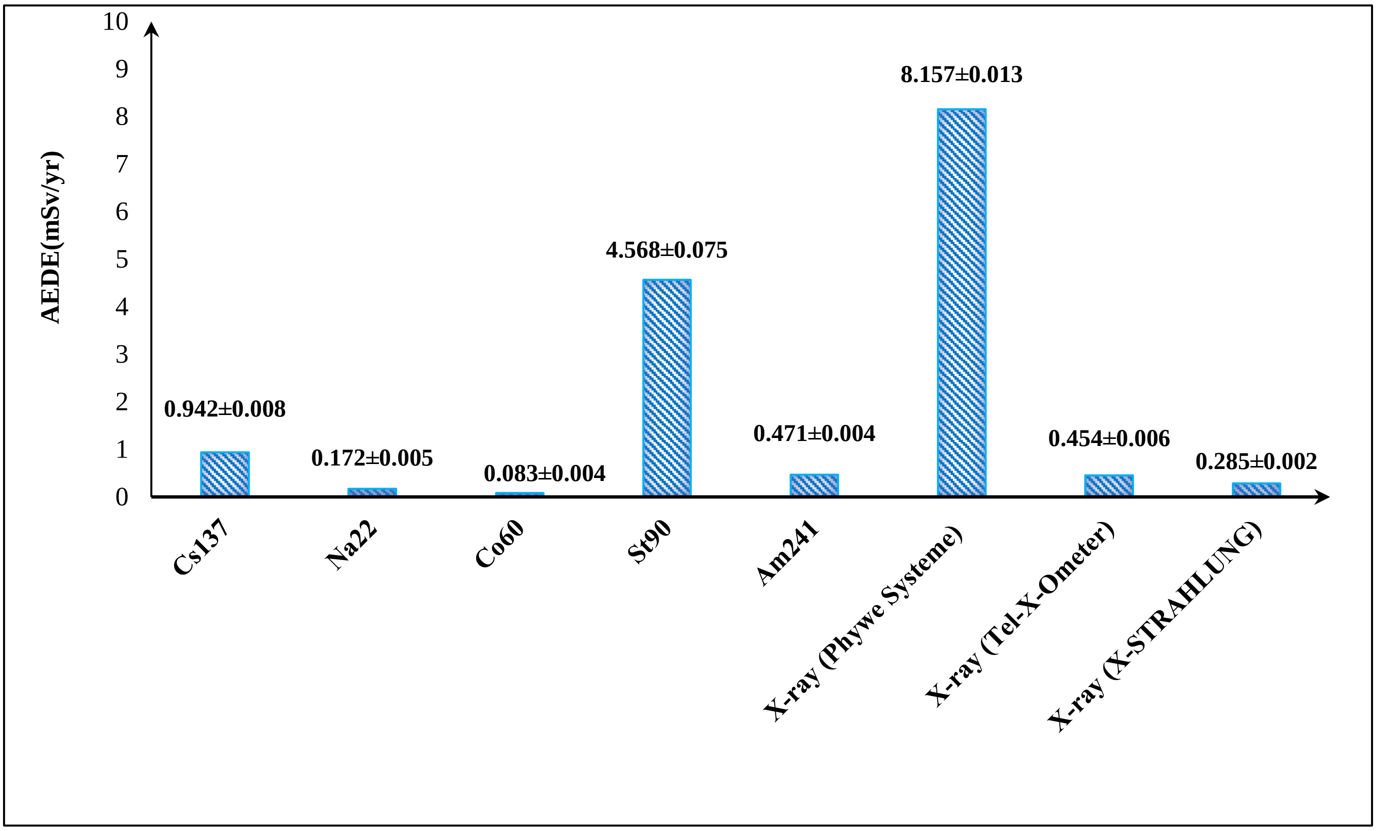

Figure 2: AEDE owing to the DERs for the Laboratory staff

