Public Dose Evaluation from Frequent Usage of Consumer Products Containing Naturally Occurring Radioactive Materials

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1. Introduction

Several consumer products containing small amounts of incorporated radionuclides are generally accessible for public use worldwide. However, frequent usage of such goods endangers the public at risk resulting from undue radiation exposure which is against the standard of radiation protection. Radionuclides from the ^{238}U and ^{232}Th family, as well as the solitary decay radionuclide, are found in abundance in all rocks and minerals on the planet. The term "naturally occurring radioactive material" (NORM) refers to substances that include such radionuclides [1]. These products, which primarily contain monazite (natural gemstone) and zircon (processed for use in many domestic applications), are promoted for their health benefits based on radiation-induced hormesis, and the theory that low-dose radiation is not only safe but also beneficial to human health by stimulating the immune system and repair mechanism. A radioactive product is a device or manufactured item that integrates or produces radionuclides via activation, or generates ionizing radiation, and can be sold to the general public without special supervision by the competent authority [2]. These products may contain byproducts or source materials. However, frequent use of these products exposes the public from the risk of unjustified radiation exposure. Several guidelines have been provided regarding the use of such products, as well as the level of control exercised by competent authorities in providing regulatory processes for exemption, as well as how to meet the criteria for justification, optimization, and authorization of such products distribution to the general public [3]. Recent ICRP recommendations are based on the reasonable assumption that there is no safe level of exposure, and that even the smallest amount of exposure might generate stochastic effects like cancer. The underlying notion of keeping all exposure levels "as low as reasonably achievable" (ALARA) was supported in addition to staying below the dose limits. In this study, public dose evaluation from widespread usage of consumer products containing naturally occurring radioactive materials (NORMs) were conducted for various usage and exposure conditions thereby assessing the dose emanating thereof. The study examines both the external and internal exposure doses to members of the public as a result of daily use of consumer products containing naturally occurring radioactive elements while adhering to radiation safety guidelines. The external and internal exposure of workers and members of the public should be examined in terms of protection level due to the radioactive nature of consumer products containing NORMs and the growing concern about the undue radiation risk to the public resulting from frequent usage of these products [4]. Analytical calculations were performed for three age-dependent groups to ascertain the effects of radiation on various tissues in addition to other external and internal dose evaluation using appropriate computer codes (Microshield and IMBA codes).

2. Materials and Method

2.1 Activity Concentration Data

Data for this research were obtained from nuclear security and safety commission (NSSC) and are statistically analyzed using Boxplot embedded in Minitab tool as shown in figure 1. The lower whiskers, median and upper whiskers for each product categories were used as input to reduce the outliers in data. A normalized value of activity concentration was used for dose evaluation.

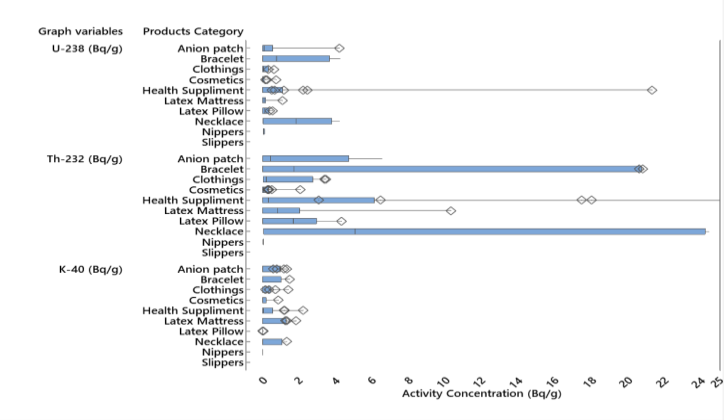

Figure 1. Analysis of ^{238}U, ^{232}Th and ^{40}K using Boxplot.

2.2 Hypothetical Usage and Exposure Scenarios

The hypothetical usage scenarios for various categories of consumer products incorporating NORMs were extracted from [5]. For each product category, suitable estimations were extracted for usage location on the body, average usage time during normal and exposure pathways. Table 1 shows the summary of the hypothetical usage and exposure scenario used for dose estimation in this study.

