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Radiation hazard assessment from NORM-added paint products in Malaysia

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ABSTRACT

Introduction: Across the globe, radioactive consumer products are widely marketed for daily use.
Objectives: The present study investigated commercially available ion paint, and the evaluations were using gamma (γ)-ray spectroscopy and Geant4 Monte Carlo (GMC) simulations.
Methods: An assessment of a radiological risk arising from using such products in the painting of living areas is conducted when Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) was observed, with a daily inhalation exposure dose being of particular concern. Organ doses were simulated using adult mathematical Medical Internal Radiation Dose 5 (MIRD5)-type phantoms, incorporating dose conversion factors (DCFs).
Results: Results showed that a product sample code of IP04 contained the highest activity, i.e., 4449 ± 530, 31888 ± 2175, and 2963 ± 405 Bq kg^{-1}, for ^{238}U, ^{232}Th, and ^{40}K, respectively. Contrarily, NP18 recorded the lowest, i.e., 16 ± 2 and 30 ± 5, Bq kg^{-1} of ^{238}U and ^{232}Th, respectively. The IP04 paint offered the most significant concentrations, with mean percentages of 0.026, 0.81, and 0.06 for ^{238}U, ^{232}Th, and ^{212}Pb, respectively. Its use in a designated Room 1 had resulted in an annual effective dose of 1.53 mSv y^{-1}, assuming an exposure for a period of 8 h day^{-1}.
Conclusion: In brief, using these ion paints could result in amounts that exceed the annual public dose limit of 1 mSv.

1. Introduction

All life on earth is subjected to continuous streams of radiation as a result of natural sources. Terrestrial NORM is the primary source of ionising radiation exposure from such sources (Joel et al., 2018). Additionally, public members may also be exposed to unexpected sources resulting from disturbed environments, typically caused by anthropogenic activities. Increased levels of NORM are found in the residue/waste streams of the extractive industries. Several consumer products contain NORM, which is of current interest. While increased NORM levels are typically unintentional by-products of industrial processes, the addition to consumer products is deliberate. Although unproven, the industries claim that radiation emanations provide health and aesthetic benefits.

The Nuclear Regulatory Commission (NRC) and the United States Environmental Protection Agency (EPA) regulate the control of NORM-added radioactive consumer products, including their distribution (Yoo et al., 2015). Natural radioactivity is most com-

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monly derived from a mixture of uranium-238 (^{238}U), thorium-232 (^{232}Th), and potassium-40 (^{40}K) (UNSCEAR, 2000, 1988). These radionuclides can be found significantly in everything, from daily food to building materials (Chae et al., 2016; Malain and Kanchana, 2019). The extractive industries, such as the waste stream of the upstream oil and gas industry, ore mining, milling, and waste, have altered the natural concentration of radionuclides and associated activity (ARPANSA, 2008). While some refer to this as TENORM, it is more commonly referred to as NORM (Chen, 2015; Cooper, 2005; Health Canada, 2011). NORM can also be found in some consumer products where radionuclide molecules are bound to specific minerals during the manufacturing process. One example is zircon, which contains trace amounts of Th and U. The half-lives of decay products can range from sub-seconds to thousands of years, such as radium-226 (^{226}Ra) from ^{238}U, which has a half-life of 1600 years. Meanwhile, radium-228 (^{228}Ra) from Th are the primary sources of radiation from natural surroundings (Hesty and Anri, 2018; Setlow, 2002).

Various sources of information on NORM have been published by national and international organisations, most notably the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP). However, there is relatively little information available for consumer products. According to Japanese guidelines, U, Th, and titanium (Ti) ores, as well as zircon, monazite, and bastnasite, are the raw materials of NORM used in consumer products. A more comprehensive account of the actual materials used by the industry, on the other hand, is not publicised (Furuta et al., 2011). It is also unclear how much radioactivity is added to each consumer product. Therefore, this issue will be partly investigated in the current study of a particular paint product.

Depending on the dose of radiation, radiation exposure can cause radiation-damaged to the tissue or organ. In addition, radiation can impair the functioning of tissue or organ beyond a certain threshold. It also can produce acute effects such as hair loss, skin reddening, radiation burns or acute syndrome. These effects are more severe at higher doses and higher dose rates. For instance, the dose threshold for acute radiation syndrome is about 1 Sv (1000 mSv) (Cullom and Bateman, 2010). Exposure to ionising radiation at moderate and high doses has been linked to increased cancer risk in epidemiological studies. Childhood exposure, in particular, raises the risk of leukaemia, breast cancer, and thyroid cancer than exposure at other ages. These cancers, which are one of the most commonly caused by radiation, have a complicated age dependency that follows the change in background rate (AAP, 1998). For instance, prolonged use of products incorporated with radioactive substances will increase the cancer risk to the consumer due to the products.