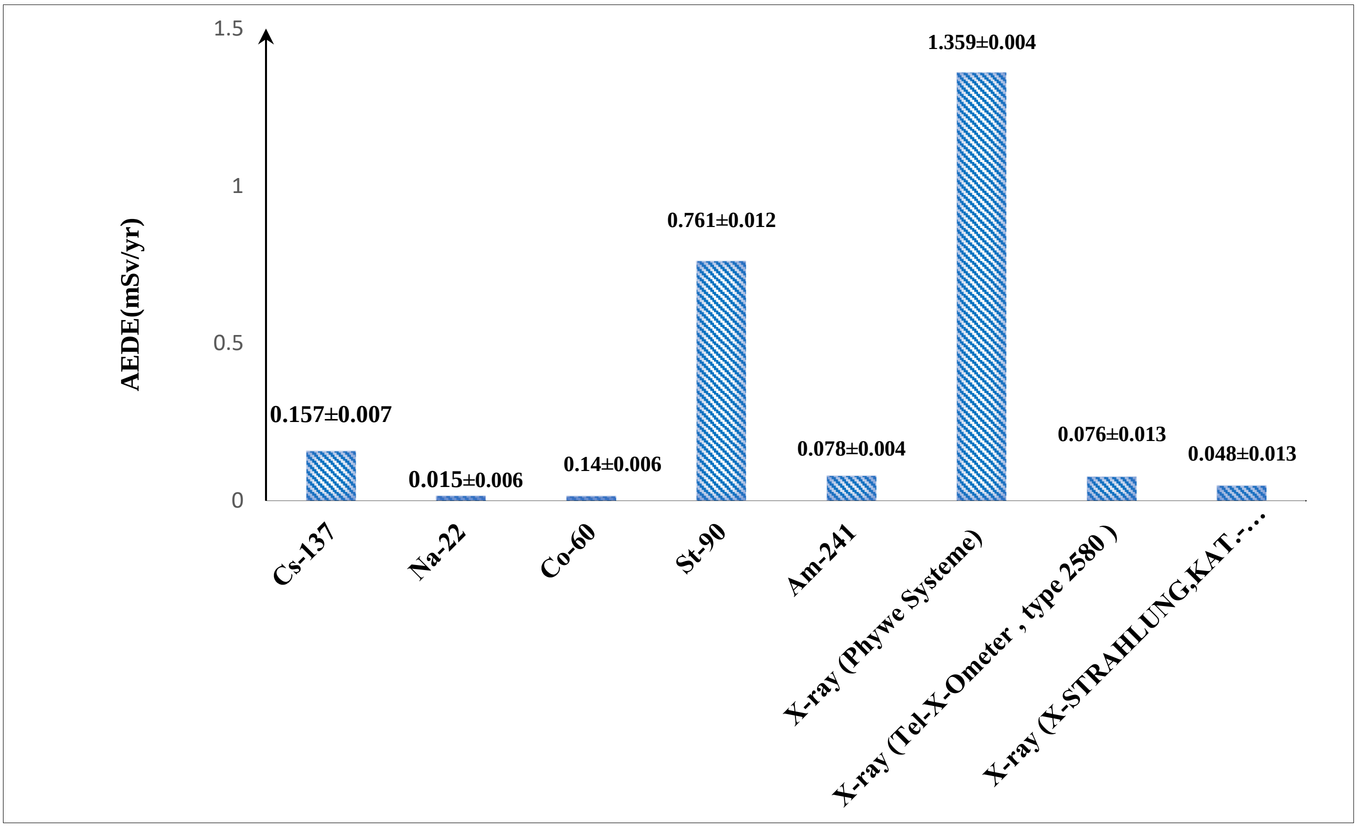

Figure 3: AEDE owing to the DERs for students

