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A study of the Effects of Radionuclides ^{238}U, ^{232}Th and ^{40}K on Human Health in Cast Samples from Fracture Patients in Karbala Governorate

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Abstract: *People are exposed to various forms of ionizing and non-ionizing radiation throughout their lives. Both natural and artificial ionizing radiation are dangerous. The greatest risk lies in the artificial form of ionizing radiation, which includes medical procedures and commercial products containing radioactive materials, Dust from nuclear testing in the atmosphere, discharges of radioactive waste from the nuclear industry, industrial gamma rays, and various elements such as consumer products and medical X-rays.*

Natural radionuclides of gypsum samples used as splint materials for fracture patients exposed to medical X-ray doses at Al-Hindiya Hospital in Karbala Governorate were measured using a gamma spectrometer with a Na(Tl) detector of the crystalline dimension type "3X3", which is a highly sensitive detector for gamma rays. The measured activity concentrations of the radionuclides ^{238}U, ^{232}Th and ^{40}K were compared with data reported from other countries. The specific activity of these radionuclides, the radium dose equivalent, the external hazard index, and the absorbed gamma dose rate were determined for these samples, which were collected from hospitals in Karbala Governorate, ground, screened to obtain small, homogeneous particles, and then placed in an oven at 45°C. Then, they were placed in special containers of the gamma system and stored for 21 days. The external exposure and the corresponding annual effective dose were calculated to estimate the exposure risks arising from the use of these materials in fracture patients.

The results showed that the average specific activity values for potassium (203.01 Bq/kg), uranium (15.29 Bq/kg), and thorium (12.02 Bq/kg) were the same. Also, the highest value for potassium activity (9.61 ± 284.11 Bq/kg) was in sample G3. The lowest value (5.16 ± 097.57 Bq/kg) was the lowest value for the potassium sample in sample 16G. Similarly, thorium had the highest value (1.19 ± 22.85 Bq/kg) in sample G2. The lowest value (0.80 ± 0.25 Bq/kg) was in sample G22. Uranium had the highest value (4.10 ± 29.50 Bq/kg) in sample G9 and the lowest value (0.70 ± 0.350 Bq/kg) in sample G13. The average values of the equivalent dose and the average values of the internal and external hazard were calculated and were (221.29 Bq/kg), (1.15 mSv) and (0.60 mSv) respectively.

All radioactivity levels for all radiation hazard factors were safe and did not pose a radiation hazard to fracture patients except for the internal exposure factor, and for all plaster cast samples.

I. Introduction

People are exposed to various forms of ionizing and non-ionizing radiation throughout their lives. Non-ionizing radiation has insufficient energy to move atoms and therefore will not change chemically, such as microwaves, radio waves, and visible light. Ionizing radiation, on the other hand, has the ability to move and remove electrons from atoms, thus damaging living cells and their DNA [1].

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One of the natural sources of ionizing radiation (such as cosmic radiation from space, gamma rays from the Earth, decay products of radon in the air, many radionuclides in food and drink, radiation from lighter unstable nuclei resulting from the bombardment of the atmosphere by cosmic radiation, and radiation from heavy unstable nuclei resulting from the decay of a few long-lived nuclides in the Earth's crust), and the other is artificial (such as medical procedures, commercial products containing radioactive materials, dust resulting from nuclear tests in the atmosphere, the discharge of radioactive waste from the nuclear industry, industrial gamma rays, and various elements such as consumer products and medical X-rays) [2].

One type of electromagnetic radiation is X-rays, which are produced in the form of packets of energy called photons. These rays are produced in two ways: bremsstrahlung and K-shell emission. Both of these processes can occur in heavy atoms, especially tungsten, which is often chosen as the target or anode material for an X-ray tube. The change in the state of electrons occurs in both ways.

X-rays have been used for diagnosis and treatment since the beginning of the last century, but there are still deficiencies in radiation protection measures when diagnosing and treating human organs. Despite following preventive instructions to reduce radiation doses for patients and professionals to a minimum, and due to the terrifying speed at which X-ray devices are developing and the technologies that depend on them are developing, the chances of exposure will increase, which requires us to highlight this exposure [3].