For this study, several so-called ion paints (NORM-added) produced locally in Malaysia were obtained online and through local market purchases, with a lack of radioactivity information given in the products. When used, these radioactive consumer products will expose users to both internal and external radiation. Surprisingly, these paints are available to the general public, with potential applications in residential housing (Yoo et al., 2018, 2015). According to the ion paint manufacturers, these products are made of tourmaline powder, volcanic materials, and/or other minerals. The purveyors and manufacturers claimed that the negative ion technology used has health benefits such as improving circulation and flexibility and the ability to detoxify and boost energy levels, which could lead to cancer prevention (Pabroa et al., 2011). They also claimed that this technology could maintain health, improve energy balance, and improve emotional well-being (Mubarak et al., 2016).

Ion paints contain U and Th, which are concentrated in their activity (Yoo et al., 2018). As the risks have recently been identified, NORM has increasingly become subject to monitoring and regulation (Lee et al., 2016). According to the IAEA's safety guide "Radiation Safety for Consumer Products," the use of such items must first be justified due to the lack of scientific evidence that such paints provide any health benefits to the general public (IAEA, 2014a, 2016). Recently, in Malaysian law, an "Assessment and licencing of a consumer product containing radioactive material" has been enacted to limit public radiation exposure from NORM-added consumer products (AELB, 2016). In other countries, such legislation was preceded by control measures, such as the United States Environmental Protection Agency's (EPA) guidelines for TENORM regulation (EPA, 2000). Despite such isolated actions, globally harmonised regulations in respect of the control of the radioactive content consumer products have yet to be established (Yoo et al., 2016). Furthermore, there are currently no procedures yet for monitoring exposure in terms of effective dose from the use of TENORM-added products.

Radiation risk assessment for NORM-added consumer products is essential; for instance, ICRP has stating that certain exposures should be deemed unjustified without further analysis unless there are exceptional circumstances (ICRP, 2007). Therefore, the current study is intended to investigate the activity of the long-lived radionuclides ^{238}U, ^{232}Th, and ^{40}K through ion paints sampling, quantifying the possible radiation hazard from the usage. The dose from the exposure to the human was also simulated using GMC. In this regard, exposure was analysed using the MIRD5 mathematical male and female phantoms, with DCFs and organ dose evaluated, focusing on assessing external exposure radiation dose.

2. Methodology

2.1. Sampling

The tourmaline powder and zirconium (Zr), which contain U and Th, are advertised as ingredients in ion paint products (Lee et al., 2016). In the present study, 20 different wall paint samples were purchased online. All the packaging or labels of the products contain no evidence of any radioactivity. We have designated the products as either ion or conventional paint, as follows: ten ion paint samples (code IP01 to IP10), ten normal paint samples (code NP11 to NP20).

2.2. Instrumentation and calibration

Each sample was transferred into a 500 mL Marinelli beaker before counted by an HPGe detector for a period of 20 h. A single geometrical configuration is maintained for all of the paint samples. The γ emissions were measured directly with an ORTEC GEM Series P-type coaxial HPGe spectrometer (GEM20-76-LB-C-SMPCFG-SV-LB-76; 1.8 keV FWHM at 1332 keV with 33% relative efficiency), which provides high-performance γ-spectroscopy over the energy range of 40 keV to several MeV. Besides Mobius cooling system, the system also employs high-resolution spectroscopy software (VISION version 8) for spectral analysis. The spectra were calibrated using a 500 mL standard multinuclides source, which provided a wide range of photon energy emissions from radionuclides distributed in a liquid matrix (^{210}Pb, ^{241}Am, ^{109}Cd, ^{57}Co, ^{123m}Te, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{88}Y, and ^{60}Co). All of the γ emissions have energies greater than 200 keV, thus are unaffected by potential differences in densities between the normal liquid and the paint samples examined in the current study.

Under current measurement conditions, the ^{238}U series had counting efficiencies of 0.64% for ^{214}Bi (609.3 keV) and 1.1% for ^{214}Pb (351.8 keV). For ^{232}Th series, they were 1.24% for ^{228}Ac (338.2 keV), 0.6% for ^{212}Bi (727 keV), 1.52% for ^{212}Pb (238.4 keV), 0.71% for ^{208}Tl (583 keV), and 0.16% for ^{208}Tl (2614 keV). Meanwhile, the counting efficiency for ^{40}K is 0.2% at 1460 keV (Al-Sewaidan, 2019; Alshahri, 2017). Except ^{40}K, all the γ lines consist of a high branching ratio (Clouvas et al., 2000).

