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ESTIMATION OF RADIOACTIVITY DOSE RATE ABSORBED WITH INGESTED FOODS

BADANIE WCHŁONIĘTEJ SKUTECZNEJ DAWKI PROMIENIOWANIA OTRZYMANEJ WRAZ ZE SPOŻYWANĄ ŻYWNOŚCIĄ

Abstract: The purpose of the study was to estimate the effective dose of ionising radiation absorbed in consequence of consuming the selected food products for relevant age groups and estimation of the resulting risk. The study was carried out with the use of food products, part of which was produced in the area contaminated with $^{137}$Cs released after the Chernobyl Nuclear Power Plant explosion. On the basis of the obtained study results, it can be stated that in consequence of consumption of the selected food products, people may receive increased radiation doses from artificial radioactive isotopes, which are one of the components of the annual effective dose. Taking into consideration other sources of ionising radiation, which are not present in food, one should assume that $^{137}$Cs contained in food has a little share in the total radiation dose absorbed by the inhabitants of the studied region.

Keywords: $^{137}$Cs, $^{40}$K, food, effective weighted dose

Introduction

The potential risk to human health was created by radioactive substances found in the environment. These substances may contain both radionuclides naturally occurring in the environment, and the ones artificially introduced. Globally, the main sources of ionizing radiation in the human environment are natural sources. Approximately 85 % of the annual total radiation dose of any person comes from natural radionuclides of both terrestrial and cosmogenic origin [1–3]. Radioactivity enters the human body through inhalation of radon and thoron gases and their decay products, and by ingestion of the important primordial radionuclides: $^{40}$K as well as those from the $^{238}$U and $^{232}$Th series [3].

Another source of radiation in the environment are artificial radionuclides. Starting from the 40’s of the twentieth century, it has been noticed a rapid increase in use of...
radioactive isotopes in various fields of human activity. Initially it was dominated by military applications, which resulted in the release of large amounts of radioactive material into the environment. This was due to a number of nuclear and thermonuclear test explosions.

Radioactive materials had also non-military applications, among them electricity and heat production. Radioactive elements are used in many industrial, medical, and research applications. Frequent use of radioactive materials caused appearance of many problems associated with radiological safety. The disadvantage concerns about the possibility of an uncontrolled penetration of radioactive materials into the environment and subsequently to the human body. Risk exists, despite to the security of today’s technology and the development of appropriate procedures for radioactive materials maintenance [4, 5]. These problems concern all the world, because the spread range of the released radioactive materials may include entire countries, continents, and even the Earth [6].

Radionuclides present in the soil are a source of both external and internal exposure to radiation of all living organisms: plants, animals and humans. Radionuclides from soil can be taken up by plants or absorbed by microorganisms, hitting at a later stage to other levels of food chains. Radionuclides in food reach the human body, where their further fate depends on the chemical properties. They can be excreted from the body or accumulated in various organs.

In many regions of the world population living in a specific area primarily feeds on products that have been produced in this area. Radiation exposure per capita is determined by the geological structure of the region, the type of locally produced food, and the presence of anthropogenic sources of radioactive substances. The content of radionuclides in the environment may be affected by the mining industry, combustion deposits, the use of phosphate fertilizers, mine water discharge into water reservoirs. Impact of radioactive substances released as a result, for example, of failure of different devices, leakage of radioactive waste can also be significant.

Due to the significant impact on human health it is necessary to monitor the radiation dose absorbed by the population living in a specific area. An important component of this dose is the part, which is supplied to the body with food. By measuring radionuclide content in food products is possible to evaluate the absorption and thus, the assessment of absorbed dose of ionizing radiation.

Estimation of radiation dose rate received with ingested food meets a number of issues. The diet structure and its seasonal changes as well as foodstuffs sources and age groups distribution in population have to be considered among others. Some of these data could be obtained from institutions which aim is to collect demographic data concerning local population or from laboratories controlling foodstuffs quality. But the necessary information is usually not readily available, even in a part of it.