Since gypsum is a mineral composed of calcium sulfate containing water (CaSO4.2H2O), it may produce natural radioactivity like limestone, plaster, gypsum, etc. Gypsum is one of the most widely used minerals in the manufacture of building products such as cement, plaster, and gypsum boards in the construction sector. Gypsum is used primarily in Portland cement (which is used in concrete) for highways, bridges, buildings, and many other structures, and also has medical uses.[2] There are varying amounts of naturally occurring radionuclides in all raw building materials derived from rocks and soil. These radionuclides, which have half-lives similar to the age of Earth (and to which humans are exposed), were formed through nucleosynthesis in stars. The primordial radionuclides of importance in soil and fertilizers are ^{238}U, ^{232}Th, and ^{40}K, which are descendants of the uranium and thorium decay chain. The concentration of these radionuclides in the Earth's crust varies according to geological processes and differences in weathering conditions. The amount of radioactivity in soil is a source of continuous human exposure and a source of terrestrial radiation, which in turn depends on the type of soil [4].

The study aims to calculate the specific radioactivity of uranium, thorium, and potassium radionuclides, their radiation dose equivalents, and their intrinsic and extrinsic risk factors. It also aims to determine their suitability for use in treating fracture patients using a thallium-doped sodium iodide detector system in cast samples and compare them with global standards.

II. Radiation risk factors

here are several radiation risk factors that must be addressed, the most important of which are:

2.1. Radioactive element activity (A_t)

The quantity that characterizes the rate of radioactive decay is called activity (or emitter activity), which is defined as the number of decays per one-time period, or the loss in the number of nuclei that have not yet decayed per one time period [5]:

$$A_t = -\frac{d}{dt}N_t = \lambda N_t \quad \dots (1)$$

2.2. Specific radioactivity of the element (S.A)

The activity per unit mass of a radioactive substance is known as the specific radioactivity, which is usually measured in units of (curies per gram) or (becquerels per kilogram), and is calculated using the following relationship [6]:

$$S.A = \frac{A^*}{\varepsilon . m . \gamma . t} \quad \dots (2)$$

where A*, ε, γ, t, and m represent the count of gamma photons, the specific gamma-ray detector efficiency, the percentage probability of gamma emission from the radionuclide, the counting time in seconds, and the mass of the sample in kilograms, respectively.

2.3. Radium dose equivalent ($Ra_{eq.}$)

Another, more widely used, radiation hazard index is known as radium equivalent activity (Raeq), which is a weighted sum of the activities of the three radionuclides ^{238}U, ^{232}Th, and ^{40}K. It produces the same dose rates as gamma rays and has been calculated using the following relationship [7]:

$$Ra_{eq.} = A_U + 1.43\ A_{Th} + 0.077\ A_K \quad \dots (3)$$

1.4. External Hazard Index ($H_{ext.}$)

Another hazard measure that is valuable for setting safety and radiation protection standards is the external hazard index ($H_{ext.}$). It is indicated by the following equation [8]:

$$H_{ext.} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad \dots (4)$$

where A_U, A_{TH}, and A_K are the specific radioactivities of the radionuclides uranium, thorium, and potassium, respectively.

III. Collection and preparation of samples

About 22 plaster cast samples were collected from the X-ray hall of patients with fractures of the upper and lower limbs at Al-Hindiya Hospital in Karbala Governorate, of different ages and both males and females. Figure 1 shows X-ray images of some types of fractures.

Fig. 1. A picture of a broken humerus bone in an accident (right). A picture showing the position and length of the fixation screws at the ankle joint (left).

The splint placed on the fracture site was crushed, ground and sieved to obtain small, homogeneous particles. It was then placed in an oven at 45°C and then placed in special containers (Merlinly Baker) and pressed with an iron disc to prepare it for measurement [9]. Figure 2 shows pictures of the splint wrapped around some human limbs.

Fig 2.a. A splint around the forearm of a patient in the fracture ward.

Fig 2.b. A splint around the leg of a patient in the fracture ward.

The samples were stored for 21 days in a tightly sealed container and then placed in a thallium-doped sodium iodide measuring system for 5 hours to measure the gamma rays emitted by the sample.