The radionuclide activities in the paint samples were evaluated in secular equilibrium, with the emission lines of the relatively short-lived decay products adequately considered. The results for ^{232}Th were calculated using an average of ^{212}Pb (238 keV), ^{228}Ac (338 keV and 911 keV), ^{212}Bi (727 keV), and ^{208}Tl (583 keV and 2614 keV) emissions, while the activities for ^{238}U were calculated using an average of ^{214}Pb (295 keV and 351.8 keV) and ^{214}Bi (727 keV) (609 keV and 1764 keV). An example of spectrum for IP04 are shown in Fig. 1. The specific activity concentration for each radionuclide, A (Bq kg^{-1}) is calculated by using Eq. (1) (Al-Sewaidan, 2019):

$$A = \frac{C}{pwt\varepsilon} \tag{1}$$

where C is the counting rate of gamma rays (counts per second), p is the absolute transition probability of gamma-decay, w is the mass of the sample (kg), t is time (second), and ε is the detector efficiency for the specific gamma ray.

2.3. Sample analysis

A Cartesian Geometry Energy Dispersive X-Ray Fluorescence (ED-XRF) spectrometer was applied for elemental analysis of the paint samples (model; NEX CG-CG1240). XRF provides a non-destructive method of determining actual content, including consumer products (Jurado-López et al., 2006; Ngo et al., 2018; Perring et al., 2017). All samples were prepared in liquid form. Four ion paint samples and two normal paint samples were analysed using XRF (Pabroa et al., 2011).

2.3.1. Monte Carlo (MC) simulation and evaluation of annual effective dose (AED)

The equivalent organ doses and AED from daily exposure to the painted walls of a hypothetical residential room have been estimated using the GMC radiation transport code (version 10.06 patch 3, Physics list: Geant4 electromagnetic (EM) physics (G4EmStandardPhysics option4)) (El Bakkali and El Bardouni, 2017). A MIRD5 mathematical male and female phantoms were also used in the study, with the male version shown in Fig. 2 (Lee et al., 2016; Olsher and Van Riper, 2005; Snyder et al., 1974). The male phantom was 178 cm and weighed 76 kg, while the female was 174 cm and 70 kg. Except for the skeleton and lungs, all organs were soft tissue material. The MIRD soft tissue density was 0.9869 g cm^{-3}, the MIRD skeleton was 1.4862 g cm^{-3}, and the MIRD lung material was 0.2958 g cm^{-3}.

The ion paint products were simulated for fictitious bedrooms with 24.31 kg and 13.52 kg of paint on the walls for Room 1 and Room 2, respectively. The room dimensions used in the simulation are from Malaysia's National Housing Standards Guidelines. The minimum size for a master bedroom (Room 1) is 3.5 m×3.2 m, while a smaller room, Room 2, is 2.0 m×3.3 m. Both rooms are standing at 2.8 m in height, as shown in Fig. 3 (CIDB, 2019). Fig. 2 depicts the simulated environment of Room 1 for the reference phantoms, which were standing at one of three distances from the walls: 20 cm, 50 cm, and in the centre of the room.

2.4. Data analysis

The organ equivalent and average effective doses associated with the exposures have been assessed by first measuring the activity of ^{238}U, ^{232}Th, and ^{40}K in the ion paint samples. DCFs calculated by GMC simulation were also used, taking into account the various tissue weighting factors. The radiological protection quan-

