DOI: 10.1002/fsh3.12058

EDITORIAL

FOOD SAFETY AND HEALTH
WILEY

Radioactivity and food safety in Serbia: Chernobyl accident and 4 decades later

1 | EXPOSURE OF THE POPULATION TO RADIATION, CHERNOBYL ACCIDENT AND REGULATIONS

Radioactivity occurs due to natural processes or as a consequence of various anthropogenic activities (nuclear power plants, military industry, etc.) (Cinelli et al., 2019; čulović et al., 2020). Radioactive contamination of the environment can arise in several ways: due to technological development, use of nuclear energy, experimental nuclear testing, as well as due to the use of nuclear weapons. Regardless of the origin, radioactive substances endanger living organisms. From the point of human population, food chain is one of the most important ways of contributing to the total radiation dose of an individual, as all types of food contain radionuclides (Figure 1). Therefore, it is essential to use food of plant and animal origin with the lowest possible amount of radionuclides, in order to minimize the exposure to radiation. However, it should be noted the levels of natural radionuclides in food and drinking water are rather low and their concentrations are considered safe for human consumption. Many laws and rulebooks are created and implemented with the aim of ensuring a high level of protection of life and health for people. Moreover, it is of high importance to protect consumer interests and ensure the production and trading of safe food, but also to protect plant and animal health and welfare, as well as the entire environment, when possible. Radionuclides that are of major interest in food monitoring programs are natural radionuclides ^{40}K, ^{210}Pb, ^{226}Ra, ^{238}U, and ^{232}Th, and artificial radionuclides ^{90}Sr, ^{131}I, and ^{137}Cs (Cinelli et al., 2019).

After the Chernobyl accident (Ukraine) in 1986, large amounts of radionuclides were released in the atmosphere. Luckily, out of 200 radionuclides that were formed during nuclear fission, less than 10 could have impacted humans due to their participation in physiological pathways. The damaged Chernobyl reactor was estimated to have emitted 1.3×10^{18} Bq ^{131}I, 3.0×10^{17} Bq ^{133}I, 8.9×10^{16} ^{137}Cs, and 2.0×10^{16} Bq ^{134}Cs into the environment. Besides them, ^{90}Sr, ^{239}Pu, and ^{241}Am also had some impact. The territory of Yugoslavia deposited approximately 2.4% of all emitted radionuclides (without inert gasses), or approximately 5% of all ^{131}I and 10% of ^{137}Cs (Federal Committee for Labor, Health and Social Security, 1987).

International Atomic Energy Agency (IAEA), European Atomic Energy Community (EAEC or Euroatom) and other professional bodies engaged in dealing with the situation, prescribing a number of regulatory rules with the aim to control the damage. Among the most important were regulations concerning the exposure of the population to radiation, directly or indirectly via consumption of food and drinking water. The first one was Council Regulation (Euroatom) Document 31987R3954 (Comission Regulation (Euroatom), 1987), issued on the maximum permitted levels of radioactive contamination of foodstuffs and feedingstuffs, followed by Commission Regulations: No 944/89 (Commission Regulation (Euroatom) 1989), No L:1990:083:TOC (Comission Regulation (Euroatom), 1990), No 770/90 (Comission Regulation (Euroatom), 1990), No 2013/51 (Comission Regulation (Euroatom), 2013) and No 2016/52 (Comission Regulation (Euroatom), 2016, in force). The import of goods from East Europe was forbidden and agricultural products from the so-called third world countries were permitted provided that they satisfied the allowed radionuclide content.

2 | BIOLOGICALLY IMPORTANT RADIONUCLIDES RELEASED AFTER CHERNOBYL ACCIDENT

The most important radionuclide for humans was ^{131}I, quantities of which were significant and it was present in the environment both in its elementary form and as iodide (IAEA/EMRAS, 2004). The risk of its inhalation directly from the air (as radioactive aerosol) was lower than indirectly by the consumption of leafy vegetables considerably radio-contaminated by atmospheric precipitation. Physical half-life of ^{131}I is 8 days, whereas its biological half-life varies between mammals and within the same species. After absorption from food, approximately 90% of ^{131}I reaches blood, and 30%–50% is further accessible and fixed by the thyroid gland, reaching saturation. The remaining ^{131}I is excreted via milk, urine, and feces. The Chernobyl accident imposed a serious challenge in food monitoring, classification, certification for consumption, and the official prescription of limits for radionuclide content. Immediately after the accident, limitations referred to ^{131}I, in order to control the consumption of milk and dairy products, which were contaminated via leafy plants and grass on