IV. NaI(TI) gamma ray spectrometer

Gamma-ray spectroscopy is based on the high penetrating power of gamma rays in materials. The gamma-ray spectrometer consists of a NaI(TI) scintillation detector with a crystal dimension of "3X3", supplied by Alpha Spectra, Inc. (12112/3), it was coupled with a 4096-channel multi-channel analyzer (MCA) (ORTEC-Digi Base) connected to an ADC (analog-to-digital converter) module through an interface. Spectral measurements and analysis were performed through MAESTRO-32 software on the laboratory computer [10], as shown in Figure 3.

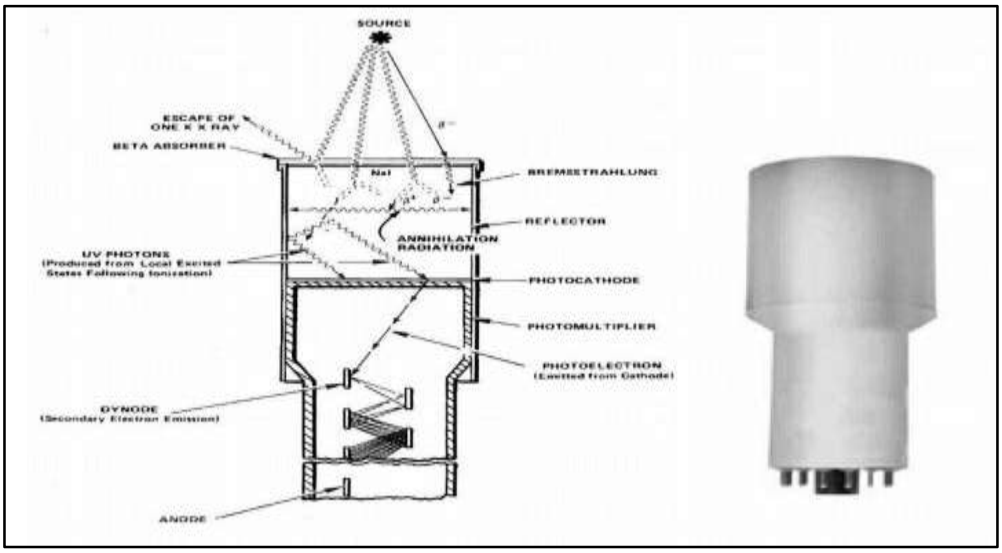

Fig. 3. Schematic diagram and image of a NaTl detector[11].

Fig. 4. Image of the detector inside the shielding chamber[12].

V. Results and discussion

The samples of patients with fractures were described in terms of gender, age, smoking, and fracture location in the body of the fractured person, as shown in table 1.

Table 1. Shows samples of patients with fracture.

Sample code	gender	Age (years)	Broken organ	Smoking
G1	male	40	Hand elbow	Non-smoker
G2	male	55	femur	Non-smoker
G3	male	46	Ankle bone	Non-smoker
G4	female	40	Palm	Non-smoker
G5	male	24	Ankle bone	Non-smoker
G6	female	30	Ankle bone	Non-smoker
G7	male	18	knee	Non-smoker
G8	male	26	Forearm bone	Non-smoker
G9	male	23	femur	Non-smoker
G10	male	20	Foot	Non-smoker
G11	female	45	Hand elbow	Non-smoker
G12	male	61	Ankle bone	Non-smoker
D13	male	41	Forearm bone	Non-smoker
D14	male	33	Foot	Non-smoker
D15	male	22	Foot	Non-smoker
G16	male	15	hand wrist	Non-smoker
G17	female	28	leg	Non-smoker
G18	male	32	Foot	Non-smoker
G19	male	46	Foot	Non-smoker
G20	male	40	Forearm bone	Non-smoker
G21	male	56	femur	Non-smoker
G22	female	63	Ankle bone	Non-smoker

The results of measurements of the three radionuclides (uranium, thorium, and potassium) and the radiation hazard factors were tabulated and presented in table 2. The minimum and maximum values for these nuclides were calculated, and the average levels of these nuclides and the mean value for all radiation hazard factors were found as recommended by the National Radiation Protection Board (NRPB) for all samples collected.

