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RESEARCH ARTICLE

Evaluation of Radiation Safety for Hospital Staff Using Dosimetric Data

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Highlights

- Calculate effective dose and determine safety limits for radiation exposure
- Ensure the dose rate at Bir Hospital adheres to the ALARA principle
- Compare annual radiation exposure with ICRP recommendations
- Investigate consistency of radiation exposure across years
- Compare radiation exposure between male and female staffs

Abstract

Hospitals utilize various manmade radiation sources for therapeutic and sterilization purposes. However, improper monitoring of these sources can lead to radiation leakage, posing potential health risks. At Bir Hospital, data from dosimeters were analysed using appropriate statistical methods. The analysis revealed that the overall absorbed dose is 0.078 mSv per year, well below the 20 mSv annual dose limit recommended by the International Commission on Radiological Protection (ICRP). This indicates that the staff at Bir Hospital are working under safe radiation exposure levels. A Chi-square test further confirmed that there is no significant gender-based variation in radiation dose absorption among the staff. These findings demonstrate that the hospital's radiation safety measures are effective, ensuring the safety of its employees. This data underscores the importance of maintaining and monitoring radiation safety. To enhance safety standards, it is recommended that all hospitals require medical staff to use dosimeters and provide access to dosimeter data for research and analysis.

Keywords: *Radiation, Dosimeter, ICRP, Chi-square.*

Introduction

Radiation refers to the emission of energy in the form of electromagnetic waves or high-energy subatomic particles and can occur naturally or artificially. In nuclear physics, nuclei with neutron-to-proton ratios that deviate from unity are unstable. These unstable nuclei emit radiation to achieve stability, a process known as radioactive disintegration or radioactivity. This involves the emission of α, β, and γ radiation. Remarkably, the existence of various types of radiation has made life possible on Earth [1]. Radiation is categorized as ionizing or non-ionizing based on its energy content. Radiation with energy greater than 10 eV is considered ionizing, as it can break chemical bonds and ionize molecules. Ionizing radiation is widely used in applications such as sterilizing medical equipment, treating medical conditions, and diagnostic imaging [2]. However, man-made sources of

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ionizing radiation can generate background radiation, which poses a potential danger to human health. When ionizing radiation interacts with living tissue, it can excite atoms, ionize molecules, divide living cells, and damage genetic material, potentially leading to cancer if exposure persists for extended periods [3]. Background radiation is defined as residual radiant energy present after the source of exposure is removed and is omnipresent. High levels of background radiation can cause severe biological effects if patients or medical staff are exposed to excessive doses. In the medical field, the thermoluminescent dosimeter (TLD) is the most used device for measuring background radiation. It is employed to monitor radiation levels in radiography departments and surrounding areas to ensure no radiation leakage occurs. Regular analysis of background radiation by radiation safety departments is essential in rooms with medical exposure.

B.F. Wall conducted studies on radiation protection dosimetry for diagnostic radiology patients. Using radiation risk projection models, Wall predicted patient risks in the UK from computed tomography (CT) examinations. The findings revealed that lifetime cancer risk could reach as high as 1 in 1,000 for children, depending on their age and sex at exposure [4]. Giri et al. surveyed 13 hospitals in Kathmandu Valley to assess radiation exposure in radiology departments. Their study revealed elevated and, in some cases, dangerously high unintentional radiation exposure levels [5]. Similarly, Adhikari et al. investigated radiation protection practices across 33 hospitals in Kathmandu and other regions of Nepal to raise awareness of radiation health hazards and long-term effects. The study focused on 28 hospitals with diagnostic radiology facilities, including 46 X-rays, 10 CT scans, two mammograms, and two catheterization laboratories, selected based on patient load, equipment, and staff [6].