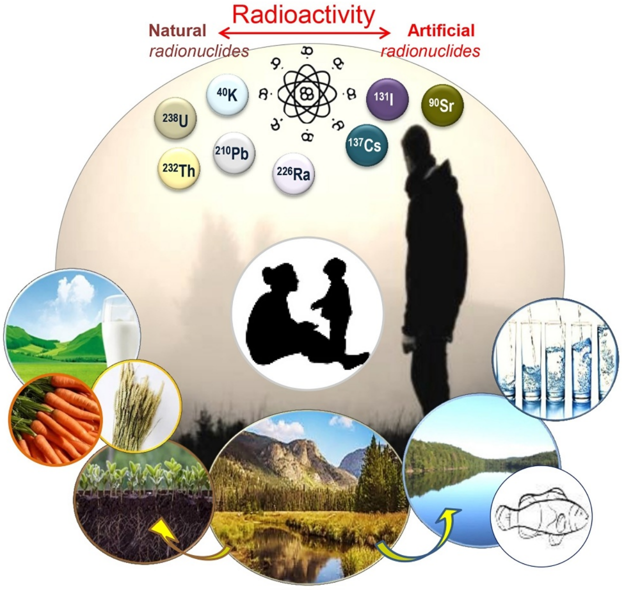

FIGURE 1 Exposure of humans to natural and artificial radioactivity.

pasture. Animal meat and other parts used for human nutrition were subjected to rigorous radiological control before declaring their safety for consumption (at the market or for individual direct use). Introduced measures immediately after the nuclear accident ensured that the exposure of thyroid to radiation was less than 0.30 Sv in children, which was achieved by limiting the content of ^{131}I in milk to 3.7 kBq/L. As time passed, the level of ^{131}I activity decreased in all types of food; thus, the permitted limits for the food content of ^{131}I were changed, taking into account that the entire body exposure had to be less than 50 mSv/year. Levels of ^{131}I in tested samples from Serbia (water, food, air, and soil) were low enough, so the consumption of preparations containing stable iodine isotopes was not needed. According to Document 31987R3954 from 1987, the maximum permitted level of ^{131}I in dairy products was 500 Bq/kg (or L) and 2 kBq/kg in other foodstuffs except minor foodstuffs, whose activity levels were regulated by documents issued before the Chernobyl accident.

The second biologically most important radionuclide was ^{137}Cs, which behaves as potassium homolog and is an organotropic radionuclide. ^{137}Cs was ingested via food and water and its further faith depended on the solubility in the gastrointestinal tract, as it is pH-dependent. Physical half-life of ^{137}Cs is 30.2 years and biological half-life in humans is 70–120 days. Investigations have shown huge genetic potential of radiocesium, as it is deposited in gonads and other organs exposing an organism additionally to internal irradiation (Melnikov & Zanoni, 2010). According to Document 31987R3954 from 1987, the maximum permitted levels of nuclides of half-life greater than 10 days (excluding ^{14}C and ^{3}H); notably ^{134}Cs and ^{137}Cs, in dairy products was 1 kBg/kg (or L) and 1.25 kBg/kg in other foodstuffs.

The permitted levels remained the same in Commission Regulation No 2016/52 from 2016, with more strict limits for infant food: 150 Bq/kg (or L) for ^{131}I and 400 Bq/kg (or L) for ^{134}Cs + ^{137}Cs. This document defined minor foodstuffs (certain plants, spices, seeds, truffles, some vegetable products, and essential oils) and their radioactivity limits: 20 kBq/kg for ^{131}I and 12.5 kBq/kg for ^{134}Cs + ^{137}Cs. The maximum permitted levels for feed are 1.25 kBq/kg for pigs, 2.5 kBq/kg for poultry, lambs, and calves, and 5.0 kBq/kg for other animals.

3 | RADIOACTIVITY MEASUREMENTS AND REGULATIONS CONCERNING THE EXPOSURE OF THE SERBIAN POPULATION TO RADIATION

Institute for the Application of Nuclear Energy (INEP) in Belgrade, Serbia was officially involved in radioactivity monitoring immediately after the Chernobyl accident and is still doing so. Immediately after the accident, the total gamma radioactivity of grass and soil in Belgrade was measured to be 30.6 kBq/kg and 6.8 kBq/kg, while the activity levels of ^{137}Cs were 5.3 kBq/kg and 1.6 kBq/kg, respectively. Animal feed was extremely contaminated - ^{137}Cs in alfalfa flour was up to 6.2 kBq/kg. Consequently, high levels of radioactivity were measured in meat; the highest ^{137}Cs was 537 Bq/kg in sheep meat. The activity of ^{137}Cs in milk increased from 0.14 Bq/L in 1985 to 72.4 Bq/L on average in 1986, with an extreme sample having 292 Bq/L.