Table 2. Represents the levels of natural radionuclides uranium, thorium, and potassium, their radium dose equivalents, and radiation hazard factors.

Sample code	A_U (Bq/kg)	A_{Th} (Bq/kg)	A_K (Bq/kg)	H_{int}	H_{ext}	Ra_{eq} (Bq/kg)
G1	27.10±3.00	12.04±1.23	190.42±8.67	1.09	0.57	209.72
G2	09.80±3.40	22.85±1.19	231.63±8.44	1.34	0.71	265.06
G3	08.80±4.20	13.82±1.35	284.11±9.61	1.51	0.82	304.55
G4	11.70±3.10	9.77±1.270	189.70±9.26	1.06	0.55	204.57
G5	18.50±4.10	13.95±1.03	241.97±8.91	1.36	0.71	263.34
G6	25.10±3.30	20.80±1.27	267.86±9.96	1.53	0.80	299.54
G7	16.80±2.90	08.99±0.68	160.57±5.16	0.90	0.47	174.72
G8	14.40±2.90	08.07±1.15	242.29±9.73	1.34	0.68	254.94
G9	29.50±4.10	10.54±1.55	255.71±9.73	1.42	0.73	273.05
G10	26.60±3.90	07.36±1.47	240.91±9.84	1.33	0.68	253.48
G11	19.20±4.10	11.99±1.15	244.89±9.02	1.37	0.71	263.51
G12	23.10±3.40	18.44±1.75	280.63±9.14	1.59	0.83	308.78
G13	03.50±0.70	07.35±0.80	197.32±6.44	1.09	0.56	208.10
G14	07.90±4.20	8.07±1.230	225.91±9.02	1.25	0.64	238.06
G15	21.70±4.40	16.37±1.19	215.02±1.19	1.22	0.64	240.10
G16	08.99±0.68	08.99±0.68	97.57±5.160	0.56	0.30	111.12
G17	08.07±1.15	08.07±1.15	201.64±1.19	1.12	0.57	213.80
G18	10.54±1.55	10.54±1.55	178.25±8.73	1.00	0.52	194.13
G19	07.36±1.47	07.36±1.47	143.42±8.67	0.80	0.41	154.51
G20	11.99±1.15	11.99±1.15	122.63±8.44	0.71	0.38	140.70
G21	18.44±1.75	18.44±1.75	088.11±9.61	0.55	0.31	115.90
G22	07.35±0.80	07.25±0.80	165.70±9.26	0.92	0.47	176.78
Min.	03.50±0.70	07.25±0.80	97.57±5.160	0.31	0.55	111.12
Max.	29.50±4.10	22.85±1.19	284.11±9.61	0.83	1.51	308.78
Ave.	15.29	12.02	203.01	0.60	1.15	221.29

Through the results obtained, it was found that the maximum values of the specific effectiveness of the radionuclides A_U, A_{Th}, A_K respectively are (29.50, 22.85 and 284.11) Bq/kg, and the minimum effectiveness of these nuclides is (03.50, 07.25, 97.57) at an average of (15.29, 12.02, 203.01) respectively, and these values were all less than the globally permissible limit according to the report of the World Organization for Radiological Protection , where the permissible limits according to the report it issued were (30 for uranium, 35 for thorium, 370 for potassium). Also, the values of the radiation dose equivalent were less than the globally permissible limit according to the UNSCEAR 2000 organization (370) Bq/kg [13].