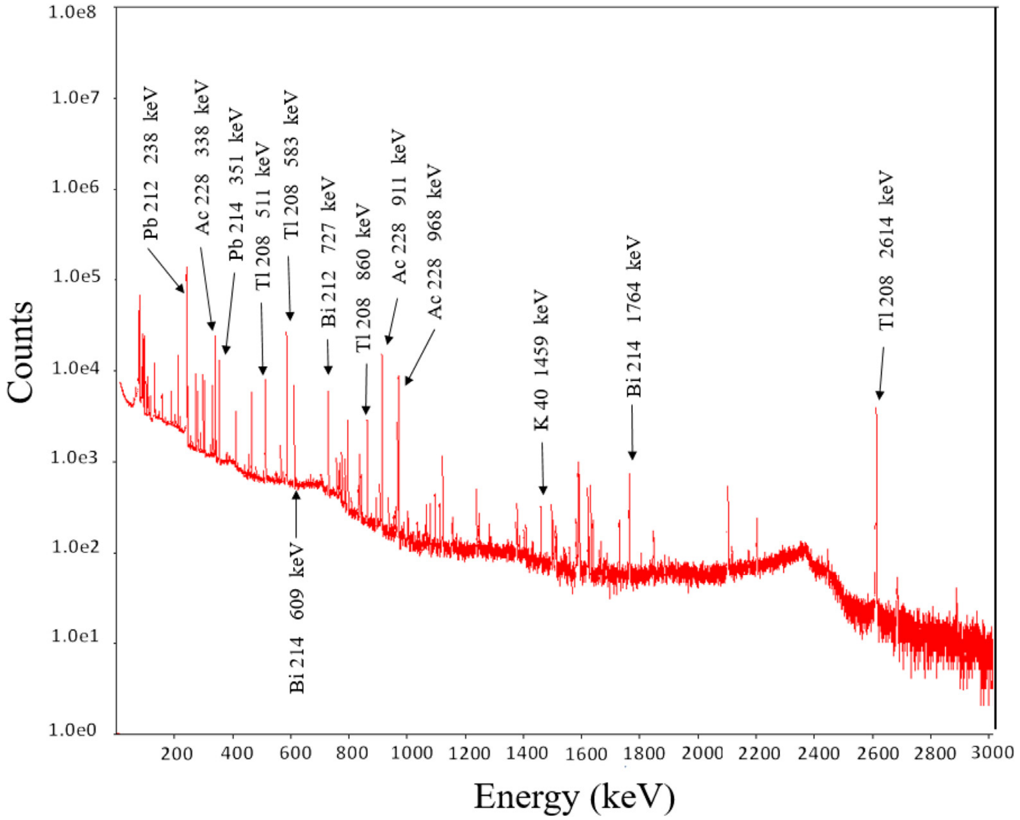

Fig. 1. Example spectra obtained from an IP04 ion paint sample.

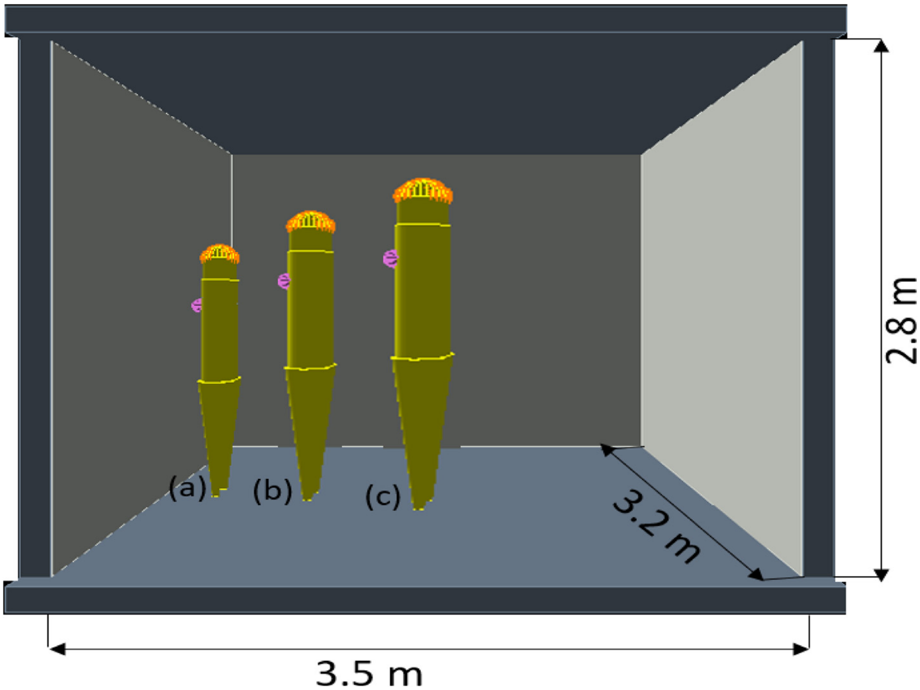

Fig. 2. MIRD human phantoms for painted walls, as used in GMC simulation; (a) standing position 20 cm from the wall; (b) standing position 50 cm from the wall; (c) standing position in the centre of the room.

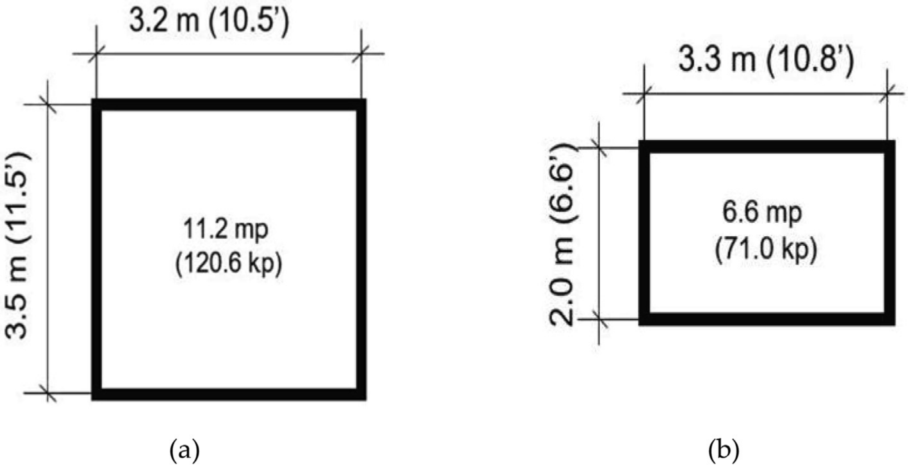

Fig. 3. Standard recommended minimum dimension for bedrooms in Malaysia: (a) master bedroom (Room 1) and (b) Room 2. Source: CIDB (CIDB, 2019).

