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Research Article

Hp(10) and Hp(0.07) Annual Average Dose Received by Industrial Facilities and Practices Using TLD Dosimeters Over the Last Ten Years in Madagascar

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Abstract

Ionizing radiations are commonly used in several sectors in Madagascar, especially in industrial field which represents a significant number of exposed workers. To protect workers against the harmful effect of ionizing radiations, all workers are covered by a personal monitoring program. This study was carried out at the Dosimetry and Radioprotection Department of the National Institute of Nuclear Sciences and Technologies (INSTN-Madagascar) to determine the average annual equivalent doses received by workers in industrial facilities and practices using TLD dosimeters over the last 10 years. The HARSHAW 6600 reader and TLDs cards, type-100 dosimeter cards were used. For this study, only annual doses below the regulatory limits [20 $mSv.y^{-1}$ for Hp(10) and 500 $mSv.y^{-1}$ for Hp(0.07)] were taken into consideration during this study. On average, 450 workers from approximately 12 industrial facilities were monitored during this period. The number of workers in 2013 (562 workers) was the highest, when compared to other years. The Hp (10) and Hp (0.07) annual equivalent doses received by industrial facilities over the last 10 years vary respectively from (0.97 ± 0.18) $mSv.y^{-1}$ to (1.99 ± 0,92) $mSv.y^{-1}$ with an average value of (1.36 ± 0.57) $mSv.y^{-1}$, and from (0.96 ± 0.16) $mSv.y^{-1}$ to (2.03 ± 0.92) $mSv.y^{-1}$ with an average value of (1.37 ± 0.56) $mSv.y^{-1}$. It has been established that the industrial radiography practice has received the highest annual doses, it varies from (0.73 ± 0.11) $mSv.y^{-1}$ to (3.59 ± 2.88) $mSv.y^{-1}$ with an average value of (1.71 ± 0.99) $mSv.y^{-1}$ for Hp (10), and from (0.70 ± 0.29) $mSv.y^{-1}$ to (3.60) ± 2.83) $mSv.y^{-1}$ with an average value of (1.72 ± 0.99) $mSv.y^{-1}$ for Hp (0.07).

Keywords

TLD Dosimeter, Facilities, Practices, Annual Equivalent Dose, Workers

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1. Introduction

Radioactivity has existed since the birth of the universe. This phenomenon has been used by humans as an asset to its developments through various nuclear techniques. Nuclear techniques are used in several fields such as agriculture, medicine, industry, energy, etc. The application of these technologies is very beneficial for the human life but however we should not forget that there are still the regulatory authorities responsibility [1] to develop the regulatory context in matters of radiation protection and to reduce and / or avoid the radiological risks that could affect human health and the environment. Several scientific studies have been carried out for the TLD individual monitoring in hospitals [2, 3] for the workers. Scientific publications relating to environment monitoring using TLD Badge have also been applied to the United States Department of Energy [4]. This study was focused specifically on industrial fields in Madagascar, on the personal monitoring system of workers using TLDs over the past 10 years (2010-2020). This work was carried out within the Dosimetry and Radiation Protection Department of INSTN-Madagascar. Dosimeter cards were read out to determine the average annual Hp (10) and Hp (0.07) equivalent doses.

2. Materials and Methods

2.1. TLD Dosimeter Carte, Type-100

The TLD card (Figure 1) is composed of two hot-pressed elements. These are chips (LiF) doped with Mg (TLD-100) whose dimensions are 3.2 mm^2 X 0.38 mm and mounted between two sheets on an aluminium substrate.

The card is provided with an identification code or barcode allowing the reader to differentiate the cards one after the other. One corner of the card is checked to ensure proper insertion into the holder and correct orientation when being read in the automatic TLD reader.

Figure 1. *TLD dosimeter Card.*

2.2. Dosimeter Reader: Dosimeter Chain at INSTN- Madagascar

At the Dosimetry and Radiation Protection Department of INSTN-Madagascar, TLD dosimeter reading system is a complete and automated set of thermoluminescence measuring instruments, shown in Figure 2.

