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ORIGINAL PAPER

Radiation safety of calcium and magnesium diet supplements*

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Abstract

Heavy metal contamination of food products has recently become a significant health concern. The widespread availability of dietary supplements increases the interest of health-conscious consumers in these food products. As a result, the consumption of dietary supplements is growing worldwide owing to their potential health benefits. However, dietary supplements may also contain other elements, including toxic ones, and thus affect human health. Previous studies have shown that they contain the radionuclides polonium, lead, uranium, and thorium, making them a source of internal exposure related to the decay of the isotopes studied. For this reason, the radiation safety associated with the presence of the radioactive isotopes ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th in calcium and magnesium supplements for adults was estimated, namely the cancer risk associated with their consumption and the risk of cancer-related death. Cancer morbidity and mortality risk ranged from 10^{-5} to 10^{-10}. The highest cancer risk morbidity and mortality was calculated for ^{210}Po and ^{210}Pb due to higher activities and radiotoxicity. The effect of the lower concentrations of ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th in the supplements analyzed is a significantly lower risk of cancer due to their consumption and activities in the product. The study showed that both effective doses and cancer risks were low, and calcium and magnesium supplements can be considered safe for human consumption.

Keywords: dietary supplements, calcium, magnesium, radionuclides, cancer risk

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INTRODUCTION

Heavy metal contamination of food products has recently become a significant health concern. The toxic heavy metals of greatest concern are mainly cadmium, lead, and mercury (Trojanowski et al. 2010). However, dietary supplements can also contain other elements, including radioactive ones, and thus affect human health. Radioactivity was discovered over 100 years ago, while artificial radioactive contamination became a reality in July 1945. Nevertheless, radionuclides occur naturally and artificially in the environment, and ionizing radiation accompanies us throughout our lives. Natural radioactivity accounts for about 70% of the total effective dose received by populations from all available sources (natural and artificial ones) worldwide, while in Poland, it is 75% (Jagielak et al. 1997). Therefore, the EU Council stated that the protection against natural radiation sources should be fully integrated within the requirements (Euratom 2013). Radiological monitoring is essential, although still underestimated in the scientific world compared to other contaminants, especially in food products.

The radioactivity phenomenon is nuclear decay, a spontaneous decay, and transformation of unstable atomic nuclei with the emission of radiation (nuclear radiation) – L'Annunziata (2016). From the radio-toxicologist's point of view, the most important nuclides are the medium- and long-living alpha- and next beta-radioactive isotopes (Strumińska-Parulska, Falandysz 2020). In alpha decay (α), an atomic nucleus produces an alpha particle and changes into a different atomic nucleus. Alpha particles interact with other atoms because of their large mass and low speed. The high mass and charge of alpha particles, compared to other forms of nuclear radiation, give them greater ionization power but the penetration depth is much smaller (L'Annunziata 2016). Beta (ß) particles are considered medium penetrating and ionizing compared to alpha emitters. However, some features are common to both beta and alpha radiation: continuous energy loss along their path, dissipation of ionizing energy, and excited atoms during their passage. Sufficient external intensity of alpha or beta-radiation can generate burns, like extreme sunburn. If alpha or beta emitters are ingested or inhaled, they can also damage internal cells and organs in several ways. This radiation can cause the early death of cells, prevent or delay cell division, alter cell properties, and pass these changes onto daughter cells. The hazard of cell damage is small at typical environmental levels of radiation or occupational radiation doses. Hence, late effects (stochastic) of lower doses are mostly precancerous mutations (Strumińska-Parulska et al. 2021). Thus, as particulate radiation, beta emitters play an essential role in internal exposure to radioactive elements (L'Annunziata 2016). Therefore, ingesting an alpha emitter and its access to human or animal internal organs could be of high concern if a food source is contaminated (Strumińska-Parulska, Falandysz 2020).

The most important sources of natural background radiation are potassium ^{40}K and the natural radioactive series of uranium ^{238}U and thorium ^{232}Th, as these radionuclides are the main source of internal exposure entering the body with food and water. Among them, alpha particle emitters play the most significant role. They are highly radiotoxic to the body due to their strong ionization ability, and can be a source of high doses of radiation against cells or tissues locally in the body. Therefore, food and air are the most significant sources of internal radiation dose (UNSCEAR, 2000). The isotopes ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th occur naturally in nature and are therefore inherent in all components of the surrounding environment. Among them, only ^{210}Pb is a beta-emitting nuclide (decay energy of 0.06 MeV), while the rest are alpha emitters with high decay energies (4.08-5.32 MeV). The isotopes of uranium (^{234}U, ^{238}U) and thorium (^{230}Th, ^{232}Th) occur naturally on Earth in the form of chemical compounds; the concentration of uranium in the Earth's crust is 1.8 ppm (e.g., in granite 2-10 mg kg^{-1} of rock), while the concentration of thorium is about six times that of uranium at 12 ppm. ^{210}Po and ^{210}Pb are among the most radiotoxic nuclides, but their concentrations in uranium ores are relatively low (7.4×10^{-11} g ^{210}Po / g ^{238}U) – Keller et al. (2002). At present, natural ^{210}Po is thought to be one of the most hazardous radioisotopes; 10 000 times more toxic than hydrogen cyanide, and together with the botulinum toxin, it is one of the most poisonous substances ever known (Ansoborlo 2014).