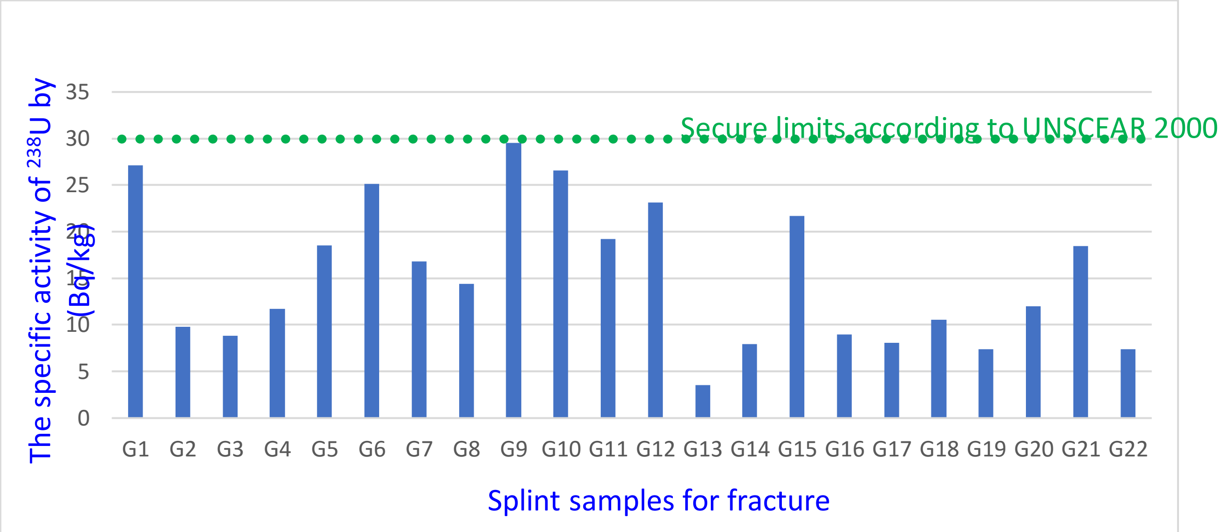

Fig. 5. Comparison of the specific activity results of uranium-238 in cast samples from fracture patients.

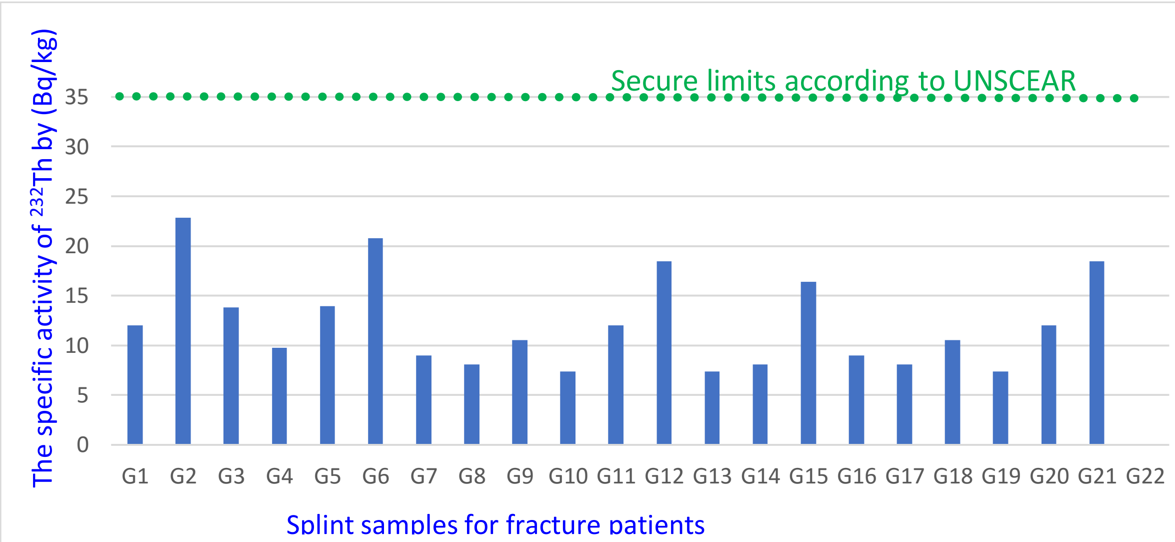

Fig. 6. Comparison of the specific activity results of Thorium-232 in cast samples from fracture patients.