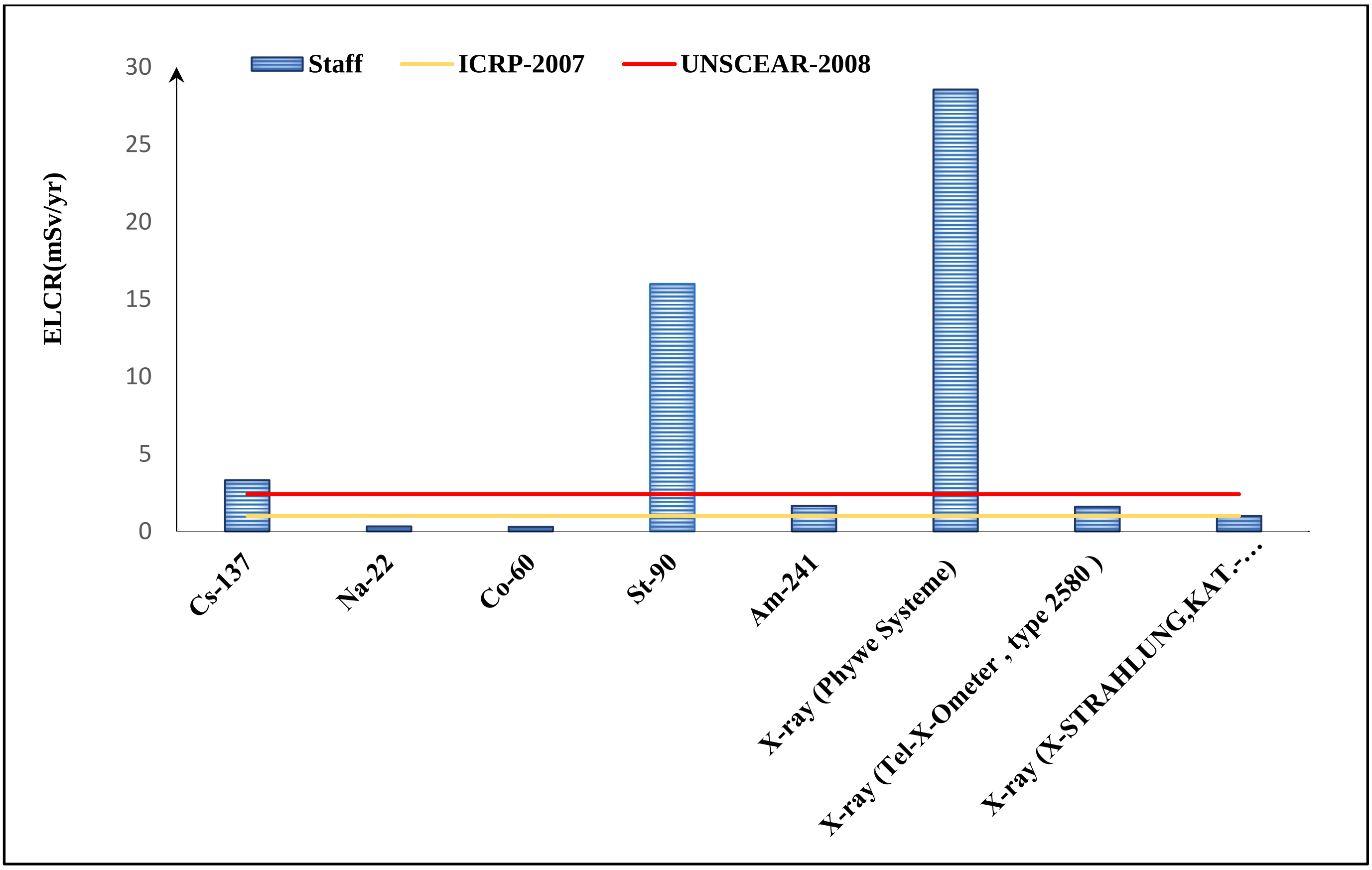

Figure 4: ELCR for the Laboratory staff compared to the global permissible values