Table 1. Hypothetical usage scenarios and exposure pathways [5].

Product Categories	Usage Location	Usage Time /day	Exposure Pathways
Pillows	Head, neck	7h 50min	Inhalation
Latex Mattress	Whole body	7h 50min	Inhalation
Clothing	Depending on usage	24h	Inhalation
Necklace	Neck	8h 7 min	Inhalation
Bracelets	hand	8h 7 min	Inhalation
Amnion Patch	Body for wound covering	8h 7 min	Inhalation and Ingestion
Cosmetics	Face and Body	8h 7min	Ingestion
Dippers	Depending on usage	20 min	Inhalation
Slippers	Foot wares	5h 1 min	Inhalation
Health Supplements	Waist, abdomen	5h 1 min	External Inhalation

2.3 Age Dependent Dose Coefficients

The ICRP developed age dose coefficients for calculating equivalent and effective doses from inhalation and ingestion. Table 2 shows the age-dependent effective dose coefficient values for Inhalation and Ingestion of radionuclides obtained from ICRP Publication 119, while external radiation exposure was extracted and calculated from ICRP 144 alongside inhalation rate from ICRP 1975, 2004, respectively.

Table 2. Age-dependent dose coefficients and inhalation rate

Nuclide	Absorption Type	1 Year	10-Year	Adult
Effective Dose Coefficient for Inhalation (Sv/Bq) [6]				
	F	1.3×10^{-6}	7.3×10^{-4}	5.0×10^{-7}
^{238}U	M	9.4×10^{-6}	4.0×10^{-4}	2.9×10^{-6}
	S	2.5×10^{-6}	1.0×10^{-4}	8.0×10^{-6}
	F	2.2×10^{-6}	1.3×10^{-4}	1.1×10^{-4}
^{232}Th	M	8.1×10^{-5}	5.0×10^{-5}	4.5×10^{-5}
	S	5.0×10^{-5}	2.6×10^{-5}	2.5×10^{-5}
^{40}K	F	1.7×10^{-8}	4.5×10^{-9}	2.1×10^{-9}
Effective Dose Coefficient for Ingestion (Sv/Bq) [6]				
^{238}U	-	1.2×10^{-7}	6.8×10^{-8}	4.5×10^{-8}
^{232}Th	-	4.5×10^{-7}	2.9×10^{-7}	2.3×10^{-7}
^{40}K	-	4.2×10^{-8}	1.3×10^{-8}	6.2×10^{-9}
Effective Dose Coefficient for External Exposure extracted and calculated from ICRP 144) (Sv/h per Bq/g) [7].				
^{238}U		1.48×10^{-16}	1.15×10^{-16}	9.44×10^{-17}
^{232}Th		5.06×10^{-16}	4.02×10^{-16}	3.37×10^{-16}
^{40}K		4.39×10^{-13}	3.79×10^{-13}	3.46×10^{-13}
Inhalation rate extracted from ICRP recommendations 1975, 2004 [8, 9].				
1 m3/h or 24 m3/d equivalents to 1225 g/h				
m^3/d		5.1	15.2	22.2
m^3/h		0.2125	0.63	0.925
g/h		260	775	1331.13

2.4 Total Effective Dose Calculation

The total effective dose equivalent $TEDE_{total}$ (mSv/y) is estimated as the sum of radiation doses from all possible exposure pathways, including direct gamma radiation from external exposure and internal exposure from inhalation and ingestion of radionuclides, and can be expressed mathematically as:

$$\mathrm{TEDE_{total}} = \mathrm{D_{ext.}} + \mathrm{D_{int(inh)}} + \mathrm{D_{int(ing)}} \quad (1)$$

where:
$TEDE_{total}$ The total effective dose equivalent (mSv/y)
$D_{ext.}$ External dose from direct gamma radiation
$D_{int(inh)}$ Internal dose due to inhallation pathway
$D_{int(ing)}$ Internal dose due to ingestion pathway