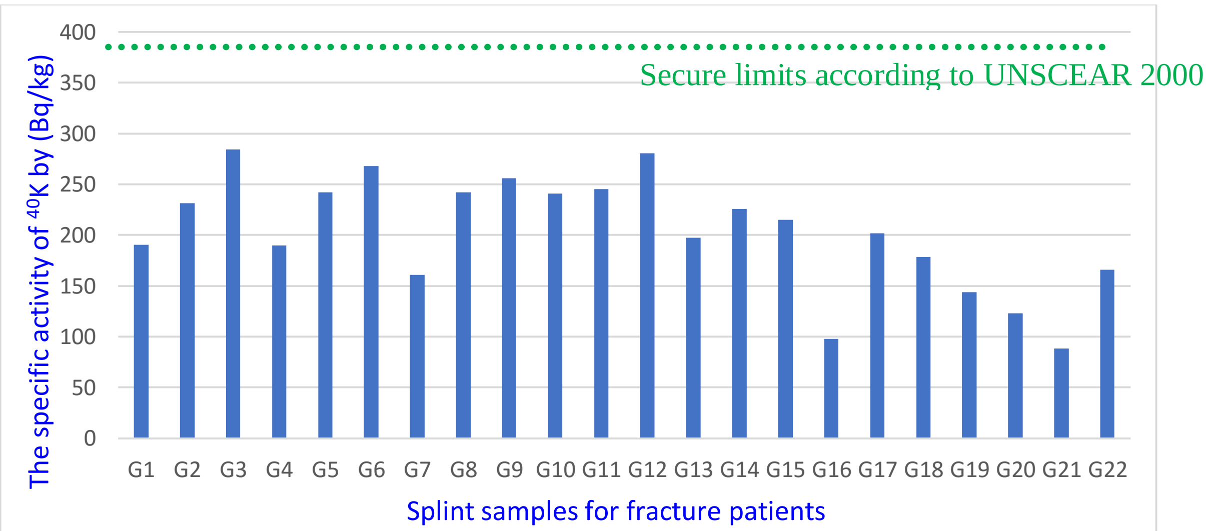

Fig. 7. Comparison of the specific activity results of Potassium-40 in cast samples from fracture patients.

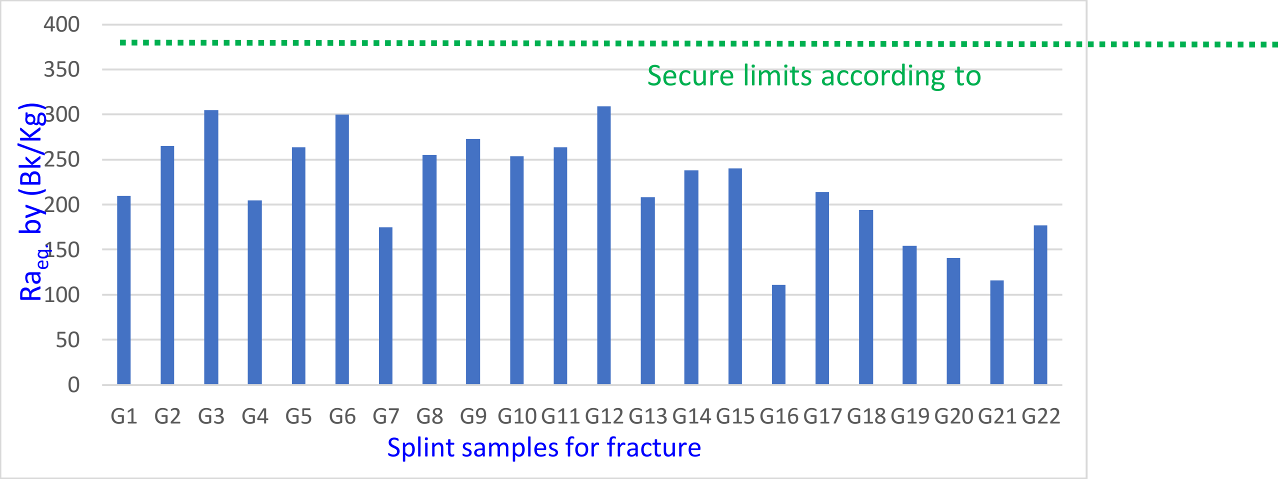

Fig. 8. Comparison of the Radium dose equivalent in cast samples from fracture patients.