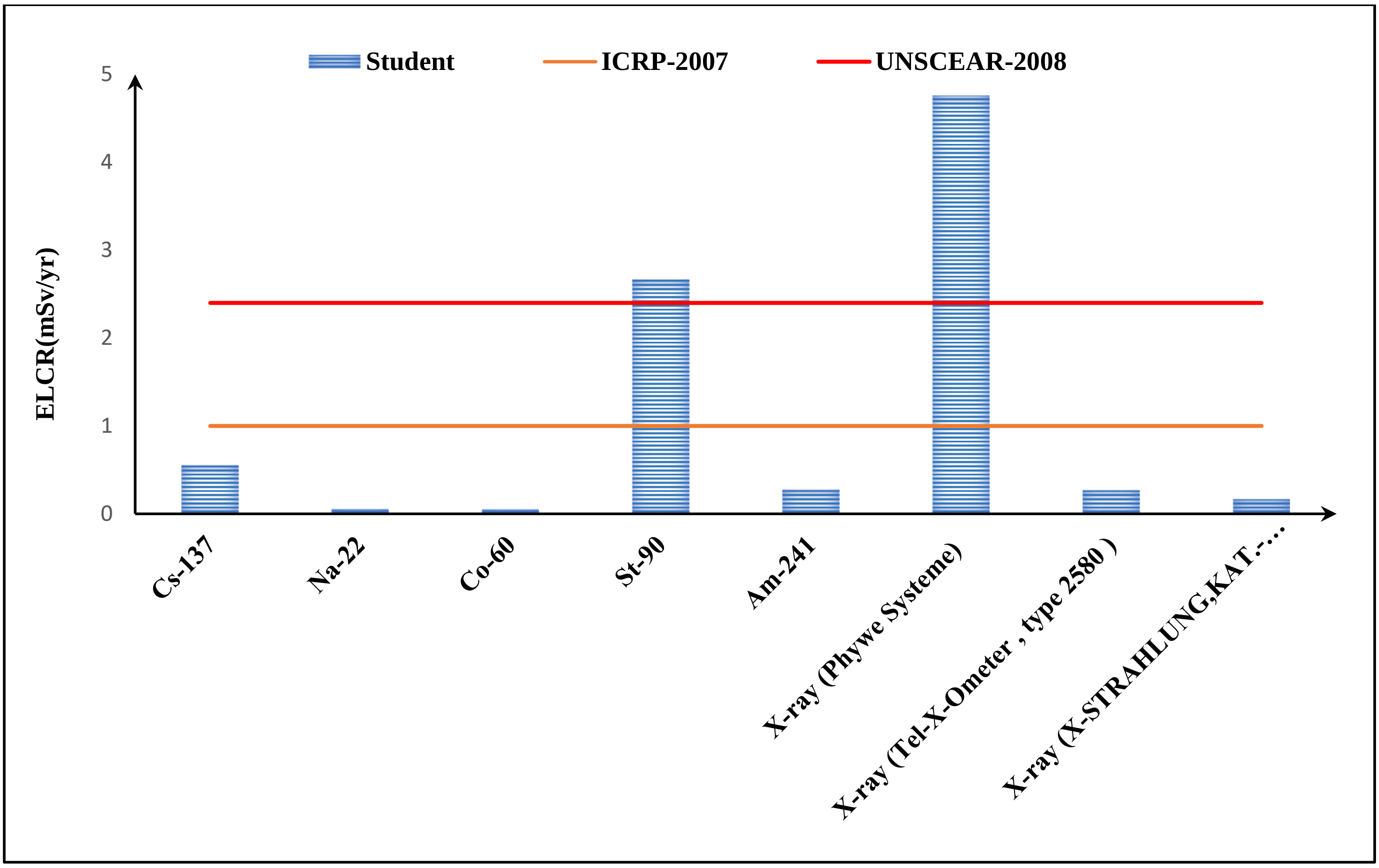

Figure 5: ELCR for the students compared to the global permissible values

The risk of developing cancer is therefore rather high for those who work in the physics department labs. The machine's exterior surface is coated in lead glass, therefore even though the X-ray findings are higher compared to the global permissible values, it does not impact the employees working in the lab. To choose reasonable and suitable safety measures for lab employees, researchers need to understand the background radiation. Laboratory personnel can safeguard themselves against radioactive particles while working by following general safety precautions.

Some findings are lower than the radiation dose that an individual would experience during cross-country travel in an airplane (about 2.5 mrem or 25 µSv annually). The National Council on Radiation Protection and Measurements (5) and ICRP both advise against doses equal to or exceeding 50 rem (26). Although this dose was 10 times greater than the annual occupational exposure limit, it slightly elevates the risk of cancer, in comparison to the significant advantages that can benefit the people who receive the life-saving therapies (Bushberg et al., 2007).

Conclusions:

The AEDE values do not fall within the permissible radiation limit as set forth by the ICRP and UNSCEAR, based on different detectors used for evaluating the optimal dose of alpha, beta, and gamma rays for various radioactive sources and X-rays. Here, the maximal AEDR value was derived from the radioactive sources within the laboratories, which was a restricted location in the department. The results of this investigation indicated that the students experienced no substantial health risks, and the exposure doses are within the permissible limit and would not hurt the students' health. Moreover, the hot spots of X-ray and Sr^{90} should be closely monitored. Since the staff personnel spends more time in the lab than students, they are more likely to be exposed to radiation and contamination. There is no effect threshold and most regulatory bodies adopt a cautious stance toward radiation exposure. Staff should therefore always be considered because theoretically, no dose is regarded safe from potential danger. Distance is considered a significant factor in minimizing occupational radiation exposure, since radiation scatters attenuate according to the inverse square law.

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