The annual effective dose from inhalation ($\boldsymbol{D_{int(inh)}}$) and ingestion ($\boldsymbol{D_{int(ing)}}$) can be calculated using the expression

$$\mathrm{D_{int(inh)}} = \mathrm{D_R} \times \mathrm{I_R} \times \mathrm{H_t} \times \mathrm{DC_{inh}} \quad (2)$$

$$\mathrm{D_{int(ing)}} = \mathrm{D_R} \times \mathrm{I_R} \times \mathrm{I_T} \times \mathrm{DC_{ing}} \quad (3)$$

where:
D_R Is the measured activity concentration of inhaled or ingested radionuclide (Bq/g)
I_R Inhalation and ingestion rate (g/h)
H_t Exposure time to contaminated air (h/y)
$\boldsymbol{I_T}$ Time of Ingestion rate (h/y)
DC_{inh} Inhalation dose coefficient (Sv/Bq)
DC_{ing} Ingestion dose coefficient (Sv/Bq)

2.5 Comparison between Microshield and IMBA

MicroShield code was developed by grove software for photon/gamma-ray shielding and dose prediction. The code calculates gamma-ray shielding using the point kernel approach and is also used for external dose evaluation. Integrated Module for Bioassay Analysis (IMBA) evaluate the internal exposure doses from radionuclides intakes or bioassay measurement data using dosimetric and biokinetic model along with other ICRP parameters.

Table 3 gives the comparison of external and internal dose estimation computer codes used in this study.

Table 3. Comparison of Microshield and IMBA code.

Code	Models	Assumptions	Calculation	Scope
Micro shield	ANSI/ANS -6.1.1-1977 standards	Point Kernel	Gamma-ray shielding and dose prediction.	External Dose

IMBA	Dosimetric Biokinetic	ICRP Publications 60 and 68, 26 and 30 or 10CFR 835	Dosimetric Bioassay	Internal Dose

3. Results and Discussion

3.1 Age Dependent TEDE

Figure 2 shows the result of age-dependent total effective dose equivalent TEDE calculation using the analytical solution.

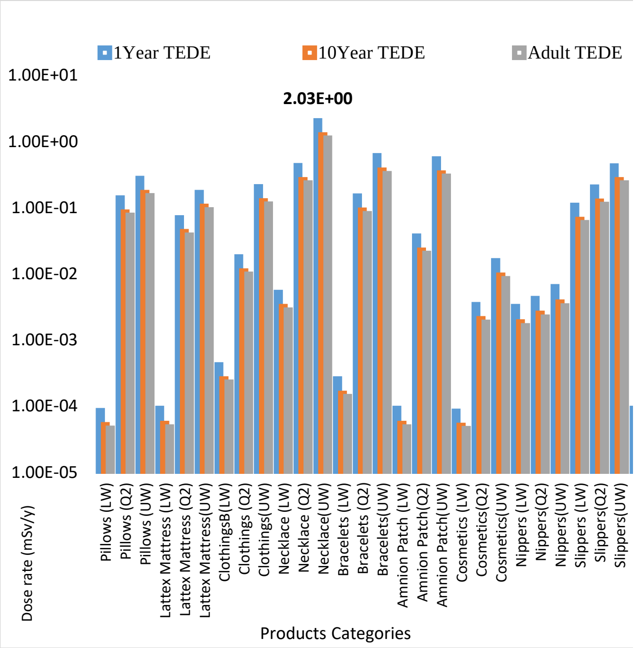

Figure 2: Age dependent TEDE

The TEDE for three age groups are presented in Figure 2. The TEDE reported at the upper whisker of necklace with an activity concentration of 4.21 Bq/g (^{238}U), 24.1 Bq/g (^{232}Th), and 0.55 Bq/g (^{40}K) are 2.03 mSv/y, 1.24 mSv/y, and 1.11 mSv/y, for 1 year, 10 years, and adult age groups which are all above the recommended ICRP public dose limit of 1 mSv/y. TEDE is high in 1 year than 10 years and adults due to sensitivity of a growing tissue to radiation than a mature tissue.