Radiation dose estimation should be based on a properly designed and carefully conducted experiment. It should involve not only utilization of radioanalytical methods but also the investigation approaches developed by the economical and social sciences. Though such multidisciplinary construction of studies would lead to reliable conclusions, its costs can be very high.
In this paper the simplified approach to the radiation dose estimation, received with
the ingested food, is described. It is based on the following assumptions:
1. only the most common foodstuffs were considered in experiment,
2. only the products from the most common in the region foodstuffs suppliers were
investigated,
3. only the radionuclides with the relatively big activity concentrations are con-
sidered in computations.
Though the results obtained could be burdened by a significant error they should be
precise enough to undertake decision whether the detailed, high quality and expensive
investigations are required or not.
In order to specify the effective dose received in a date defined period, the
radiological protection summarises the effective doses $E_z$ from external exposure during
that period and the doses received in consequence of penetration of radioactive nuclides
to an organism, during the same period.
Pursuant to the Polish Regulation of the Council of Ministers of 18 January 2005 on
Ionizing Radiation Dose Limits [7], the dose limit of ionizing radiation from artificial
sources, expressed as the effective dose, amounts to 1 mSv in a calendar year for the
total population.
The purpose of the study was to define the effective dose in consequence of
consuming the selected food products, for relevant age groups and estimation of the
resulting risk. The studies were carried out in the area, which was particularly
contaminated with radioactive dust after the Chernobyl disaster. The food products
available in the local market were used for measurements.
In order to calculate the effective dose, the obtained results of activity measurements
were converted pursuant to the principles described in the standards applicable in
Poland. Considering that these standards have been based on the recommendations of
international organisations, the conclusions drawn from the studies are of universal
nature.

**Experimental**

The food products for studies were purchased in the shops in Opole (PL). It is a town
with 100 thousand inhabitants, in the south-west of Poland. There was a fall of
radioactive dust in the Opole region in 1986, in consequence of the nuclear reaction
breakdown in Chernobyl (the former Soviet Union) [eg 8–10]. One of the elements
included in the falling dust was $^{137}\text{Cs}$, which is still present in considerable quantities in
the regional environment.
The study covered the food products, which are relatively popular ingredients of the
local diet. These include: potato, rice, barley pearl, white and red kidney bean, oatmeal
and sugar. There are products made locally, brought from other regions of Poland and
also imported. Also wheat samples from local farms were analysed, as it was the raw
material for many other food products.
The products were purchased in large supermarkets, local convenience stores and
market places. Different product brands were selected and an approximately 50 g
A sample was taken from each purchased portion or a packaging. Potato samples were additionally dried to the constant mass at the temperature of 105 °C. The potatoes mass was reduced to approximately 1/4 of the initial value. The obtained materials were mixed and radioactivity assessment was carried out with an approximately 0.5 dm³ sample.

The measurements of activity concentrations of gamma radionuclides were carried out by means of a gamma-spectrometer with a germanium detector HPGe (Canberra) of high resolution: 1.29 keV (FWHM) at 662 keV and 1.70 keV (FWHM) at 1332 keV. Relative efficiency: 21.7 %. Energy and efficiency calibration of the gamma spectrometer was performed with the standard solutions type MBSS 2 (Czech Metrological Institute, Prague, CZ) which covers an energy range from 59.54 keV to 1836.06 keV. Geometry of calibration source was Marinelli (447.7 ± 4.5 cm³) with density 0.99 ± 0.01 g/cm³, containing ²⁴¹Am, ¹⁰⁹Cd, ¹³⁹Ce, ⁵⁷Co, ⁶⁰Co, ¹³⁷Cs, ¹¹³Sn, ⁸⁵Sr, ⁸⁸Y and ²⁰⁶Hg. Geometry of samples container was Marinelli, 450 cm³. Measuring process and analysis of spectra were computer controlled with use of the software GENIE 2000. The radiation spectrum was recorded day and night.

Results and discussion

In the foodstuff samples the activity concentrations of gamma radioactive nuclides were determined. The number of radionuclides detected was different in each sample. In the gamma radiation spectrum the energies characteristic for, among others, ²²⁸Ac, ²¹¹Bi, ²¹²Pb, ²³⁵U were detected but activity concentrations of them were lower than the Minimum Detectable Activity (MDA).

The measurements showed that the most active in food samples were ⁴⁰K and ¹³⁷Cs. The measurement uncertainty, estimated by the GENIE 2000 software, was limited in the range 10–50 % for ¹³⁷Cs and 2–5 % for ⁴⁰K. Further computations focused on the results of activity concentration measurements of these radionuclides.

Due to the importance of potassium for living organisms’ physiology, one should expect that the content of ⁴⁰K in food products depends mainly on the type of the used vegetable material. The content of ¹³⁷Cs depends mainly on the local soil contamination with this radionuclide [11–13].

Table 1 presents the activity values of ⁴⁰K and ¹³⁷Cs for the foods studied in the present work and, for comparison, some activities measurements results found in the literature.