tity effective dose, E_{eff} (Sv) is calculated using the following parameters as shown in Eq. (2)(Yoo et al., 2015):

$$E_{eff} = \Sigma w_T \Sigma w_R D_{T,R} = \Sigma w_T H_T \quad (2)$$

whereby w_T is the tissue weighting factor summing to unity (IAEA, 2012, 2014b; ICRP, 2007; Mubarak et al., 2016), w_R is the radiation weighting factor (for γ radiation, unity), $D_{T,R}$ (Gy) is the mean absorbed dose of γ radiation in an organ or tissue (T) (ICRP, 2007), and H_T(Sv) is the equivalent dose of an organ or tissue. The H_T, can be derived using the DCFs obtained from the simulation (Eq.3)(Hassan et al., 2021):

$$H_T = DCF \times A \times t \quad (3)$$

where *DCF* is the dose coefficient factor from Monte Carlo simulation, *A* is the activity concentration of the paint product and *t*, time exposed to the wall paint.

The dose equivalent from exposure to the ion paint samples was also measured using a calibrated IdentiFinder 2, FLIR Survey Meter. The exposure dose rates (in Sv h^{-1}) were recorded three times for each product, and the average was calculated, which was quoted along with the standard deviation. Finally, the radionuclides contained in the ion paint samples were identified.

3. Results and discussions

3.1. Activity concentration of ^{238}U, ^{232}Th, and ^{40}K in samples

Analysis of activity concentration for ^{238}U, ^{232}Th, and ^{40}K were conducted for 20 samples of paint and calculated using Eq. (1). Table 1 shows the data for the radioactivity in the wall paints, which shown ion paint IP04 had the highest activity, with values of 4449 ± 530, 31888 ± 2175, and 2963 ± 405 Bq kg^{-1}, from ^{238}U,

Table 1
Radioactivity (in Bq kg$^{-1)}$ of ^{238}U, ^{232}Th, and 40 K in the wall paint.

Sample	^{238}U	^{232}Th	^{40}K
Ion Paint			
IP01	2380 ± 280	24001 ± 1722	2178 ± 202
IP02	2087 ± 327	15648 ± 1069	1426 ± 207
IP03	1677 ± 264	16787 ± 1129	1418 ± 223
IP04	4449 ± 528	31888 ± 2175	2963 ± 405
IP05	1929 ± 248	18768 ± 1217	1749 ± 256
IP06	2239 ± 323	16044 ± 1097	1484 ± 246
IP07	2289 ± 324	16119 ± 1017	1508 ± 250
IP08	2419 ± 337	17158 ± 1205	1530 ± 245
IP09	2138 ± 258	21096 ± 1469	1923 ± 269
IP10	2549 ± 313	18152 ± 1270	1600 ± 231
Normal Paint			
NP11	39 ± 5	67 ± 4	327 ± 47
NP12	37 ± 4	62 ± 3	298 ± 44
NP13	47 ± 5	81 ± 6	366 ± 65
NP14	82 ± 4	91 ± 9	233 ± 41
NP15	68 ± 4	67 ± 7	189 ± 27
NP16	24 ± 3	40 ± 3	2605 ± 468
NP17	29 ± 3	211 ± 25	2443 ± 439
NP18	16 ± 2	30 ± 5	1834 ± 272
NP19	24 ± 2	38 ± 6	2293 ± 411
NP20	48 ± 8	87 ± 7	149 ± 21

^{232}Th, and ^{40}K, respectively. There were significant differences in radioactivity content among the ion paints. The variation of ^{238}U series activity was found to be between 1687 ± 264 and 4449 ± 528 Bq kg^{-1}, while the ^{232}Th series activity was between 15649 ± 1064 and 31888 ± 2175 Bq kg^{-1}. The variation of ^{40}K was found to be between 1418 ± 223 and 2963 ± 405 Bq kg^{-1}. Surprisingly, normal paint samples showed the least amount of activity, to the point where they could be safely considered non-radioactive from a legal standpoint. Meanwhile, all of the ion paint products contain the U and Th amount that exceeds the exemption limit of 1000 Bq kg^{-1} (IAEA, 2014a).