Calcium and magnesium are among the most essential elements in living organisms, especially vertebrates. An adult's body contains about 1.2 kg of calcium, and 99% of this amount is found in bones and teeth. Conversely, magnesium accounts for about 0.05% of total body weight (22-35 g), 60% of which is in the skeleton. Dietary recommendations for adults' daily calcium intake are 1 g, while magnesium's recommended amount is 300-400 mg (Ross et al. 2011, Watson et al. 2013). Vitamin and mineral deficiencies are commonly observed due to changes in dietary habits. Calcium intake among Polish residents covers 58-60% of recommended values (Dybkowska et al. 2004), and hypomagnesemia is also common (Ayuk, Gittoes 2014, Majewski, Kucharczyk 2018). Therefore, calcium and magnesium supplements, which many of us are familiar with, have become extremely popular and are the second most commonly taken group of dietary supplements available on the market (Suplindex 2017).

Nowadays, more and more attention is being paid to what we eat (Yoon, Choi 2023). We care about healthy food, but the average knowledge of its radiological effects needs to be improved, and their consequences should be considered. Previous studies have shown that calcium and magnesium supplements can significantly source ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th in the daily diet. Therefore, this study aimed to evaluate the radiotoxicity of selected calcium and magnesium supplements for adults available on the Polish market by calculating the risk of cancer or cancer-related death and thus determining their radiological safety.

MATERIALS AND METHODS

The study included 17 calcium supplements and 18 magnesium supplements for adults available on the Polish market. The medicaments were purchased at a pharmacy, and the calcium supplement samples analyzed ranged in weight from 4 to 35 g and contained 375 to 6000 mg of pure Ca. In comparison, the magnesium supplement samples ranged in weight from 4 to 31 g and had 17 to 375 mg of pure Mg (Table 1).

Table 1

Characteristics of the analyzed calcium and magnesium supplements
(list of supplement manufacturers available from the authors on request)

Sample ID	Chemical form	Ca / Mg content in 1 tablet (mg)
Ca1	calcium gluconate	45
Ca2	calcium lactate*	350
Ca3	calcium carbonate	500
Ca4	calcium pantothenate	15
Ca5	calcium carbonate*	300
Ca6	calcium diglycynate	280
Ca7	calcium carbonate (dolomite)	108
Ca8	calcium carbonate (mussel shells)	600
Ca9	calcium lactate*	180
Ca10	calcium carbonate*	300
Ca11	calcium carbonate	250
Ca12	calcium carbonate,	260
Ca13	calcium lactate*	500
Ca14	calcium carbonate	120
Ca15	mineral extract from fish	180
Ca16	calcium lactate*	400
Ca17	calcium carbonate (chalk)	500
Mg1	magnesium carbonate	300
Mg2	magnesium dioxide	375
Mg3	magnesium chloride	64
Mg4	magnesium carbonate	120
Mg5	magnesium dioxide	375
Mg6	magnesium heavy oxide	150
Mg7	magnesium lactate	51
Mg8	magnesium lactate	51
Mg9	magnesium citrate	60
Mg10	magnesium chelate	100
Mg11	magnesium chelate	94
Mg12	magnesium aspartate	17
Mg13	magnesium aspartate, mg carbonate	18
Mg14	magnesium aspartate	17
Mg15	magnesium aspartate	40
Mg16	magnesium dioxide (from the dead) sea)	375
Mg17	magnesium carbonate (dolomite)	64
Mg18	magnesium dioxide	56

* soluble

Polonium was determined by its direct deposition on silver plates, and ^{210}Pb lead was determined indirectly. Uranium and thorium fractions were isolated and purified on ion-exchange resins, and measurement preparations were prepared by electrolysis. The activity of ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th isotopes was measured radiometrically on an alpha spectrometer (Strumińska-Parulska 2015, 2016*a*, *b*, 2017, Moniakowska et al. 2019, 2022). Based on the previously obtained results of ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th activity in supplements, the magnitude of the risk of cancer morbidity and mortality were calculated for a life expectancy of 50 years for an adult assuming that they take one tablet per day or the recommended value of daily intake (RDI) calcium (1000 mg) or magnesium (400 mg) using Equation 1.

$$R = A \cdot c_r \cdot 50 \cdot 365,$$

where: R – risk of morbidity or mortality from cancer resulting from exposure to ionizing radiation emitted by the radioisotope;
A – activity of radioisotope in 1 tablet or relative to the value of recommended daily intake (Bq);
c_r – conversion coefficient (cancer risk coefficient) for radioisotope (Bq^{-1}),
$50 \cdot 365$ – consumption of supplements for 50 years per day (365 days per year).