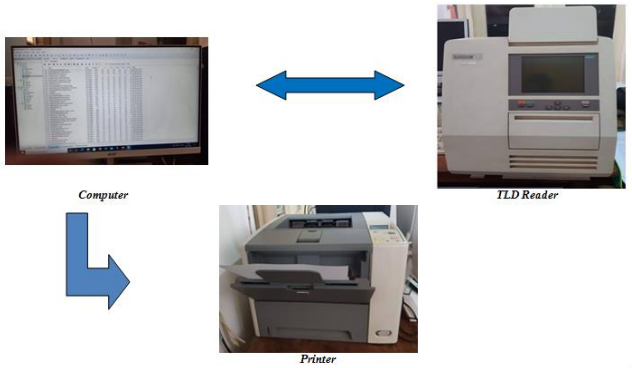

Figure 2. *Dosimeter Reader System.*

The computer was used for the dosimeter data storage, processing and management accompanied by the TLD-REMS Software [5]. This software helps maintain a reader calibration and quality assurance.

The TLD cards were inserted into the HARSHAW 6600 reader for readout [6]. The latter is capable of automatically reading up to 200 cards in an automatic and continuous manner. A Sr-90 source with activity 0.5 MBq placed inside this reader ensures the system calibration.

2.3. Legal Framework

As part of the peaceful use of nuclear techniques in Madagascar, the first regulations in radiation protection were implemented in 1993 consisting of a single decree with 10 interministerial decrees [7]. Following the increase of the number of ionizing radiation sources users, a new law has been adopted within the Malagasy national assembly uniform Law N° 97-041 on 02 January 1997 on protection against the harmful effect of ionizing radiation and the radioactive waste management in Madagascar [8] followed by four (4) application decrees [9-12]. This legislation strengthens the activities of the radiation protection regulatory body, in particular the personal monitoring of workers exposed to ionizing radiation [13]. This activity is carried out by the Dosimetry and Radiation Protection Department of INSTN-Madagascar, as the technical body of the radiation protection.

2.4. Dosimeter Workers Monitoring

TLDs are worn by the exposed workers in facilities and send for readout at the Dosimetry and Radiation Protection

Department of the INSTN-Madagascar four times a year (Figure 3), to determine the corresponding Hp(10) and Hp(0.07). The obtained exposition doses are recorded to the national exposition dose database.

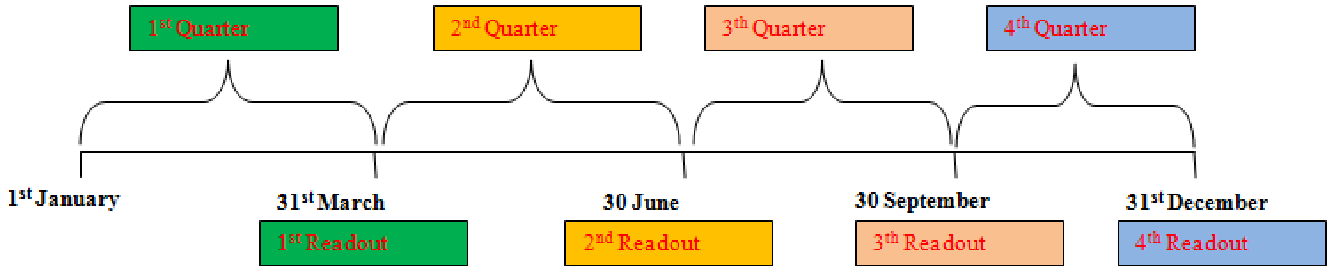

Figure 3. *TLD readout cycle within a year at the Dosimetry and Radiation Protection Department of INSTN-Madagascar.*

3. Results and Measurements

3.1. Number of Monitored Workers

Personal monitoring of workers under ionizing radiation has been carried out since the creation of INSTN-Madagascar in 1992. At that time, the HARSHAW 4000 reader was used. With the increase of the number of ionizing radiation sources users at national and regional level, the IAEA granted the Department of Dosimetry and Radiation Protection a new HARSHAW 6600 dosimetrer reader replacing the 4000 one. The number of workers in industrial facilities during this period are shown in Table 1. On average, 450 workers per year were monitored between the years 2010 and 2020 on the 12 average industrial facilities (Table 1).

In 2010, 195 workers in industrial fields out of the eight (8) industrial establishments were monitored dosimetrically, this represents the lower figure, when compared to other years, because industrial techniques were based on industrial radiography, nuclear gauges (density and moinsture gauge), baggage scanner machine and the radioactive ore transportations. The number of workers monitored in 2013 were three times higher than in 2010, which was 562 workers, this shows the increase of the number of workers due to the existence of the two major exploration mining projects, in the East [18.20161; 49.35630] and in the South East [-24.94970; 47.01679] of Madagascar which employ more than 300 workers using density and level gauges.