3.2 *External Dose Estimation.*

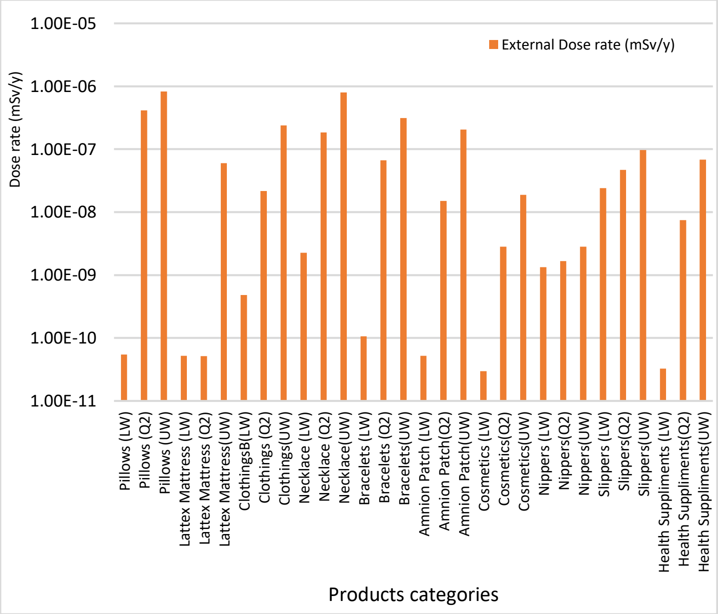

Figure 3. External dose from Microshield.

Figure 3 shows the estimation of external doses using Microshield computer code. The external dose are all below the ICRP public dose limit of 1 mSv/y. Low external dose is due to 11% contribution of gamma decay during ^{40}K decay.

3.3 Internal Dose Estimation.

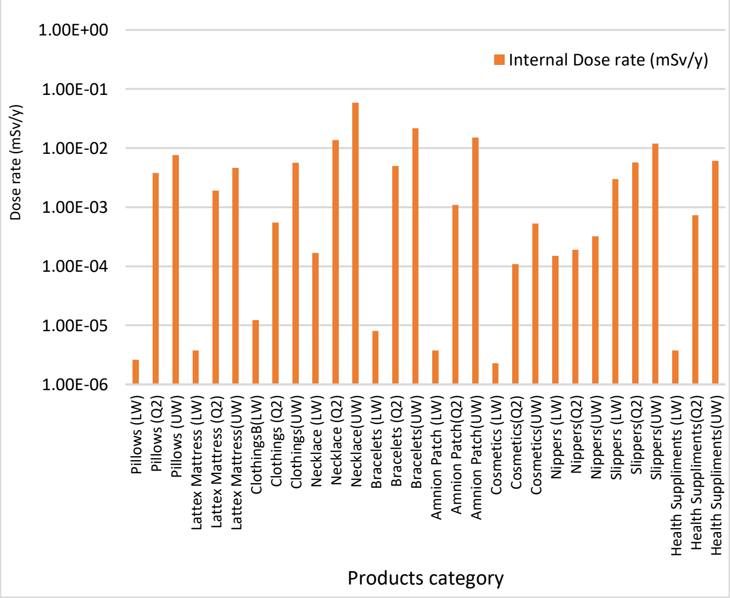

Figure 4. Internal dose from IMBA code.

Figure 4 shows internal dose calculated using IMBA code. The internal dose from inhalation is higher than that from ingestion for all products due to inhalation of radon and thoron gas emitted by the decay product of ^{238}U and ^{232}Th. Contribution of ingestion dose is negligible since it is hard to ingest such products directly but inhalation of gaseous decay products is possible. All the internal dose are all below the ICRP public dose limit of 1 mSv/y.

4. Conclusion

The ICRP dose limits are intended to act as a boundary condition, preventing deterministic consequences while reducing stochastic impacts. If the dose is greater than 1 mSv/y, public safety measures must be implemented. In this study, public dose evaluation from frequent use of consumer products containing NORMs was performed using various usage and exposure scenarios for each product category. The data in this study was analyzed using Boxplot with lower whiskers, median and upper whiskers used as input for analysis. A normalized activity concentration values was used to perform external and internal dose assessment using analytical calculation by applying ICRP dose coefficients and other input parameters. The results using analytical method shows that the highest TEDE received from necklace products for various age groups are all above the ICRP recommended public dose limit of 1 mSv/y. External and internal exposure dose evaluation results from Microshield and IMBA code are all below the recommended public dose limit of 1 mSv/y.

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