The conversion coefficient values for determining cancer risk morbidity are 6.09×10^{-8} Bq^{-1} (^{210}Po), 3.18×10^{-8} Bq^{-1} (^{210}Pb), 2.58×10^{-9} Bq^{-1} (^{234}U), 2.34×10^{-9} Bq^{-1} (^{238}U), 3.22×10^{-9} Bq^{-1} (^{230}Th), 3.60×10^{-9} Bq^{-1} (^{232}Th), while for the calculation of cancer risk mortality they take the value: 4.44×10^{-8} Bq^{-1} (^{210}Po), 2.31×10^{-8} Bq^{-1} (^{210}Pb), 1.66×10^{-9} Bq^{-1} (^{234}U), 1.51×10^{-9} Bq^{-1} (^{238}U), 2.16×10^{-9} Bq^{-1} (^{230}Th), and 2.45×10^{-9} Bq^{-1} (^{232}Th) – EPA (1999).

RESULTS AND DISCUSSION

Previous studies have shown that calcium and magnesium supplements can be a significant source of ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th for their consumers. Supplements of natural origin, mainly dolomite and chalk (sedimentary rocks), which are the most considerable source of natural radionuclides, are the most important. The highest effective doses come from the decay of ^{210}Po and ^{210}Pb contained in calcium supplements and were estimated at 2.52 μSv $year^{-1}$ and 1.19 μSv $year^{-1}$ for the consumption of 1 tablet of the preparation per day (Strumińska-Parulska, 2015, 2016*a*). Magnesium supplements also had the highest effective doses from the decay of ^{210}Po and ^{210}Pb, namely 1.35 μSv $year^{-1}$ and 0.593 μSv $year^{-1}$ (Strumińska-Parulska 2016*b*, 2017). The content of uranium and thorium is much lower than polonium and radiolead. The values of effective doses resulting from the decay of these isotopes contained in 1 tablet in earlier studies were calculated to be 246 and 230 nSv year^{-1} for ^{234}U and ^{238}U, and 820 and 59.7 nSv year^{-1} for ^{230}Th and ^{232}Th contained in calcium supplements. In contrast, the values of effective doses from the decay of uranium and thorium isotopes contained in magnesium supplements were estimated at 66.7 and 71.9 nSv year^{-1} for ^{234}U and ^{238}U, and 310 and 39.1 nSv year^{-1} for ^{230}Th and ^{232}Th (Moniakowska et al. 2019, 2022). The estimated values of effective doses appear low relative to the total annual effective dose. Still, a deeper analysis indicated that calcium and magnesium supplements might be the source of an additional 25% of the value of the dose received from the decay of ^{210}Po and 10% of the dose derived from the decay of ^{210}Pb ingested with food. When consumed with the supplements analyzed, ^{234}U and ^{238}U can increase the value of the received effective dose by nearly two times its content in the daily diet, while ^{230}Th and ^{232}Th can increase the value of the received effective dose by up to 9 times (Strumińska-Parulska 2015, 2016*a*, *b*, 2017, Moniakowska et al. 2019, 2022).

Because of the significant effects of the radioisotopes ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th present in calcium and magnesium supplements on the effective doses resulting from their decay, the magnitude of the risk of cancer or death from cancer was investigated for a life expectancy of 50 years for an adult assuming two scenarios that the consumers take either one supplement tablet per day or the recommended value of the daily requirement (recommended daily intake) for calcium (1000 mg) or magnesium (400 mg). The pioneering results show that the risk values vary widely, with the highest calculated for ^{210}Po and the lowest for ^{230}Th and ^{232}Th (Figures 1-4).

Risk of cancer morbidity

Suppose a consumer takes one tablet of a calcium supplement; the magnitude of the risk of developing cancer due to consuming the ^{210}Po ranges from $1.00x10^{-7}$ to $6.39x10^{-6}$. At the same time, for ^{210}Pb, it varies from $6.09x10^{-7}$ to $1.28x10^{-5}$, and when they wish to take the recommended daily intake, the risk increases to $3.21x10^{-5}$ for ^{210}Po and $1.28x10^{-5}$ for ^{210}Pb. The effect of the lower concentrations of ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th in the supplements analyzed is a significantly lower risk of cancer due to their consumption. If a single tablet of a calcium supplement is taken, the magnitude of the risk of disease as a result of consuming the ^{234}U and ^{238}U present there ranges from $1.29x10^{-8}$ to $6.48x10^{-7}$, while for ^{230}Th and ^{232}Th, it ranges from $6.05x10^{-10}$ to $6.29x10^{-7}$. If the consumer wishes to take the recommended daily intake, the risk rises to $1.73x10^{-6}$ for ^{234}U and ^{238}U and $2.21x10^{-6}$ for ^{230}Th and ^{232}Th (Figure 1).