The results of measurements of ⁴⁰K and ¹³⁷Cs activity presented in Table 1 in the selected food products indicate the presence of anthropogenic isotope ¹³⁷Cs in potato, wheat, barley pearl and sugar. The presence of the isotope in the tested products signifies contamination of environment with ¹³⁷Cs and transfer of the isotope from soil to edible plants and then to food products.

It should be noted that radionuclides activity in potatoes refers to the dry mass of the sample. In the drying process, the samples decreased to approximately 25 % of the initial mass. That is why it can be assumed that the specific activity of fresh, not dried potatoes is approximately 4 times lower than the activity of the dry mass.
Table 1

Results of determination of $^{40}$K and $^{137}$Cs activity concentrations obtained in the present work and described in the literature

<table>
<thead>
<tr>
<th>Samples</th>
<th>$^{40}$K [Bq/kg d.m.]</th>
<th>$^{137}$Cs</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato</td>
<td>633.9</td>
<td>0.6</td>
<td>Present work</td>
</tr>
<tr>
<td>Wheat</td>
<td>117.8</td>
<td>1.1</td>
<td>Present work</td>
</tr>
<tr>
<td>Rice</td>
<td>22.8</td>
<td>—</td>
<td>Present work</td>
</tr>
<tr>
<td>Barley pearl</td>
<td>107.7</td>
<td>0.3</td>
<td>Present work</td>
</tr>
<tr>
<td>White kidney bean</td>
<td>496.5</td>
<td>—</td>
<td>Present work</td>
</tr>
<tr>
<td>Red kidney bean</td>
<td>428.0</td>
<td>—</td>
<td>Present work</td>
</tr>
<tr>
<td>Oatmeal</td>
<td>118.4</td>
<td>—</td>
<td>Present work</td>
</tr>
<tr>
<td>Sugar</td>
<td>4.58</td>
<td>0.18</td>
<td>Present work</td>
</tr>
<tr>
<td>Potato</td>
<td>166.7</td>
<td>—</td>
<td>[14]</td>
</tr>
<tr>
<td>Wheat</td>
<td>150.8</td>
<td>—</td>
<td>[14]</td>
</tr>
<tr>
<td>Rice</td>
<td>70.3</td>
<td>—</td>
<td>[14]</td>
</tr>
<tr>
<td>Soy</td>
<td>311</td>
<td>$&lt; 0.13$</td>
<td>[15]</td>
</tr>
<tr>
<td>Bean</td>
<td>434</td>
<td>$&lt; 0.29$</td>
<td>[15]</td>
</tr>
<tr>
<td>Wheat</td>
<td>96</td>
<td>$&lt; 0.07$</td>
<td>[15]</td>
</tr>
<tr>
<td>Rice</td>
<td>14.7</td>
<td>$&lt; 0.04$</td>
<td>[15]</td>
</tr>
<tr>
<td>Wheat no. 1</td>
<td>127.9</td>
<td>0.26</td>
<td>[16]</td>
</tr>
<tr>
<td>Wheat no. 2</td>
<td>145.1</td>
<td>0.15</td>
<td>[16]</td>
</tr>
</tbody>
</table>

Data in Table 1 show much larger activities of the natural isotope $^{40}$K than activities of $^{137}$Cs. The activities measured during our experiments are similar to the values referred to in literature [14–16]. Due to the abundance of $^{40}$K in potassium amounting to 0.0118 %, activity of this isotope is directly related to the content of potassium in the analysed material. That is why assessment of $^{40}$K activity can be performed on the basis of the results of chemical analysis of potassium content in a sample.

The obtained measurement results, as well as the information published in relevant legal acts binding in Poland, were used for the assessment of risk related to the consumption of foods. The method of calculating internal exposure doses presented in the regulation is based on the following international regulations:

– basic international standards of protection from ionizing radiation and security of radiation sources (developed under the auspices of UN, IAEA, International Labour Organization),


The indicators included in the Polish Regulation [7], were applied in order to calculate the annual dose of internal exposure, caused by the consumption of selected foods. The loading effective dose $E$, being a result of a nuclide penetrating through the digestive system, was calculated from the formula 1:
\[ E = e(g)A \] (1)

where: \( e(g) \) is conversion factor for persons in the age group \( g \) expressed in Sv/Bq, and \( A \) is the activity of a radionuclide, which penetrated into the organism through the digestive and respiratory systems, expressed in Bq.

Together with the consumed foods, our organism is penetrated not only by the natural radioactive isotopes (especially \(^{40}\text{K})\), but also by the radioactive \(^{137}\text{Cs}\), which is accumulated in all soft tissues, and consequently removed from the organism.