Radiation exposure poses inherent health risks, but these can be minimized by proper equipment management and strict adherence to regulations. Ensuring that medical staff are thoroughly trained before operating devices in the radiography department is essential. Radioactive materials are highly effective even in small doses, making it vital to use radiation monitors to assess the environment whenever such materials are handled. A thermoluminescence dosimeter (TLD) is a device designed to measure ionizing radiation exposure by detecting visible light emitted when its crystal detector is heated [7]. Invented in 1954 by Professor Farrington Daniels at the University of Wisconsin-Madison, the TLD uses lithium fluoride to trap energy from ionizing radiation. During evaluation, heating the crystal releases this stored energy as light, with the light intensity being directly proportional to the radiation dose, as reported by the International Atomic Energy Agency (IAEA). A thermoluminescence dosimeter (TLD) operates based on the principle of thermoluminescence. This involves two key stages: first, the system absorbs energy from ultraviolet (UV) or ionizing radiation, causing it to transition from equilibrium to a metastable state. Then, upon thermal stimulation, the system releases this stored energy as light, returning to equilibrium. In a pure solid, electrons typically do not become trapped in the energy band gap between the conduction and valence bands. However, introducing impurities to the solid allows electrons to be trapped within the band gap, where they remain as stored energy. When heat is applied, the trapped electrons return to their ground state, releasing light in the process. This emitted light is measured to determine the radiation dose to which the dosimeter has been exposed [8].

The absorbed dose measures the concentration of energy deposited in tissue due to ionizing radiation, assessing the potential for biochemical changes in specific tissues. The equivalent dose accounts for the varying biological damage caused by different types of radiation, while the effective dose evaluates the potential long-term effects of radiation exposure, considering the sensitivity of different tissues or organs. Measured in Sieverts (Sv), with 1 Sv equaling 1 joule per kilogram, it reflects the biological impact of radiation.

Materials and Methods

Data Collection

Data were obtained from Bir Hospital in this research. The focus was on radiation absorbed by the hospital staff, recorded using dosimeters over different years from 2018-2020.

Methodology

The study applied the statistical theory of radioactive decay. According to this theory, if there are N radioactive nuclei present at a given time and no new nuclei are introduced, the number of nuclei decaying dN over a time interval dt is proportional to N. This relationship is expressed mathematically as:

$$\lambda = -\frac{dN/dt}{N}$$

Where λ is a decay constant. The half-life ($t_{1/2}$) of each radionuclide, ranging from seconds to billions of years, was also considered.

Radiation Exposure Limit

The radiation exposure focused on ensuring compliance with dose limits established by the Nuclear Regulatory Commission (2004). Staff radiation doses were analyzed against key thresholds, including 50 mSv/year for whole-body exposure, 150 mSv/year for the lens of the eye, 500 mSv/year for skin and extremities, 0.5 mSv/month for fetal exposure during pregnancy, 5 mSv/year for the entire gestation period, and 1 mSv/year for public exposure. The absorbed doses were categorized to assess occupational risks, identifying individuals who might have exceeded the recommended limits for professional exposure. Additionally, public safety compliance was evaluated to ensure that radiation use in proximity to non-occupational individuals remained within permissible guidelines. For female staff, particular emphasis was placed on fetal safety by monitoring doses against the stringent gestational limits. The analysis focused on potential overexposure compared the recorded doses to regulatory benchmarks and identified trends or patterns in radiation exposure over the years. There are limits to those individuals who may get exposed because of their employment and to those individuals who may get exposed because they are in the area where radiation is used [9]. The limit of effective doses reduces the risk arising from the radiation effect. The dose limit may help to be aware of the deterministic effect in almost all tissues [10].

Statistical Analysis

The following statistical tools were used to analyze the data:

Z-Test for Single Mean

Used to test if the mean absorbed dose for staff differed significantly from the regulatory limits.

- Test statistic: $z = \frac{(\bar{X} - \mu)}{s\sqrt{n}}$

Where is the sample mean dose, μ is the reference regulatory dose, s is the sample standard deviation, and n is the sample size (11).