Magnesium supplements have much lower activity concentrations of ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th, and as a result, the risk associated with their consumption is also lower. If a single tablet of magnesium supplement is taken, the magnitude of the risk of cancer-related death as a result of the ^{210}Po content ranges from $9.00x10^{-8}$ to $3.42x10^{-6}$, while for ^{210}Pb it ranges

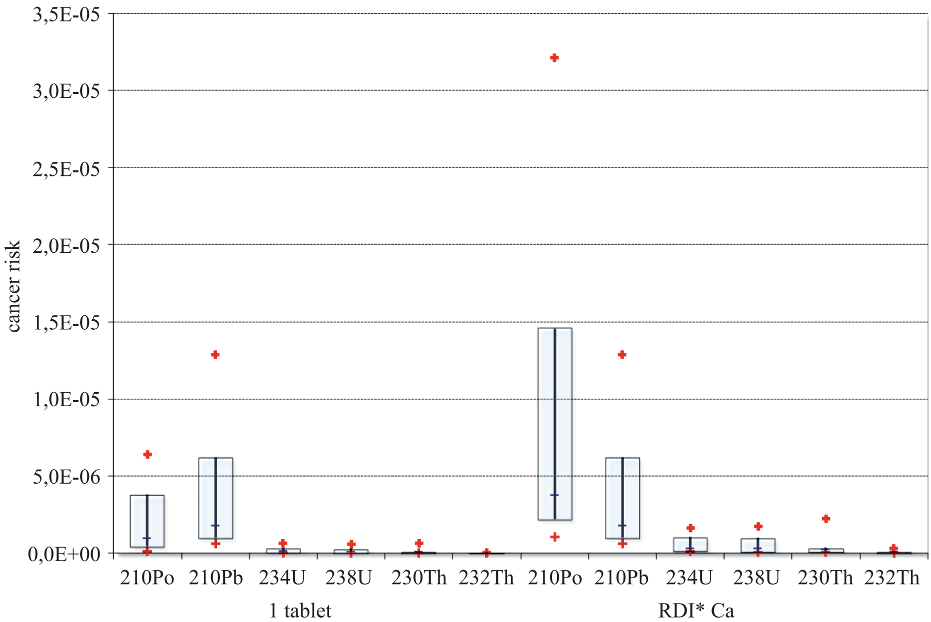

Fig. 1. Cancer risk morbidity values due to intake of ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th over 50 years of life with calcium supplements consumed – 1 tablet per day and *RDI – recommended daily intake (1 g)

from 6.11x10^{-8} to 8.67x10^{-6}. In contrast, if the consumer wishes to take the recommended daily intake, the risk rises to 2.15x10^{-5} for ^{210}Po and 8.67x10^{-6} for ^{210}Pb. Also, concerning magnesium supplements, radioisotopes ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th are present in them in much smaller amounts, resulting in a lower risk of death from cancer as a result of their consumption. If one tablet of a calcium supplement is taken, the magnitude of the risk of death as a result of consuming the ^{234}U and ^{238}U present there ranges from 1.35x10^{-9} to 1.87x10^{-7}, while for ^{230}Th and ^{232}Th, it ranges from 5.14x10^{-10} to 2.38x10^{-7}. If the consumer wishes to take the recommended daily intake, the risk increases to 1.17x10^{-6} for ^{234}U and ^{238}U and 1.49x10^{-6} for ^{230}Th and ^{232}Th (Figure 2).

Risk of cancer mortality

Due to the lower conversion coefficients, the risk of cancer-related death is significantly lower. If one tablet of a calcium supplement is taken, the magnitude of the risk of cancer-related death from consuming the ^{210}Po present there ranges from 1.38x10^{-7} to 4.66x10^{-6}, while for ^{210}Pb it varies from 4.64x10^{-8} to 1.99x10^{-6}. In contrast, if the consumer wishes to take the recommended daily intake, the risk rises to 2.34x10^{-5} for ^{210}Po and 9.32x10^{-6} for ^{210}Pb. As in calcium supplements, the radioisotopes ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th are in much smaller amounts, resulting in a much lower risk of cancer death due to their consumption. If a single tablet of a calcium supplement