Even in the presence of the Covid-19 pandemic which hit the country around 2020, the industrial field continued to operate with a figure of 476 workers monitored, when compared to the year 2019 (443 workers) (Table 1).

Table 1. *Number of workers in industrial facilities using TLD dosimeters in the last 10 years.*

Period	Number of Industrial Facilities	Number of Monitored Workers
2020	9	476
2019	10	443
2018	11	395
2017	12	467
2016	14	556
2015	14	535
2014	14	554
2013	13	562
2012	11	387
2011	12	389
2010	8	195
Average	11.64 ± 2.06	450.82 ± 108.89

3.2. Hp(10) and Hp(0.07) Average Equivalent Dose for the Industrial Facilities Over 10 Last Years

The International Commission on Radiological Protection (ICRP 103) defines in their publication [14] that Hp (10) and Hp (0.07) are respectively the skin individual equivalent dose and wholebody effective dose. The Hp (10) and Hp (0.07) annual equivalent doses from industrial facilities in Madagascar over the past 10 years vary from (0.97 ± 0.18) mSv.y^{-1} to (1.99 ± 0.92) mSv.y^{-1} with an average value of (1.36 ± 0.57) mSv.y^{-1} and from (0.96 ± 0.16) mSv.y^{-1} to (2.03 ± 0.92) mSv.y^{-1} with an average value of (1.37 ± 0.56) mSv.y^{-1} (Table 2) respectively.

In 2013, the values of the Hp (10) and Hp (0.07) average annual equivalent doses received were respectively (1.99 ± 0.92) mSv.y^{-1} and (2.03 ± 0.92) mSv.y^{-1}. These two values are higher when compared to other years, as the recruitment of workers in the two major exploration and mining projects in the East [18.20161; 49.35630] and in the South East [-24.94970; 47.01679] of Madagascar were numerous, leading the increase of new workers to the safety use of ionizing radiations. Such a situation increases the average annual dose for workers.

From 2014 to 2020, the Hp (10) and Hp (0.07) annual average equivalent doses obtained have slightly decreased, because the radiation protection training program [15] and the safety culture [16] transmitted to industrial users of the ionizing radiation sources performed by INSTN-Madagascar team.

Table 2. Average Value of Hp(10) et Hp(0.07) equivalent dose of the industrial facilities over 10 last years.

Period	Number of industrial Facilities	Hp(10) [mSv.y^{-1}]	Hp(0.07) [mSv.y^{-1}]
2020	9	1.08 ± 0.42	1.06 ± 0.41
2019	10	1.08 ± 0.30	1.06 ± 0.31
2018	11	1.08 ± 0.32	1.07 ± 0.36
2017	12	0.97 ± 0.18	0.96 ± 0.16
2016	14	1.19 ± 0.39	1.19 ± 0.39
2015	14	1.49 ± 0.51	1.53 ± 0.50
2014	14	1.56 ± 0.65	1.44 ± 0.41
2013	13	1.99 ± 0.92	2.03 ± 0.92
2012	11	1.36 ± 0.55	1.40 ± 0.54
2011	12	1.72 ± 0.78	1.80 ± 0.83
2020	8	1.49 ± 1.30	1.51 ± 1.30
Average	11.64 ± 2.06	1.36 ± 0.57	1.37 ± 0.56

3.3. Hp(10) and Hp(0.07) Average Equivalent Dose for the Industrial Practices

Tables 3 and 4 were used to determine the Hp (10) and Hp (0.07) average annual equivalent doses, respectively, in industrial practice. The annual equivalent doses Hp (10) and Hp (0.07) obtained by industrial radiography practice (Tables 3 and 4) which vary respectively from (0.73 ± 0.11) mSv.y^{-1} to (3.59 ± 2.88) mSv.y^{-1} with an average value of (1.71 ± 0.99) mSv.y^{-1}, and from (0.70 ± 0.29) mSv.y^{-1} to (3.60 ± 2.83) mSv.y^{-1} with an average value of (1.72 ± 0.99) mSv.y^{-1}, are higher compared to the nuclear gauge practice (density gauges and level, and density and humidity gauges), because, according to the IAEA radioactive sources categorization [17], the workers using sources with higher radiological risks, receive higher doses. It is normal because of the activity level and the equipment design.