High levels of ^{137}Cs persisted until 1991 in snail meat (maximum was 521 Bq/kg), deer, and meat from other wild animals (up to 60 Bq/kg). Although much higher than before the Chernobyl accident, these levels were still much lower than in a similar samples measured in North European countries. Considerable contamination in terms of ^{134,137}Cs was measured in 1986 and 1987 in sour cherry concentrate (maximum 273 Bq/kg), apple concentrate (maximum 261 Bq/kg), powder milk (maximum 220 Bq/kg), and chocolate (maximum 102 Bq/kg). Medicinal plants were significantly contaminated with ^{137}Cs: *Herba asperulae* 4.2 kBq/kg and *Sumitates crataegi* 5.6 kBq/kg. Activity levels of ^{137}Cs in bioindicators were up to 2.4 kBq/kg in (edible) fungi and 13.6 kBq/kg in lichen *Cladonia fimbriata* (Čučulović et al., 2020).

Food chain is the main route to radionuclides exposure today. Certain plants and animals absorb radioactive material due to similar characteristics of radionuclides and essential elements. For example, humans accumulate radiocesium due to its chemical and metabolic homology with potassium. The concentrations of radionuclides taken in by plants and animals mainly rely on the radioactivity of source medium (soil or water). Additionally, the ability of plants to accumulate the element from the soil and transfer it from roots to different vegetative organs is a species-specific characteristic, which is associated with the distribution of elements within a food chain (Cinelli et al., 2019). Regulations concerning radioactivity levels issued successively after the Chernobyl accident, the last being No. 2016/52, remain valid in European Community (EC) countries, while a rulebook on population safety (Rulebook on radionuclide content limits in drinking water, food, animal feeds, drugs, items for general use, construction materials, and other goods put on the market (Official Gazette, 2018)), was issued in Serbia several years ago. According to this document, radionuclide limits were lowered for a number of foods and other items. New limit for milk and dairy products, infant food, vegetables, fruits, cereals, meat and meat products, eggs and other groceries such as lard, oil, sugar, sweets, alcohol and non-alcohol drinks is 15 Bq/kg (or/L). Higher limits (but still less than those in EC) are allowed for: powder milk, wild berry fruits, wild animal meat, fish, seafood, mushrooms (fresh and their products), medicinal plants, tea, and coffee, which is 150 Bq/kg (or L); whereas, the limit for dry mushrooms, aromas, spices, and other foods used less than 2 kg per year per individual is 600 Bq/kg (or L). The same rule book also prescribes permitted levels of natural radionuclides in mineral fertilizers: ^{238}U 1.6 kBq/kg for market-ready phosphorus-based fertilizers or 3.2 kBq/kg for the components used for the production of phosphorus-based fertilizers, ^{226}Ra 1.0 kBq/kg for both market-ready and raw material for phosphorus-based fertilizers, and ^{40}K 27.0 kBq/kg, for both market-ready and raw material for the production of potassium-based fertilizers.

Nowadays, the radioactivity levels of ^{137}Cs are below 1.0 Bq/kg in meat (domestic and wild animals), milk, and dairy products originating from Serbia. Radioactive residues of ^{137}Cs can still be detected in bioindicators: fungi (up to 20 Bq/kg), lichens, and mosses, but they are naturally expected and at the level before Chernobyl accident.

4 | SUMMARY

Chernobyl accident and radioactivity spreading resulted in very high levels of radionuclides in foods and the entire environment, imposing a need to revise official regulations concerning the intake and exposure of the population. Four decades later, radioactivity levels mostly correspond to the pre-Chernobyl period. However, regular everyday gamma spectrometric monitoring can still be prescribed for the imported goods, preventing the arrival of items with higher activity levels of ^{137}Cs that can be found in the region, thus protecting the local population. All the above-mentioned supports the importance of continuous control of radioactivity levels in food, and inclusion of such data in publicly accessible databases.

AUTHOR CONTRIBUTIONS

Ana Čučulović: Investigation; resources; writing – original draft. **Jelena Stanojković**: Investigation. **Olgica Nedić**: Methodology; resources; writing – review & editing. **Jelena Popović-Djordjević**: Conceptualization; supervision; visualization; editing.

KEYWORDS

Chernobyl accident, food, health, radioactivity, regulations

ACKNOWLEDGMENTS

The authors would like to thank the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia for financial support (Grant No. 451-03-66/2024-03/200019, 451-03-65/2024-03/200116).

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

FUNDING INFORMATION

Ministry of Science, Technological Development, and Innovation of the Republic of Serbia, Grant/Award Numbers: 451-03-66/2024-03/200019, 451-03-65/2024-03/200116.