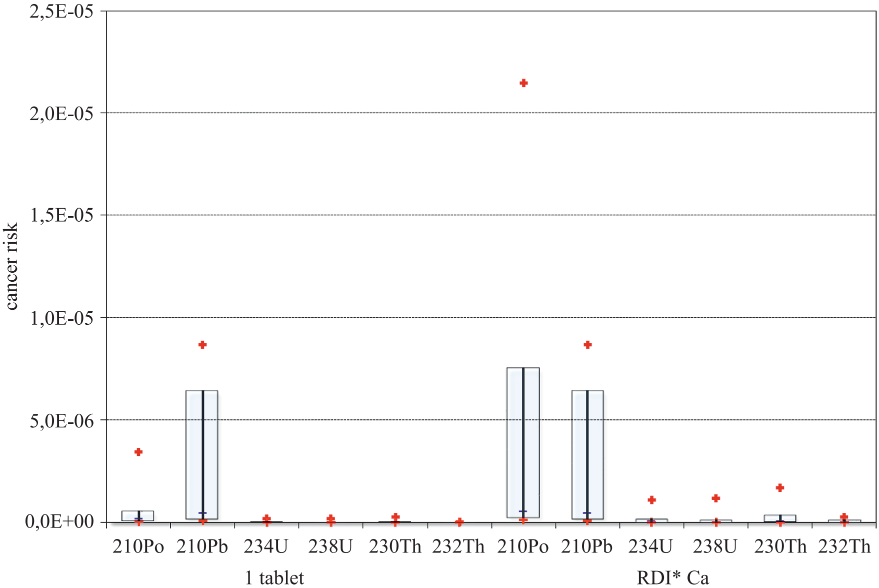

Fig. 2. Cancer risk morbidity values due to intake of ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th over 50 years of life with magnesium supplements consumed – 1 tablet per day and *RDI – recommended daily intake (0.4 g)

is taken, the magnitude of the risk of death as a result of consuming the ^{234}U and ^{238}U present ranges from 8.33x10^{-9} to 1.13x10^{-7}, while for ^{230}Th and ^{232}Th, it ranges from 2.50x10^{-9} to 4.17x10^{-7}. If the consumer wishes to take the recommended daily intake, the risk rises to 1.05x10^{-6} for ^{234}U and ^{238}U and 1.04x10^{-6} for ^{230}Th and ^{232}Th (Figure 3).

Magnesium supplements have much lower risk values associated with their consumption. If one tablet of a magnesium supplement is taken, the magnitude of the risk of cancer-related death as a result of the ^{210}Po contained ranges from 1.46x10^{-8} to 1.27x10^{-6}, while for ^{210}Pb it ranges from 1.05x10^{-8} to 1.01x10^{-6}. In contrast, if the consumer wishes to take the recommended daily intake, the risk rises to 1.56x10^{-5} for ^{210}Po and 6.30x10^{-6} for ^{210}Pb. Also, regarding magnesium supplements, the radioisotopes ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th are in much smaller amounts, resulting in a lower risk of cancer death due to their consumption. If one tablet of a calcium supplement is taken, the magnitude of the risk of death as a result of consuming the ^{234}U and ^{238}U present there ranges from 8.69x10^{-10} to 1.21x10^{-7}, while for ^{230}Th and ^{232}Th, it ranges from 5.84x10^{-10} to 1.60x10^{-7}. If the consumer wishes to take the recommended daily intake, the risk rises to 7.54x10^{-7} for ^{234}U and ^{238}U and 1.13x10^{-6} for ^{230}Th and ^{232}Th (Figure 4).

The risk of cancer incidence or death associated with consumption of the calcium and magnesium supplements analyzed was calculated in the range of 10^{-5} to 10^{-10}. The results are lower than the risk values obtained for ^{210}Po and ^{210}Pb in dietary supplements containing algae, which were determined

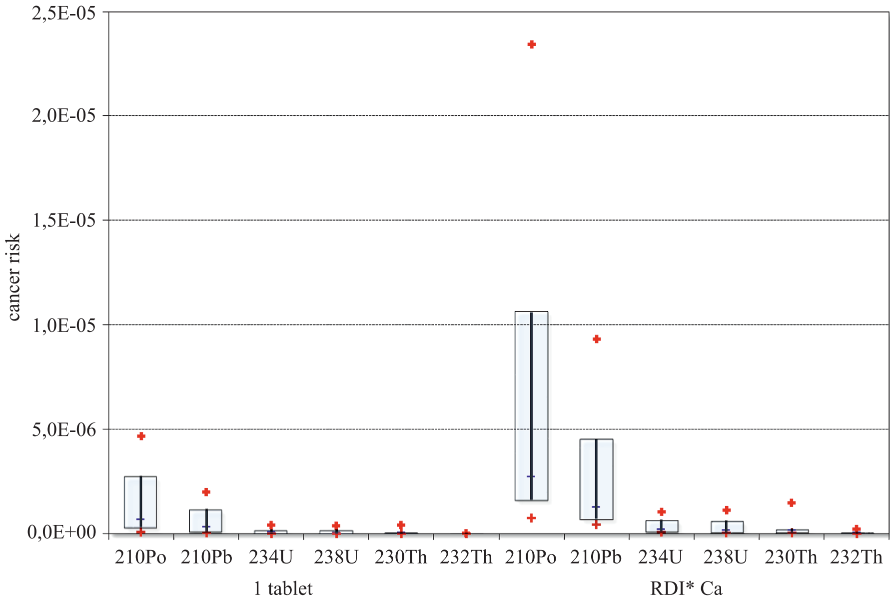

Fig. 3. Cancer risk mortality values due to intake of ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th over 50 years of life with calcium supplements consumed – 1 tablet per day and *RDI – recommended daily intake (1 g)