The committed effective doses of \(^{137}\text{Cs}\) and \(^{40}\text{K}\), included in table 4 of the Regulation for the total population, related to the penetration of a nuclide with the activity concentration of 1 Bq, are shown in Table 2.

| Values of the committed effective doses of \(^{137}\text{Cs}\) and \(^{40}\text{K}\) in different age groups \( g \), related to penetration of a nuclide with the activity concentration of 1 Bq [7] |
|---|---|---|---|---|---|---|
| \( e(g) \) \([\text{Sv/Bq}]\) | \( g \leq 1 \) year | \( g > 1 \) year | \( g = 2-7 \) years | \( g = 7-12 \) years | \( g = 12-17 \) years | \( g > 17 \) years |
| \(^{137}\text{Cs}\) | 2.1 \( \cdot 10^{-8} \) | 1.2 \( \cdot 10^{-8} \) | 9.6 \( \cdot 10^{-9} \) | 1.0 \( \cdot 10^{-8} \) | 1.3 \( \cdot 10^{-8} \) | 1.3 \( \cdot 10^{-8} \) |
| \(^{40}\text{K}\) | 6.2 \( \cdot 10^{-8} \) | 4.2 \( \cdot 10^{-8} \) | 2.1 \( \cdot 10^{-8} \) | 1.3 \( \cdot 10^{-8} \) | 7.6 \( \cdot 10^{-9} \) | 6.2 \( \cdot 10^{-9} \) |

Tables 3 and 4 present the calculated effective doses received in consequence of absorbing isotopes \(^{137}\text{Cs}\) and \(^{40}\text{K}\) with the consumed food for the persons in a relevant age group. The values presented in the tables are the values of the dose absorbed in consequence of consumption of 1 kg of product, depending on a person’s age.

| Comparison of effective weighted dose size obtained from the radionuclide \(^{137}\text{Cs}\) after consumption of 1 kg of product by people of different age groups |
|---|---|---|---|---|---|
| Name of samples | Size of effective weighted dose \( e(g) \) \([\text{nSv}]\) | \(^{137}\text{Cs}\) |
| Radionuclide | \( g \leq 1 \) year | \( g > 1 \) year | \( g = 2-7 \) years | \( g = 7-12 \) years | \( g = 12-17 \) years | \( g > 17 \) years |
| Age | | | | | | |
| Potato | 12.2 | 7.0 | 5.6 | 5.8 | 7.54 | 7.5 |
| Wheat | 23.1 | 13.2 | 10.6 | 11.0 | 14.3 | 14.3 |
| Barley | 6.3 | 3.6 | 2.88 | 3.0 | 3.9 | 3.9 |
| Sugar | 3.8 | 2.1 | 1.7 | 1.8 | 2.3 | 2.3 |

Wheat contains the largest dose of radiation originating from \(^{137}\text{Cs}\). Potatoes and barley pearl provide considerably lower doses. The lowest doses are absorbed when consuming sugar. As the quantity of sugar in an average diet is much lower than other foodstuffs, the radiation dose supplied with it is relatively small.
Table 4

Comparison of effective weighted dose size obtained from the radionuclide $^{40}$K after consumption of 1 kg of product by people of different age groups

<table>
<thead>
<tr>
<th>Name of samples</th>
<th>Size of effective weighted dose $e(g)$ [nSv]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radionuclide</td>
<td>$^{40}$K</td>
</tr>
<tr>
<td>Age</td>
<td>g ≤ 1 year</td>
</tr>
<tr>
<td>Potato</td>
<td>39400</td>
</tr>
<tr>
<td>Wheat</td>
<td>7300</td>
</tr>
<tr>
<td>Rice</td>
<td>1410</td>
</tr>
<tr>
<td>Barley</td>
<td>6680</td>
</tr>
<tr>
<td>Bean</td>
<td>30800</td>
</tr>
<tr>
<td>Black bean</td>
<td>26500</td>
</tr>
<tr>
<td>Oatmeal</td>
<td>7340</td>
</tr>
<tr>
<td>Sugar</td>
<td>284</td>
</tr>
</tbody>
</table>

The seemingly largest radiation dose originating from $^{40}$K is consumed with potatoes. As mentioned above, the activity measurements were made using dried potatoes. Usually, however, potatoes are not dried before consumption (except for potato crisps); one may assume 4 times lower value of the dose provided by fresh potatoes.