Four ion paint samples and two normal paint samples were analysed for elemental content using an ED-XRF spectrometer (Table 2). The six tested samples are primarily composed of Si, Ca, and Ti, and rare earth elements (REEs). Results showed that -NORM (U, Th and K) were found in the four ion paint samples, while in the two normal paint samples, only K has been found. In comparison to normal paint, no P was detected in any ion paint sample. It was also discovered that the rare earth element cerium (Ce) was found in IP04 and europium (Eu) in IP06 at concentrations of 0.09% and 0.26%, respectively. For safety reasons, it appears that the white material Ti has been used in place of lead. As a result, a trace amount of lead element was discovered in all six samples tested. IP04 had the highest concentrations of U, Th, and Pb, with 0.026%, 0.81%, and 0.06%, respectively. U and Th concentrations (and activities) in IP04 were 260 ppm (3211 Bq kg^{-1}), and 8100 ppm (32886 Bq kg^{-1}), respectively. The results for IP04, as shown in Tables 1 and 2, are consistent.

3.2. Equivalent dose analysis

The measured energy distribution from the use of the MIRD5 mathematical phantom code was applied as the probability distribution in the generation of the source on the Rooms 1 and 2 wall surfaces. Fig. 4 depicts the IP04 results for 28 organs/tissue, with the organ equivalent dose calculated using Eq. (3) based on the location of the MIRD5 male and female phantoms. The male and female phantoms were used in two different room simulations (Rooms 1 and 2), each with three various standing positions. Fig. 4 (a-c) depicts phantom standing positions from Room 1, whereas (d-f) depicts the standing position in Room 2.

The maximum organ/tissue equivalent dose was observed in Room 1 at 20 cm from the wall, while the minimum organ equivalent dose was observed in Room 2. The superficial organs/tissues, such as the lung, breast, rib cage, thymus, leg bone, and thyroid, were among the most exposed organs compared to deep organs. For example, in case (a), the most significant organ equivalent dose for IP04 was found to be to the lung, at 1.25 and 1.31 mSv y^{-1} for the male and female phantoms, respectively. The current GMC simulations are the only other known work on such material, apart from the previous study reported here (Yoo et al., 2015).

3.3. Annual effective dose analysis

By averaging the effective doses for the male and female phantoms using Eq. (2), the AED was calculated. It was assumed that a receptor would remain in the room for 8 h per day (UNSCEAR, 2000). In Room 1, with the phantom 20 cm from the wall, IP04 was associated with the most significant annual effective dose, at 1.51 mSv y^{-1}, whereas NP15 recorded the least yearly effective dose of 0.006 mSv y^{-1} (Table 3). These findings implied that the former has a yearly effective dose more significant than the annual dose limit of 1 mSv y^{-1} for public members (IAEA, 2016, 2014a). The effective dose was also discovered to be four times higher than that found in the centre of the same room.

Table 2
Elemental composition of the wall paint (ND: Non-Detectable, indicating below minimum detectable levels).

Element	Samples (in % concentration)					
	IP04	IP06	IP08	IP09	NP14	NP17
Mg	0.97	0.79	0.85	0.81	0.64	0.11
Al	1.12	0.65	0.4	0.88	0.75	1.3
Si	2.41	1.93	1.86	1.63	1.67	2.53
P	ND	ND	ND	ND	0.17	0.10
S	0.65	0.31	0.51	0.98	0.43	0.81
Ca	7.28	12.7	12.8	6.79	8.97	3.15
K	0.11	0.15	0.12	0.164	0.22	0.31
Ti	12.2	10.9	11.1	8.84	11.9	14.2
Ac	ND	ND	ND	ND	ND	0.06
Sr	0.04	0.08	0.09	0.04	0.03	0.01
Zr	0.41	0.39	0.45	0.37	0.11	0.06
U	0.026	0.022	0.019	0.017	ND	ND
Pb	0.06	0.03	0.03	0.04	0.02	0.03
Ce	0.09	ND	ND	ND	ND	ND
Th	0.81	0.46	0.44	0.53	ND	ND
Eu	ND	0.26	ND	ND	ND	ND
Ba	0.08	0.09	0.12	0.06	ND	ND