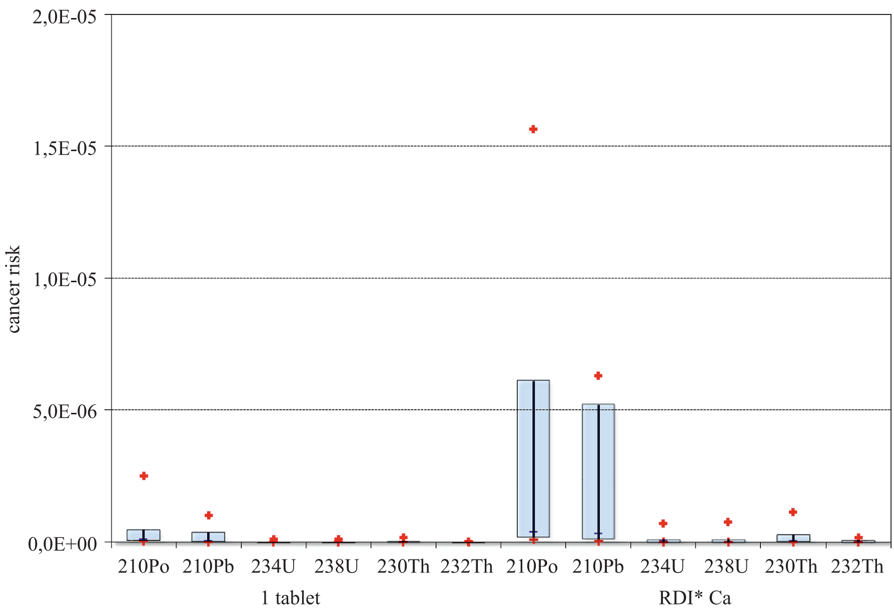

Fig. 4. Cancer risk mortality values due to intake of ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th over 50 years of life with magnesium supplements consumed – 1 tablet per day and *RDI – recommended daily intake (0.4 g)

in the range of 10^{-4} to 10^{-8} (Zhang et al. 2023). Similar risk values, in the range of 10^{-4} to 10^{-5}, were estimated for ^{210}Po and ^{210}Pb contained in wild medicinal herbs from Poland and Ukraine (Moniakowska et al. 2023, 2024). Based on the data given by different authors (Pietrzak-Flis et al. 1997, Skwarzec et al. 2001*a*, *b*, *c*, 2003, 2004), it was possible to evaluate the risk of cancer or death from cancer caused by ionizing radiation from the decay of the studied radionuclides present in the total diet of Polish inhabitants or certain food products. According to the literature, the highest risk of developing cancer comes with ^{210}Po presence in cigarettes at 2.13x10^{-4}, while the risk of cancer-related death ranged 1.54x10^{-4} (Table 2).

The study showed that the obtained values for the risk of cancer or death caused by ionizing radiation from the decay of radioactive isotopes ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th seem low. Some of the analyzed supplements would cause a cancer risk at the level estimated for typical food products. However, most of them show much lower values of cancer morbidity or mortality hazard. Thus, the analyzed calcium and magnesium supplements can be considered as safe products for human consumption.

Table 2

The radiation risk connected with the presence of ^{210}Po, ^{210}Pb, ^{234}U, and ^{238}U in Polish food, calculated based on available data

Food product	Average cancer risk		Reference
	morbidity	mortality	
Total diet			Pietrzak-Flis et al. (1997)
^{210}Po	1.33x10^{-4}	9.72x10^{-5}	
^{210}Pb	7.22x10^{-5}	5.24x10^{-5}	
Drinking water			Skwarzec et al. (2001*a*)
^{210}Po	7.31x10^{-7}	5.33x10^{-7}	
^{234}U	1.84x10^{-8}	1.19x10^{-7}	
^{238}U	1.61x10^{-7}	1.04x10^{-7}	
Mineral water			Skwarzec et al. (2003)
^{210}Po	1.22x10^{-5}	8.88x10^{-6}	
^{234}U	3.23x10^{-7}	2.08x10^{-7}	
^{238}U	2.93x10^{-7}	1.89x10^{-7}	
Beer			Skwarzec et al. (2004)
^{210}Po	9.44x10^{-7}	6.88x10^{-7}	
^{234}U	3.48x10^{-8}	2.24x10^{-8}	
^{238}U	3.86x10^{-8}	2.49x10^{-8}	
Cigarettes			Skwarzec et al. 2001*b*, *c*
^{210}Po	2.13x10^{-4}	1.56x10^{-4}	