The average annual equivalent doses received by workers in practice using X-rays for baggage inspection (1.17 ± 0.29 mSv.h^{-1}) for Hp (10) and 1.20 ± 0.28 mSv.h^{-1} for Hp (0.07)) are higher when compared to that of foreign body inspection (0.39 ± 0.08 mSv.h^{-1}) for Hp (10) and 0.37 ± 0.12 mSv.h^{-1} for Hp (0.07) (Figure 5). This shows that the high voltage (HT) applied to the X-ray tube for baggage scanners is higher than foreign body scanners. In addition, the beginning of workers dosimeter monitoring using foreign body inspection practice began around 2016 until 2020, which made it possible to reduce the average value of annual equivalent doses to this practice.

The transportation of radioactive ores was a very rare activity in Madagascar. The subscription application of personal dosimeters TLDs on this activity is also rare as indicated in Tables 3 and 4. Between [2014- 2015] and [2017 and 2020], no request for TLDs dosimeters subscription was received at INSTN-Madagascar, this also makes it possible to reduce the average equivalent dose value of the practice using the transportations of radioactive ores in Madagascar.

Table 3. Average value of Hp(10) annual equivalent dose of every industrial Practice since 2010 to 2020.

Industrial Practice	y-2020 [$mSv.y^{-1}$]	y- 2019 [$mSv.y^{-1}$]	y-2018 [$mSv.y^{-1}$]	y- 2017 [$mSv.y^{-1}$]	y-2016 [$mSv.y^{-1}$]	y-2015 [$mSv.y^{-1}$]
Industrial Radiography	0.73± 0.11	0.93±0.07	0.73±0.31	0.94±0.76	1.28±0.45	1.34±0.57
Level and Density Gauge	1.74± 0.59	1.35±0.57	1.55±1.1	1.3±1.01	1.79±1.68	1.52±0.87
Level and Moisture Gauge	1.25± 0.67	0.88±0.30	1.13±0.18	0.85±0.51	0.94±0.29	0.89±0.47
Cargo Inspection	0.91± 0.05	1.09±0.23	1.2±0.21	1.04±0.27	1.39±0.70	1.38±0.43
Foreign Body Inspection	0.79± 0.07	0.73±0.01	1.17±0.30	0.88±0.42	0.71±0.04	0
X RF	0	1.51±0.15	0.71±0.40	0.8±0.28	1.43±1.21	2.3±0.01
Transportation of Radioactive Ore	0	0	0	0	0.78±0.04	0

Table 3. Continued.

Industrial Practice	y-2014 [$mSv.y^{-1}$]	y-2013 [$mSv.y^{-1}$]	y- 2012 [$mSv.y^{-1}$]	y-2011 [$mSv.y^{-1}$]	y-2010 [$mSv.y^{-1}$]
Industrial Radiography	1.65±0.77	2.81±1.57	2.05±0.98	2.74±1.73	3.59±2.88
Level and Density Gauge	1.26±0.63	1.53±1.24	1.32±0.85	0.66±0.38	0
Level and Moisture Gauge	1.13±0.59	3.34±2.96	1.75±0.51	2.02±0.57	1.34±0.32
Cargo Inspection	1.11±0.18	0.95±0.36	1.35±0.21	1.31±0.22	1.14±0.32
Foreign Body Inspection	0	0	0	0	0
X RF	2.65±1.06	2±0.01	1.4±0.01	0	0
Transportation of Radioactive Ore	0	1.31±0.08	0.45±0.07	1.89±0.13	1.39±0.22

Table 4. Average value of Hp(0.07) annual equivalent dose of every industrial Practice since 2010 to 2020.