Chi-Square (χ2) test

This test is used to compare the observed and expected frequencies. The observed frequencies (O) are those obtained empirically by direct observation or experiment. The expected frequencies are those generated based on some hypothesis or line of theoretical speculation (12). The (χ2) test statistic is given by,

$$(\chi^2) = \frac{\Sigma(O-E)^2}{E}$$

Data Visualization

Data were plotted using Microsoft Excel and Jupyter Python for visual analysis of the dose absorbed by hospital staff. Graphs depicted the relationship between absorbed dose and staff over different years.

Results and Discussion

Data

The value of anual radiation dose for the staft from 2018 to 2020 are presented in the folloning table :

Table 1. Annual Radiation Dose Data for Staff from 2018–2020

ID of Staffs	2018	2019	2020	Dose from 2018-2020
B1	0	0	0	0

B2	0	0.16	0	0.16
B3	0	0	0	0
B4	0	0	0	0
B5	0	0	0.25	0.25
B6	0	0	0	0
B7	0.16	0	0	0.16
B8	0	0.16	0	0.16
B9	0	0	0	0
B10	0	0	0	0
B11	0	0	0.10	0.10
B12	0	0	0	0
B13	0	0.10	0	0.10
B14	0	0.14	0	0.14
B15	0.40	0	0.20	0.60
B16	0	0	0	0
B17	0.20	0.34	0	0.54
B18	0	0.60	0	0.60
B19	0	0.30	0.30	0.60
B20	0	0	0	0
B21	0	0.10	0	0.10
B22	0	0	0	0
B23	0	0.35	0.10	0.45
B24	0	0.35	0	0.35
B25	0	0	0	0
B26	1.35	0	0.30	1.65
B27	0	0.10	0	0.10
B28	0	0	0.25	0.25
B29	0	0	0	0
B30	0	0.10	0.10	0.20
B31	0	0.14	0	0.14
B32	0.30	0.14	0	0.44
B33	0	0.16	0	0.16
B34	0	0	0	0
B35	0.65	0	0	0.65
B36	0	0	0	0
B37	0	0.15	0	0.15
B38	0.20	0	0	0.20
B39	0.20	0	0	0.20
B40	0	0	0	0
B41	0	0	0	0
B42	0	0	0.80	0.80
B43	0.15	0.10	0.20	0.45
B44	0	0	0	0
B45	0	0.15	0	0.15
B46	0	0	0	0

B47	0	0	0	0
B48	0	0	0	0
B49	0	0	0	0
B50	0	0.20	0	0.20
B51	0	0.10	0	0.10
B52	0		0.55	0.55
Total	3.4	3.85	3.05	
Count	44	51	52	
Mean	0.077	0.075	0.058	

Radiation Dose Assessment using Z-test

The annual radiation dose data for Bir Hospital staff from 2018 to 2020 were analyzed to evaluate compliance with the International Commission on Radiological Protection (ICRP) recommended annual dose limit of 20 mSv. A Z-test was conducted each year to determine if the mean effective dose exceeded the safety threshold. The findings are summarized as follows:

In 2018, The Z-test revealed a calculated Z value of -585.42, significantly exceeding the critical value of Z0.01=−2.33 for a left-tailed test. This indicates that the mean effective dose was far below the 20 mSv threshold. The null hypothesis ($H0{:}\mu \geq 20$) was rejected, confirming that staff exposure was well within safe limits. The variance analysis showed that individual dose values were tightly clustered, reflecting consistent radiation protection measures across the staff.

However, in 2019, the Z-test produced an even more pronounced result, with a Z value of -1164.21. Like 2018, this value far exceeded the critical threshold, leading to the rejection of the null hypothesis. The findings highlight that the mean effective dose remained significantly below the recommended limit. The slightly increased sample size in 2019 contributed to a lower variance, indicating improved precision in radiation monitoring. This year's analysis reinforced the hospital's commitment to maintaining occupational safety standards. Similarly, 2020 analysis further supported the trend of safe radiation exposure levels, with a Z value of -915.28. This outcome confirmed that the mean effective dose was well below the 20 mSv threshold, aligning with the results from the previous years. The slightly higher variance compared to 2019 was attributed to minor fluctuations in individual dose values; however, these variations did not compromise overall compliance with safety standards.