CONCLUSIONS

The study aimed to evaluate the radiotoxicity of selected calcium and magnesium supplements for adults available on the Polish market by calculating the cancer risk morbidity and mortality and assessing their radiological safety. The risk of cancer or death caused by ionizing radiation from the decay of radioactive isotopes ^{210}Po, ^{210}Pb, ^{234}U, ^{238}U, ^{230}Th, and ^{232}Th was calculated and ranged 10^{-5}-10^{-10}. The calcium and magnesium supplements analyzed in this study and dedicated for human consumption can be considered as safe products from the radiation protection point of view.

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Authors' contribution

Conceptualization and methodology – D.S.-P., formal analysis – A.M. and. K.B., investigation – D.S.-P., resources – D.S.-P., data curation – D.S.-P., writing – original draft preparation – D.S.-P., writing – review and editing – A.M. and K.B., visualization – D.S.-P.

Conflicts of interest

The authors of this study declare no conflict of interest.

Data availability statement

Data are available on request from the authors. The raw data supporting this study's findings and sample information are available from the corresponding author upon reasonable request.

REFERENCES

Ansoborlo, E. (2014). Poisonous polonium. *Nature Chem.*, 6, 454. https://doi:10.1038/nchem.1928

Ayuk, J. and Gittoes, N.J. (2014). Contemporary view of the clinical relevance of magnesium homeostasis. *Ann. Clin. Biochem.*, 51, 179-188. https://doi.org/10.1177/0004563213517628

Dybkowska, E., Świderski, F., and Waszkiewicz-Robak, B. (2004). Mineral components intake in average diet of Warsaw adult inhabitants in the comparison with Polish diet. *Ann. Univ. Mariae Curie-Skłodowska*, 2004, Sect. D LIX, SUPPL.

EPA – US Environmental Protection Agency. (1999). Cancer Risk Coefficients for Environmental Exposure to Radionuclides, Federal Guidance Report No. 13. Office of Radiation and Indoor Air United States Environmental Protection Agency, Washington, USA.

Euratom. (2013). Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32013L0059

Jagielak, J., Biernacka, M., Henschke, A., and Sosińska, A. (1997). Radiologiczny Atlas Polski, PIOŚ, CLOR, PAA, Warszawa: Biblioteka Monitoringu Środowiska.

Keller, C., Wolf, W., and Shani, J. (2002). Radionuclides, 2. Radioactive Elements and Artificial Radionuclides. *Ullmann's Encyclopedia of Industrial Chemistry*, T. 31. Wiley-VCH.

L'Annunziata, M.F. (2016). Radioactivity. Elsevier Science. Amsterdam. https://doi.org/10.1016/B978-0-444-52715-8.X5000-2.

Majewski, M., and Kucharczyk, E. (2018). Dietary magnesium intake in the Polish population of oncological patients. *J. Elem.*, 23(1), 85-93. http://dx.doi.org/10.5601/jelem.2017.22.2.1274

Moniakowska, A., Dzierwanowska, A., and Strumińska-Parulska, D. (2019). On uranium ^{234}U and ^{238}U radionuclides in calcium and magnesium supplements and the potential effective radiation dose assessment to the consumers. *Food Addit. Contam. Part B*, 12, 175-181. https://doi.org/10.1080/19393210.2019.1588388

Moniakowska, A., Block, K., and Strumińska-Parulska, D. (2022). Determination of natural thorium isotopes (^{230}Th and ^{232}Th) in calcium and magnesium supplements and the potential effective exposure radiation dose for humans. *J. Food Comp. Anal.*, 105, 104263. https://doi.org/10.1016/j.jfca.2021.104263

Moniakowska, A., Konieczyński, P., Block, K., Lysiuk, R., Shapovalova, N., and Strumińska--Parulska, D. (2023). The presence of radiotoxic ^{210}Po and ^{210}Pb in Ukrainian wild medicinal plants and the assessment of related dose and cancer risk. *J. Environ. Quality*, 53, 378-389. https://doi.org/10.1002/jeq2.20555

Moniakowska, A., and Strumińska-Parulska, D. (2024). Assessing cancer risk and radiological effects from ^{210}Po and ^{210}Pb with consumption of wild medicinal herbal plants. *J. Trace Elem. Med. Biol.*, 84, 127452. https://doi.org/10.1016/j.jtemb.2024.127452.