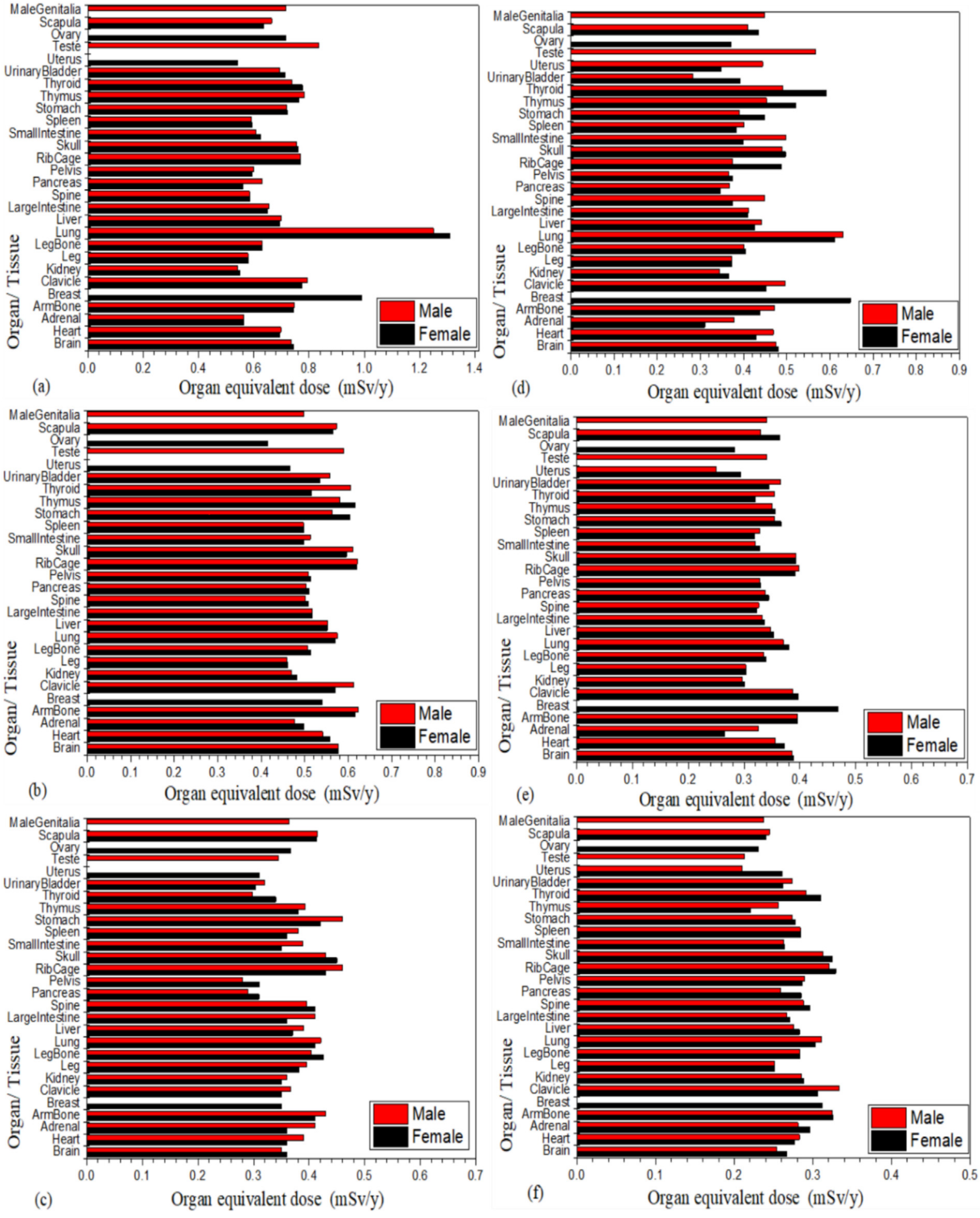

Fig. 4. Organ equivalent dose (in mSv y^{-1}) for 28 organs/tissue using the MIRD5 mathematical male and female phantoms in standing position, for Room 1; (a) 20 cm from the wall; (b) 50 cm from the wall; (c) in the centre of the room. Room 2; (d) 20 cm from the wall; (e) 50 cm from the wall; (f) in the centre of the room.

Furthermore, standing 20 cm from the wall in Room 1 was assessed to give 25% greater exposure than standing in Room 2 at the same distance. The AED was much lower than the limit set for a public member when one of the ten normal paint samples was used. The alpha emissions were absorbed mainly by the wall paint, with adequate air exchange posing no significant health risk. γ radiation, on the other hand, was profoundly penetrating, affecting large areas of tissue and organs. Here, it is worth noting that the internal dose was not included in the current assessment.

The dose equivalent was also determined for the ten ion paint samples, yielding AED of more than 1 mSv y^{-1}. A calibrated IdentiFinder 2, FLIR survey metre was used for this, recording dose rates in Sv h^{-1} and identifying the radionuclides contained within the paint samples (Table 4). IP04 presented the most effective dose

Table 3
AED (in mSv) associated with standing position using the twenty investigated paints.