Industrial Practice	y-2020 [$mSv.y^{-1}$]	y- 2019 [$mSv.y^{-1}$]	y-2018 [$mSv.y^{-1}$]	y- 2017 [$mSv.y^{-1}$]	y-2016 [$mSv.y^{-1}$]	y-2015 [$mSv.y^{-1}$]
Industrial Radiography	0.71±0.71	0.92±0.07	0.7±0.29	0.88±0.71	1.29±0.51	1.38±0.59
Level and Density Gauge	1.71±0.59	1.34±0.55	1.59±1.09	1.23±0.96	1.83±1.74	1.65±0.90
Level and Moisture Gauge	1.2±0.64	0.87±0.33	1.17±0.16	0.85±0.52	0.98±0.33	0.94±0.47
Cargo Inspection	0.88±0.06	1.11±0.22	1.27±0.21	1.07±0.27	1.43±0.59	1.39±0.43
Foreign Body Inspection	0.8±0.10	0.66±0.08	1.03±0.45	0.86±0.53	0.7±0.16	0
X RF	0	1.48±0.20	0.65±0.36	0.85±0.21	1.3±1.05	2.3±0.01
Transportation of Radioactive Ore	0	0	0	0	0.81±0.10	0

Table 4. *Continued.*

Industrial Practice	y-2014 [mSv.y^{-1}]	y-2013 [mSv.y^{-1}]	y-2012 [mSv.y^{-1}]	y-2011 [mSv.y^{-1}]	y-2010 [mSv.y^{-1}]
Industrial Radiography	1.58±0.72	2.84±1.52	2.1±0.93	2.88±1.96	3.6±2.83
Level and Density Gauge	1.3±0.69	1.54±1.33	1.44±0.95	0.7±0.37	0
Level and Moisture Gauge	1.12±0.55	3.4±3.14	1.73±0.56	2.10±0.63	1.35±0.40
Cargo Inspection	1.12±0.23	0.98±0.36	1.37±0.12	1.41±0.26	1.15±0.35
Foreign Body Inspection	0	0	0	0	0
X RF	2.1±1.13	2±0.01	1.5±0.01	0	0
Transportation of Radioactive Ore	0	1.41±0.11	0.51±0.11	1.89±0.15	1.39±0.31

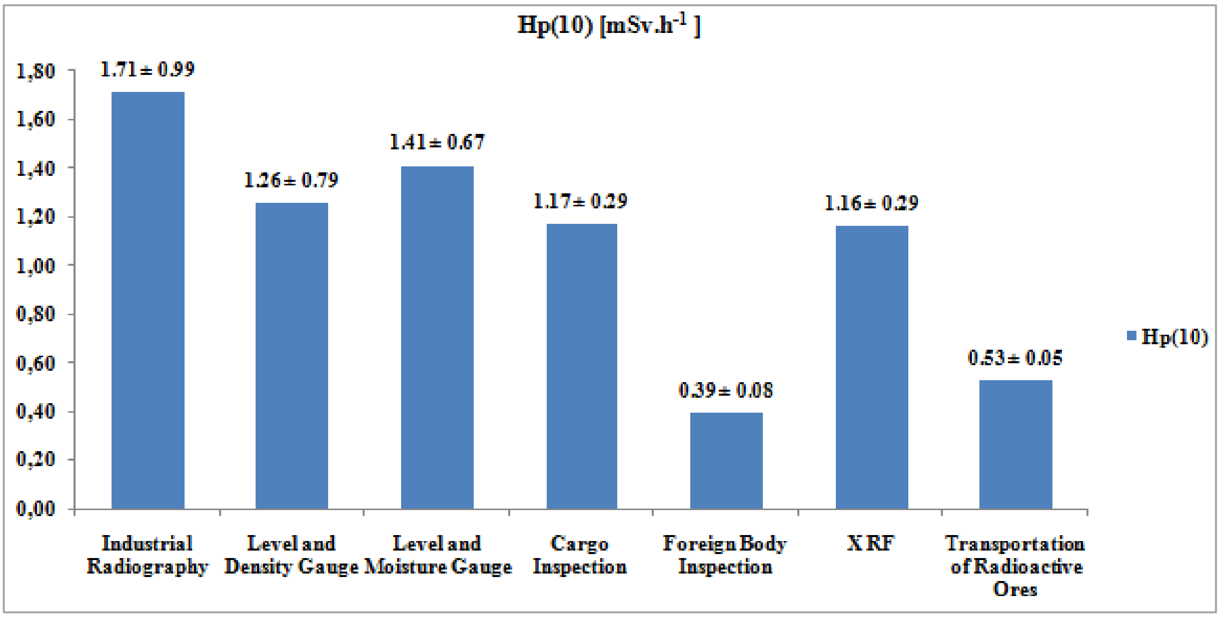

Figure 4. *Average value of Hp(10) annual whole doby effective dose for the industrial Practice over ten last years.*