Ana Čučulović[1]
Jelena Stanojković[1]
Olgica Nedić[1]
Jelena Popović-Djordjević[2]

[1] *University of Belgrade, Institute for the Application of Nuclear Energy (INEP), Belgrade, Serbia*
[2] *Department of Food Technology and Biochemistry, University of Belgrade-Faculty of Agriculture, Belgrade, Serbia*

Correspondence
Jelena Popović-Djordjević,
Department of Food Technology and Biochemistry, University of Belgrade-Faculty of Agriculture, Belgrade 11080, Serbia.
Email: jelenadj@agrif.bg.ac.rs

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

ETHICS STATEMENT

The authors confirm that the study did not involve any human or animal subjects.

ORCID

Ana Čučulović https://orcid.org/0000-0001-9315-4559
Jelena Stanojković https://orcid.org/0000-0003-3784-842X
Olgica Nedić https://orcid.org/0000-0003-2042-0056
Jelena Popović-Djordjević https://orcid.org/0000-0003-4057-3826

REFERENCES

Cinelli, G., De Cort, M., & Tollefsen, T. (Eds.). (2019). *European atlas of natural radiation*. Publication Office of the European Union. Retrieved from https://op.europa.eu/en/publication-detail/-/publication/a8c08fd3-56b6-11ea-aece-01aa75ed71a1/language-en

Comission Regulation (Euroatom) Document L:1990:083:TOC. (1990). Maximum permitted levels of radioactive contamination of feedingstuffs following a nuclear accident or any other case of radiological Emergency. *Official Journal of the European Communities*, *L-83*, 78–79. Retrieved from https://eur-lex.europa.eu/legal-content/DA/TXT/?uri=OJ:L:1990:083:TOC

Commission Regulation (Euroatom) No 770/90. (1990). Maximum permitted levels of radioactive contamination of feedingstuffs following a nuclear accident or any other case of radiological emergency. Retrieved from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31990R0770

Commission Regulation (Euroatom) No 944/89. (1989). Maximum permitted levels of radioactive contamination in minor foodstuffs following a nuclear accident or any other case of radiological emergency. *Official Journal of the European Communities*, *L-101*, 17–18. Retrieved from https://eur-lex.europa.eu/eli/reg/1989/944/oj

Council Directive (Euroatom) No 2013/51. (2013). Requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2013.296.01.0012.01.ENG

Council Regulation (Euroatom) 2016/52. (2016). Maximum permitted levels of radioactive contamination of food and feed following a nuclear accident or any other case of radiological emergency, and repealing Regulation (EUROATOM) No 3954/87 and Commission Regulations (Euratom) No 944/89 and (Euratom) No 770/90. Retrieved from https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32016R0052

Council Regulation (Euroatom) Document 31987R3954. (1987). Maximum permitted levels of radioactive contamination of foodstuffs and of feedingstuffs following a nuclear accident or any other case of radiological emergency. *Official Journal of the European Communities*, *L-371*, 11–13. Retrieved from https://eur-lex.europa.eu/eli/reg/1987/3954/oj

Čučulović, A., Stanojković, J., & Veselinović, D. (2020). A twenty-year radiocontamination study of edible fungi of Serbia: Activity levels of ^{137}Cs and estimated dose to the population. *Nuclear Technology & Radiation Protection*, *35*(2), 165–171. https://doi.org/10.2298/NTRP2002165C

Federal Committee for Labor, Health and Social Security. (1987). The level of radioactive contamination of the human environment and population irradiation in Yugoslavia in 1986 due to accident in nuclear power station in Chernobyl.

International Atomic Energy Agency / Environmental Modelling for RAdiation Safety (IAEA/EMRAS). (2004). The Chernobyl I-131 release: Model validation and assessment of the countermeasure effectiveness working group. Retrieved from https://www-pub.iaea.org/MTCD/publications/PDF/TE_1678_CD/Reports/Theme_1_WorkingGroup3(Chernobyl_I-131_Release)/The%20Chernobyl%20I-131Release-ModelValidationandAssessmentoftheCountermeasureEffectiveness.pdf

Melnikov, P., & Zanoni, L. Z. (2010). Clinical effects of cesium intake. *Biological Trace Element Research*, *135*(1–3), 1–9. https://doi.org/10.1007/s12011-009-8486-7

Official Gazette of the Republic of Serbia. (2018). Rulebook on radionuclide content limits in drinking water, food, animal feeds, drugs, items for general use, construction materials and other goods put on the market36/2018 (Službeni glasnik Republike Srbije). (in Serbian).