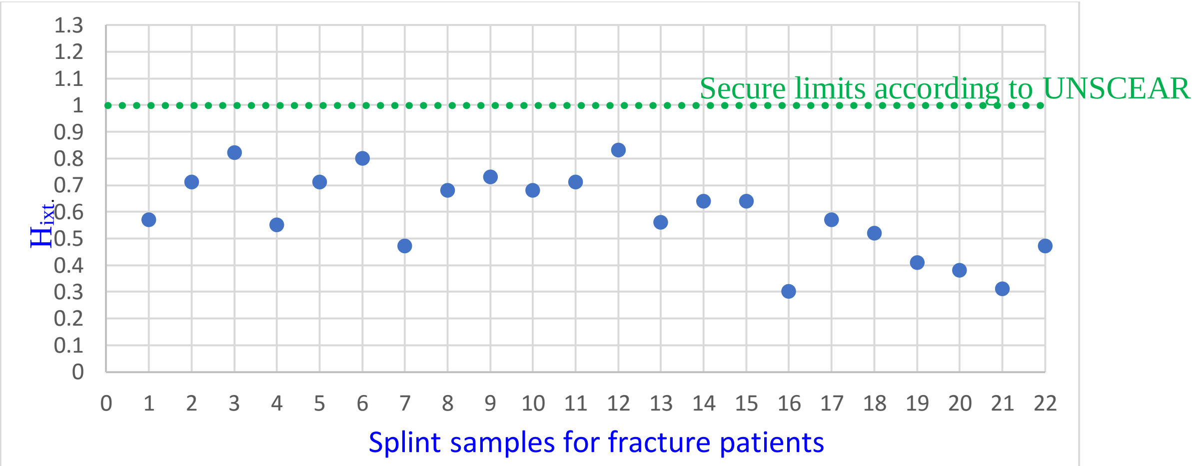

Fig. 9. Comparison of the $H_{ext.}$ in cast samples from fracture patients.

The radiological hazard factor Hext. had maximum limits of (0.83) and minimum limits of (0.31) and average of (0.60). The $H_{ext.}$ values for all samples were below the internationally permitted limit, which means that their use is safe and within the limits approved by UNSCAIR 2000 [13,14]. The measured activity concentrations of the radioactive isotopes ^{226}U, ^{232}Th and ^{40}K were also compared with data reported from other countries and are shown in table 3.

Table 3. Shows a comparison of the activity concentrations of ^{238}U, ^{232}Th and ^{40}K measured in the current study of gypsum with the corresponding values measured in other countries [15].

Materials	Country	Activity concentration (Bq kg^{-1})			References
		^{238}U	^{232}Th	^{40}K	
Gypsum	Bulgaria	13.3	5.3	39.5	Krstić *et al.*(7)
	EU	10.0	10.0	80.0	European Commission Report(26)
	India	8.3	—	26.7	Xinwei and Xiaolan(10)
	Macedonia	32.4	70.3	143.8	Krstić *et al.*(7)
	Pakistan	6.2	13.3	173.7	Khan and Khan(5)
	Syria	14.0	2.0	31.0	Othman and Mahrouka(8)
	Tanzania	5.0	—	—	Msaki and Banzi(6)
	Turkey	9.4	3.9	40.7	**Seref Turhan**

Table 3 compares the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K measured in the current gypsum study with corresponding values measured in other countries. This can be seen in table 2. The table shows that the mean value of ^{226}Ra activity concentration obtained for the gypsum sample is comparable to those obtained from other studies except Macedonia while the mean values of ^{232}Th and ^{40}K activity concentration obtained for the gypsum samples are comparable to those obtained for gypsum samples in Bulgaria and Syria. This study is considered complementary to many studies in the field of radiation, which examine everything related to human life, whether it is building materials, soil, air, medical materials, food and drink[16-19].

VI. Conclusions

Since the specific activities of all three radionuclides are below the international limits, their levels do not pose any radiation risk to the patient's body while wearing this splint. Likewise, the risk of these radionuclides accumulating according to the factor (radiation dose equivalent) does not pose any risk either. The radiation hazard stems from the intrinsic risk factor ($H_{int.}$) which is higher than permitted for some models. This may be due to exposure to X-rays during imaging sessions, for intermittent periods and at energies that may be high, as these are short-wavelength, high-energy rays with high penetrability and interaction with materials they pass through, including the splint, which can be a source of radiation hazard to the patient's body.