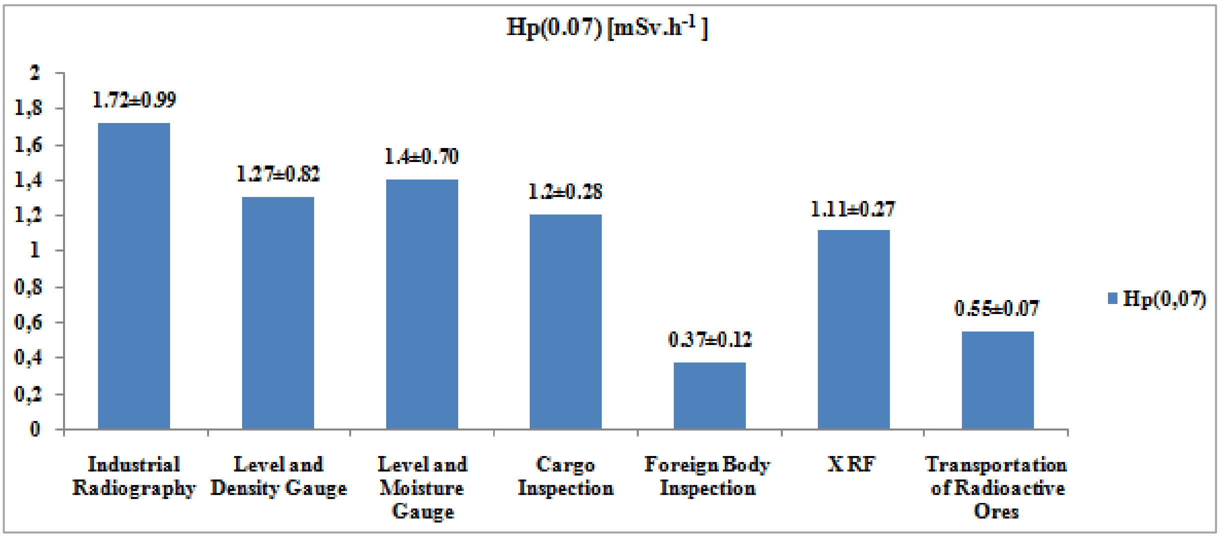

Figure 5. *Average value of Hp(0.07) annual skin equivalent dose for the industrial Practice over ten last years.*

4. Conclusions

The annual equivalent dose exceeding the regulatory limit is a very rare phenomenon in Madagascar. The Dosimetry and Radiation Protection Department Team of INSTN-Madagascar conducted investigations to identify the causes that could lead to such an over exposition. This work was focused only on the annual effective doses study of facilities using industrial activities below the regulatory limit in radiation protection during the last 10 years. Industrial facilities are defined by the number of companies carrying out industrial practice. Industrial radiography, nuclear gauges (density / level, and density / humidity), scanners for baggage inspection, X-ray fluorescence, and the activity on radioactive ore transportations are among the main industrial practices using ionizing radiation sources in Madagascar. Personal monitoring is part of the activity of the regulatory authority in the radiation safety framework of workers. Personal Dosimeter data have already been stored in the INSTN-Madagascar database (name and number of workers, name and number of facilities, annual doses of workers) from 2010 until 2020. During this period, an average of 450 workers out of the 12 establishments was monitored by INSTN-Madagascar. The Hp (10) and Hp (0.07) average annual equivalent doses were calculated for industrial facilities. The increase of annual equivalent doses from industrial facilities in 2013 is due to the presence of two huge mining projects using nuclear gauges (density and level) to monitor more than 300 workers. The presence of radiation protection training performed by INSTN-Madagascar led to the reduction of Hp (10) and Hp (0.07) annual equivalent doses in facilities between 2014 and 2020.

The industrial radiography practice receives the highest annual equivalent dose, when compared to the nuclear gauge practice. The average annual equivalent doses received by workers in practice using X-rays for baggage inspection are higher when compared to that for X-rays foreign body inspection. The annual equivalent doses received during the transportation of radioactive ores are not significant.

Abbreviations

INSTN	National Institute of Nuclear Sciences and Techniques
TLD	Thermoluminescent Dosimeter
XRF	X-ray Fluorescence
ICRP	International Commission on Radiological Protection

Conflicts of Interest

The authors declare no conflicts of interest.

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