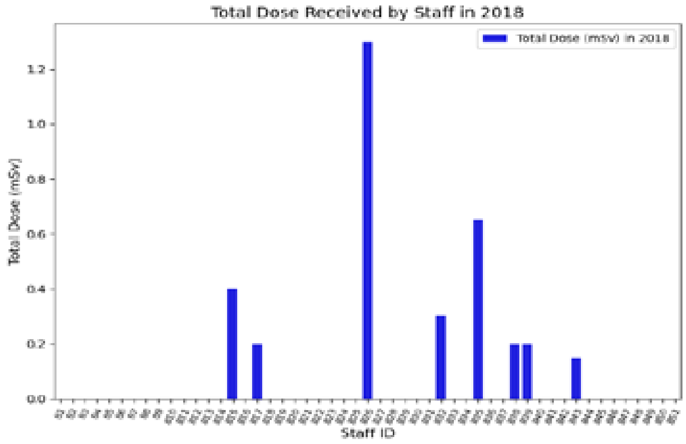

Fig 1. Bar chart showing radiation exposure experienced by staff in 2018

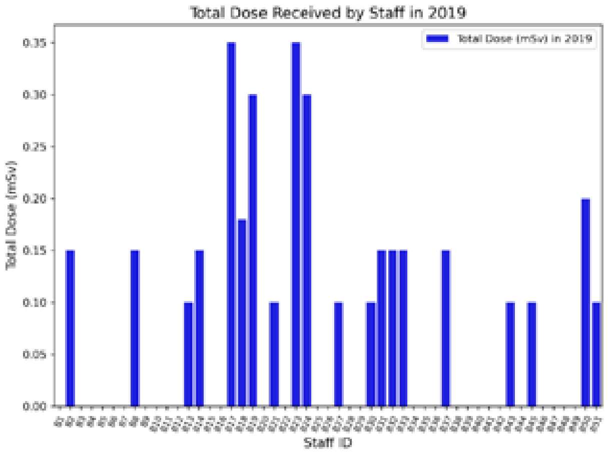

Fig 2. Bar chart showing radiation exposure experienced by staff in 2019

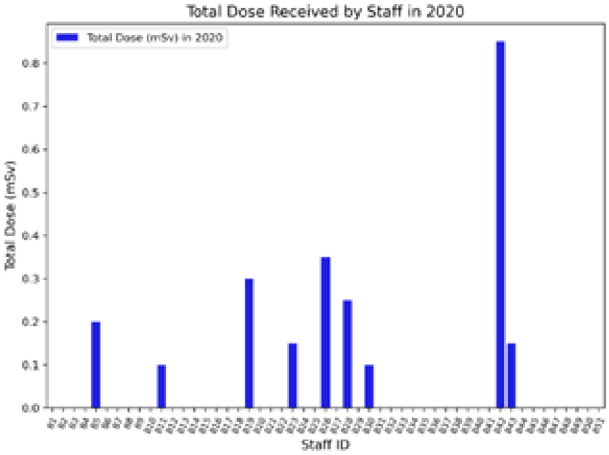

Fig 3. Bar chart showing radiation exposure experienced by staff in 2020

From the above graphs figure 1, figure 2, and figure 3, we can say that in the year 2018, staff B26 absorbed quite a greater number of radiations compared to others. We may say that staff B26 might have longer duty hours nearby to the man-made sources of radiation. But also, the dose limits the staff absorb doesn't exceed 20 mSv. Hence, we can say the environment is safe from radiation in the Radiological Unit.

From the graphs, we can say that in the year 2019, staff B17, B19, B27 absorbed quite a greater number of radiations compared to others. We may say that those staff might have longer duty hours near to the manmade sources of radiation. But also, the dose limits the staff absorb doesn't exceed 20 mSv. Hence, we can say the environment is safe from radiation in the Radiological Units. The trend line shows the nature of distribution is non-uniform.