Considering the above, it can be assumed that the largest radiation dose is connected with consumption of white and red beans. Rice contains the least potassium; therefore, its consumption has the smallest influence on the absorbed dose size.

The analysis of data from Table 3 and 4 shows that an effective dose received after consumption of food containing both $^{137}$Cs and potassium is much lower for caesium than the dose originating from the natural isotope $^{40}$K. The dose, which source is potassium naturally present in food, is approximately $10^4$–$10^5$ times bigger than the dose originating from artificial $^{137}$Cs. When analysing the influence of an age group on a dose value, one can notice that in the case of isotope $^{137}$Cs such a dose slightly decreases with age, however, in the case of natural isotope $^{40}$K, the decrease is considerable.

It can be noticed that with the same level of nuclide activity penetrating the organisms of a child and adult, the child will receive a bigger dose. Due to the smaller total weight, the absorbed energy for one body weight unit will be higher for a child than for an adult.

On the basis of the data from Central Statistical Office in Poland [18], annual food consumption in Polish households in 2010 was estimated. Our estimates show that annual food consumption in 2010 is approximately 635 kg [1399.9354 pounds]/person. Figure 1 shows the correlation between the consumption volumes of the food contaminated with $^{137}$Cs and the level of contamination, assuming that the limit dose of 1 mSv will be achieved (conversion index $1.3 \cdot 10^{-5}$).
The analysis of the graph in Figure 1 shows that consumption of 600 kg [1322.7736 pounds] of food during a year, with the activity of $^{137}$Cs at approximately 130 Bq/kg, will result in absorbing the dose of 1 mSv, referred to in the Polish Regulation [7]. The largest activity of $^{137}$Cs was noted in wheat. This activity is, however, two orders of magnitude lower than that, which could cause exceeding the allowed level of radiation dose, which originates from artificial sources. People absorb much larger radiation doses, which originate from natural sources rather than artificial ones. Apart from the natural isotopes present in food, people are exposed to radiation emitted by other unstable isotopes, in particular $^{222}$Rn. Considering the above measurements of the analysed food products, one can note that they are not a major source of radiation for the population of the studied area. Despite the increased content of $^{137}$Cs in many food products, radiation doses from that source are much lower than those allowed by the regulations. However, there are food products, which contain much higher than average activities of $^{137}$Cs. This regards, for example, mushrooms – boletus species ($Xerocomus badius$), which activity could even exceed 1000 Bq/kg of dry mass [19]. Therefore, it is justified to implement tests for the presence of anthropogenic radiation isotopes in food products, which enable calculation of radiation doses received in consequence of food consumption.

Conclusions

Little activity of $^{137}$Cs was confirmed in the analysed products. This illustrates the level of environment pollution with this isotope, and the possibility of its migration from soil to edible plants and food products.

The described studies showed that in consequence of consumption of food products, the inhabitants of the studied area may receive an increased radiation dose, which is one of the elements of the annual effective dose.
In the analysed foodstuffs, activities of natural isotope $^{40}$K were much higher than $^{137}$Cs. Taking into consideration other sources of ionising radiation, which are not present in food, one should assume that $^{137}$Cs contained in food has a little share in the total radiation dose absorbed by people.

It could be stated that the detailed investigations of the ingested radiation dose rate related to the food consumption in the investigated area are not currently required. The simplified investigations can be temporarily repeated to detect possible changes in radioactive contamination in foodstuffs.

References


BADANIE WCHŁONIĘTEJ SKUTECZNEJ DAWKI PROMIENIOWANIA OTRZYMANEJ WRAZ ZE SPOŻYWANĄ ŻYWNOŚCIĄ

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Abstrakt: Celem tego badania było określenie skutecznej dawki promieniowania jonizującego, pochłoniętej wskutek spożywania wybranych produktów żywnościowych. W ocenie ryzyka uwzględniono grupy wiekowe ludności. Badania przeprowadzono z wykorzystaniem produktów spożywczych, z których część została wyprodukowana na obszarach skażonych 137Cs, uwolnionym po wybuchu elektrowni jądrowej w Czarnobylu. Wyniki przeprowadzonych badań potwierdzają zwiększenie dawki promieniowania, pochodzące od sztucznych izotopów promieniotwórczych. Biorąc pod uwagę inne niż żywność źródło promieniowania jonizującego, można stwierdzić, że 137Cs zawarty w artykułach spożywczych ma mały udział w całkowitej dawce promieniowania pochłoniętego przez mieszkańców badanego regionu.

Słowa kluczowe: 137Cs, 40K, żywność, dawka skuteczna promieniowania jonizującego