VII. References

1. T. Ramachandran, "Background radiation, people and the environment," 2011.
2. M. Charles, "Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation: UNSCEAR 2006 Report, Volume 1—Report to the General Assembly, with Scientific Annexes A and B," ed: Oxford University Press, 2010.
3. A. Ridha, M. M. Mutter, and M. D. Salim, "Estimation of natural radioactivity in surface soil samples from Baghdad, Nahrain and Al-Mustansiriyah Universities Using Gamma-Ray Spectroscopy," J. of Coll. of Educat, vol. 5, pp. 61-74, 2015.
4. E. C. Atherton, Valuing The Future: Issues in Modelling Intertemporal Decisions: The University of Manchester (United Kingdom), 1999.
5. E. B. Podgoršak, Radiation physics for medical physicists vol. 1: Springer, 2006.
6. Kovler, K., et al., Basic aspects of natural radioactivity, in Naturally occurring radioactive materials in construction. 2017, Elsevier. p. 13-36.
7. Salman, A. Y., Kadhim, S. A., Alaboodi, A. S., & Alhous, S. F. (2020). Study the contamination of radioactivity levels of 226Ra, 232Th and 40K in (water) Iraq and their potential radiological risk to human population. In IOP Conference Series: Materials Science and Engineering (Vol. 928, No. 7, p. 072008). IOP Publishing.
8. R. L. Heath, Scintillation spectrometry gamma-ray spectrum catalogue: Phillips petroleum Company Atomoc energy division, 1957.
9. Tiwari, M., Sahu, S. K., Bhangare, R. C., Pulhani, V. A., & Kumar, A. V. (2023). A review on current status of radioactivity monitoring in Indian nonnuclear industries. Radiation Protection and Environment, 46(1&2), 3–13.
10. Salman, A. Y., Kadhim, S. A., Hussain, H. M., and Sharrad, F. I., 2025, "Assessing the Excess Lifetime Cancer Risk from Water in the Euphrates River, Najaf, Iraq," Health Phys., 129(4), pp. 245–255.
11. S. H. Frisbie, E. J. Mitchell, and B. Sarkar, "World Health Organization increases its drinking-water guideline for uranium," Environmental Science: Processes & Impacts, vol. 15, pp. 1817-1823, 2013.
12. R. K. Law, J. G. Schier, C. A. Martin, D. E. Olivares, R. G. Thomas, A. C. Bronstein, et al., "National surveillance for radiological exposures and intentional potassium iodide and iodine product ingestions in the United States associated with the 2011 Japan radiological incident," Clinical toxicology, vol. 51, pp. 41-46, 2013.
13. S. Unscear, "effects of Ionizing Radiation," United Nations, New York, pp. 453-487, 2000.

14. Charles, M., 2001, “UNSCEAR Report 2000: Sources and Effects of Ionizing Radiation,” J. Radiol. Prot., 21(1), p. 83
15. S. Leong, P. Mc Laughlin, O. J. O'Connor, S. O'Flynn, and M. M. Maher, "An assessment of the feasibility and effectiveness of an e-learning module in delivering a curriculum in radiation protection to undergraduate medical students," Journal of the American College of Radiology, vol. 9, pp. 203-209, 2012.
16. Manyoba, N., Olukotun, S. F., John, S. O., & Mathuthu, M. (2025). Health impact assessment of naturally occurring radioactive materials (NORMs) from a gold mine tailing in Mpumalanga Province, South Africa. Polytechnica, 8(1), 3.
17. Melman, N. (2010). Radiation and health. Xlibris Corporation. ISBN: 978-1-4500- 2744-1
18. Michalik, B., Dvorzhak, A., Pereira, R., Lourenço, J., Haanes, H., Di Carlo, C., ... & Popic, J. M. (2023). A methodology for the systematic identification of naturally occurring radioactive materials (NORM). Science of the Total. Environment, 881, 163324.
19. Morishita, Y., Tomioka, A., Fujisawa, M., & Izaki, K. (2024). Measurement of naturally-occurring radioactive materials (NORM) using a scintillator-based alpha detector. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 1065, 169527.