We can say that, in the year 2020, staff B42 absorbed quite a greater number of radiations compared to others. We may say that the staff B42 might have longer duty hours nearby to the manmade sources of radiation. But also, the dose limits the staff absorb don't exceed 20 mSv. Hence, we can say the environment is safe from radiation in the Radiological Unit.

Radiation Dose Assessment using χ^2-test

Tests for absorption of radiation are done according to gender. X^2 test is applied to the test.

Null Hypothesis (H_0): Males and females absorb radiation equally.

Alternative Hypothesis (H_1): There is a significant difference in radiation absorbed by males and females which is presented in the graph below in figure 4.

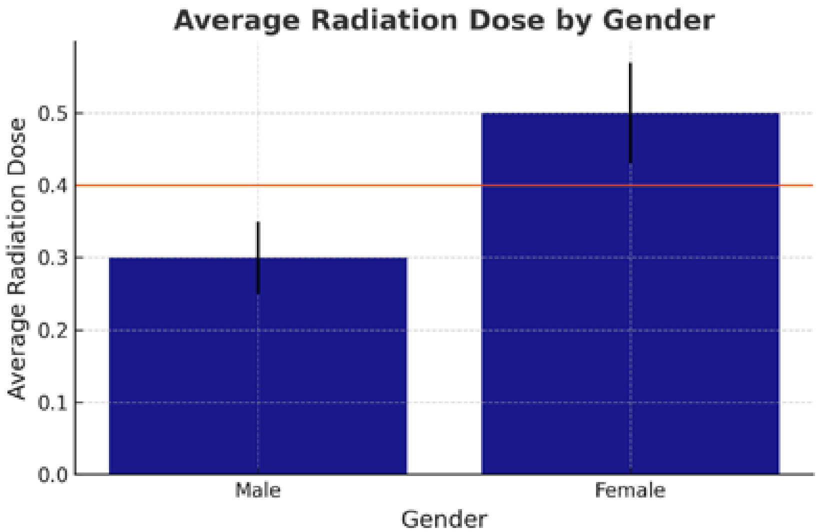

Fig 4. Bar chart displaying the average radiation dose absorbed by gender, including the expected value as a reference line

The bar chart figure 4 shows that there is a difference between the radiation absorbed by the male staff and female staff. However, the result from the Chi-square test shows that the male and female are absorbing the radiation equally. This is due to the contribution of single female staff who absorbed very much greater than others. So, we can say that males and females are equally absorbing the radiation.

Prospects

Analyzing hospital dosimeter data can greatly assist medical physicists in raising awareness among medical staff about their health status. It also plays a vital role in ensuring hospitals maintain a radiation leakage-free environment. Such studies can serve as a benchmark for detecting and addressing radiation leakage in healthcare facilities. Furthermore, they can support hospitals and other institutions in formulating effective plans and policies to promote safe practices and implement robust safety measures.

Conclusions

The staff member of 2018 among this year the B26 absorbed significantly higher radiation doses compared to others. This could be attributed to longer duty hours near man-made radiation sources. However, the absorbed dose remained well below the 20 mSv limit. Similarly, in 2019, staff members B17, B19, and B27 recorded higher radiation doses, likely due to extended exposure near radiation sources, but their doses also did not exceed the 20 mSv limit. In 2020, staff member B42 absorbed notably higher radiation levels than others, which might also be linked to longer duty hours in high-radiation areas.

The Chi-square test results revealed no significant difference in radiation absorption between male and female staff. This parity is due to one female staff member absorbing much higher radiation compared to others, balancing the gender-wise averages. Thus, it can be concluded that radiation exposure is nearly equal for both genders, and the Radiological Unit environment is safe. The z-test further confirmed that the radiation doses at Bir Hospital are significantly lower than the limits recommended by the ICRP. Consequently, staff members in the Department of Nuclear Medicine are operating within safe exposure levels. Chi-square analysis reaffirms that both male and female staff are absorbing similar radiation levels at the hospital.

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Conflict of Interest

There is no conflict of interest.

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