Sample	Room 1			Room 2		
	20 cm from the wall	50 cm from the wall	Centre of the room	20 cm from the wall	50 cm from the wall	Centre of the room
Ion Paint						
IP01	1.124	0.582	0.241	0.714	0.531	0.221
IP02	0.735	0.381	0.161	0.462	0.335	0.148
IP03	0.794	0.431	0.171	0.514	0.391	0.163
IP04	1.513	0.824	0.341	0.964	0.732	0.321
IP05	0.871	0.473	0.182	0.563	0.421	0.172
IP06	0.781	0.421	0.163	0.507	0.381	0.154
IP07	0.763	0.392	0.159	0.487	0.362	0.149
IP08	0.803	0.431	0.178	0.515	0.396	0.165
IP09	0.981	0.517	0.212	0.625	0.489	0.201
IP10	0.861	0.464	0.191	0.545	0.421	0.172
Normal Paint						
NP11	0.0072	0.0045	0.0031	0.0069	0.0038	0.0022
NP12	0.0068	0.0041	0.0029	0.0063	0.0035	0.0021
NP13	0.0087	0.0051	0.0034	0.0081	0.0044	0.0025
NP14	0.0074	0.0048	0.0028	0.0068	0.0041	0.0022
NP15	0.0061	0.0039	0.0023	0.0054	0.0033	0.0017
NP16	0.0464	0.0035	0.0182	0.0371	0.0031	0.0118
NP17	0.0523	0.0321	0.0173	0.0413	0.0267	0.0112
NP18	0.0341	0.0171	0.0113	0.0261	0.0141	0.0082
NP19	0.0452	0.0175	0.0121	0.0336	0.0142	0.0104
NP20	0.0069	0.0043	0.0024	0.0051	0.0033	0.0016

Table 4
Dose rate and annual dose of radioactivity in the wall paint, using survey meter (IdentiFinder 2) portable detector.

No.	Sample	Dose rate (μSv h^{-1})	Annual dose (mSv y^{-1})
1	IP01	0.409 ± 0.03	1.194
2	IP02	0.344 ± 0.02	1.004
3	IP03	0.381 ± 0.03	1.112
4	IP04	0.571 ± 0.07	1.667
5	IP05	0.416 ± 0.05	1.214
6	IP06	0.390 ± 0.04	1.138
7	IP07	0.373 ± 0.03	1.089
8	IP08	0.377 ± 0.04	1.100
9	IP09	0.387 ± 0.03	1.130
10	IP10	0.371 ± 0.03	1.083

equivalent, at 0.571 ± 0.07 μSv h^{-1}. Assuming daily exposure time of 8 h, the annual dose reached 1.67 mSv y^{-1}, which is comparable to the GMC results.

The use of radioactive materials in consumer products is typically regulated in developed countries. “Evaluation of EPA’s guideline for TENORM” is an example from the United States (EPA, 2000). While Malaysia’s Atomic Energy Licencing Board (AELB) has published consumer product guidelines titled “LEM/TEK/69” (AELB, 2016), there is still a need for safe control in the use of NORM-added consumer products. Unjustified exposures, as described in ICRP-103 (ICRP, 2007), can be applied to various consumer products. Suppose the benefits of using a consumer product to which NORM has been added cannot be demonstrated to outweigh the risks. In that case, a ban is required (EURATOM, 2013; Furuta, 2011), as appears to be the case for the currently investigated ion paint products. Consequently, a strong recommendation is made to prohibit the marketing and distribution of ion paint products in Malaysia.

4. Conclusions

This study investigated the radioactivity of 20 ion and normal paint products using an HPGe detector. All ion paint samples showed much greater activity compared with normal paint samples. Paint code IP04 indicated the highest level of radioactivity of ^{238}U, ^{232}Th, and ^{40}K. A simulation implementing the GMC method was used to identify the organ equivalent and AED. Our finding revealed that using ion paint for the walls of modest-sized residential rooms can result in an AED of up to 1.5 mSv y^{-1}, exceeding the annual dose limit of 1 mSv y^{-1} recommended by the IAEA for public exposure. The addition of radioactive materials in the ion paint products is claimed to enhance the supposed functionality of the product, albeit with practically no consideration given to the health risks posed to consumers. In Malaysia, ion paint products are available for public purchase without any information being provided indicating that the product contains NORM-added media. It is important to review the concentration of radioactivity in the paint products to better evaluate the risk of harm from their use. Ion paint products exceeding the recommended exemption levels without further justification should be subject to control, currently with an absence of conclusive studies showing advantages outweighing risks. With potential for internal and external radiation exposures, prolonged use of such consumer products should be a matter of concern. In this view, as ion paint products surpass the exemption dose limit and are unable to demonstrate the benefits over risks, we strongly recommend that AELB, as the regulatory body for Malaysia, prohibit the importation or sale of these ion paint products.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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