Pietrzak-Flis, Z., Chrzanowski, E., and Dembinska, S. (1997) Intake of ^{226}Ra, ^{210}Pb and ^{210}Po with food in Poland. *Sci. Total Environ.*, 203(2), 157-165. https://doi.org/10.1016/S0048-9697(97)00144-7

Ross, A.C., Taylor, C.L., Yaktine, A.L., and Del Valle, H.B. (2011). *Dietary Reference Intakes for Calcium and Vitamin D*. Institute of Medicine, The National Academy Press, Washington DC.

Skwarzec, B., Strumińska, D.I., and Boryło, A. (2001a) The radionuclides ^{234}U, ^{238}U and ^{210}Po radionuclides in drinking water in Gdańsk agglomeration (Poland). *J. Radioanal. Nucl. Chem.*, 250(2), 250, 315-318,. https://doi.org/10.1023/A:1017903814852

Skwarzec, B., Strumińska, D.I., Boryło, A., and Ulatowski, J. (2001b) Polonium in cigarettes produced in Poland. *J. Env. Sci. Health A*, 36, 465-474. https://doi.org/10.1081/ESE-100103476

Skwarzec, B., Ulatowski, J., Strumińska, D.I., and Boryło, A. (2001c) Inhalation of ^{210}Po and ^{210}Pb from cigarette smoking in Poland. *J. Environ. Radioact.*, 57, 221-230. https://doi.org/10.1016/S0265-931X(01)00018-2

Skwarzec, B., Strumińska, D.I. and Boryło, A. (2003) Radionuclides of ^{210}Po, ^{234}U and ^{238}U in drinking bottled mineral water in Poland. J. Radioanal. Nucl. Chem., 256, 361-364. https://doi.org/10.1023/A:1023970308882

Skwarzec, B., Strumińska, D.I., Boryło, A., and Falandysz, J. (2004) Intake of radionuclides of ^{210}Po, ^{234}U and ^{238}U with beer in Poland. *J. Radioanal. Nucl. Chem.*, 261(3), 661-663. https://doi.org/10.1023/B:JRNC.0000037110.93853.91

Strumińska-Parulska, D.I. (2015). Determination of ^{210}Po in calcium supplements and the possible related dose assessment to the consumers. *J. Environ. Radioact.*, 150, 122-125. https://doi.org/10.1016/j.jenvrad.2015.08.006

Strumińska-Parulska, D.I. (2016a). Radiolead ^{210}Pb and ^{210}Po/^{210}Pb activity ratios in calcium supplements and the assessment of their possible dose to consumers. *J. Environ. Sci. Heal. Part A*, 51(10), 851-854. https://doi.org/10.1080/10934529.2016.1181457

Strumińska-Parulska, D.I. (2016b). Radioactive ^{210}Po in magnesium supplements. *Radiochim. Acta*, 104(5), 321-325. https://doi.org/10.1515/ract-2015-2520

Strumińska-Parulska, D.I. (2017). ^{210}Pb in magnesium dietary supplements. *Isotopes Environ. Health Stud.*, 53(2), 111-115. https://doi.org/10.1080/10256016.2016.1207639

Strumińska-Parulska, D., and Falandysz, J. (2020). A review of the occurrence of alpha-emitting radionuclides in wild mushrooms. *Int. J. Environ. Res. Pub. Health*, 17(21), 8220. https://doi.org/10.3390/ijerph17218220.

Strumińska-Parulska, D., Falandysz, J., Moniakowska, A. (2021). Beta-emitting radionuclides in wild mushrooms and potential radiotoxicity for their consumers. Trends in Food Sci. & Tech., 114, 672-683. https://doi.org/10.1016/j.tifs.2021.06.015

Suplindex; Suplementy diety – pacjent, rynek, trendy, regulacje. (2017).

Trojanowski, P., Trojanowski, J., Antonowicz, J., and Bokiniec, M. (2010). Lead and cadmium content in human hair in central Pomerania (northern Poland). *J. Elementol.*, 15(2), 363-384.

UNESCAR – United Nations Scientific Committee on the Effects of Atomic Radiation. (2000). *Sources and effects of ionizing radiation*. United Nations, New York.

Watson, R.R., Preedy, V.R., and Zibadi, S. (2013). *Magnesium in Human Health and Disease*. Humana Press.

Yoon, S.H., and Choi, M.-K. (2023). Dietary intake of minerals (Ca, P, Na, K, Mg, Fe, Zn, Cu, Mn, I, Se, and Mo) in young Korean adults with a self-selected diet. *Journal of Elementology*, 28(3), 671-685. http://dx.doi.org/10.5601/jelem.2023.28.3.2394

Zhang, D., Niemczyk, A., Moniakowska, A., Block, K., Olszewski, G., and Strumińska-Parulska, D. (2023). On ^{210}Po and ^{210}Pb in algae diet supplements - The assessed radiation hazard of aquatic superfoods. *Mar. Pollu. Bull.*, 188, 114591. http://dx.doi.org/10.1016/j.marpolbul.2023.114591