



Evaluation of stable iodine status of the areas affected by the Chernobyl accident in an epidemiological study in Belarus and the Russian Federation

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ABSTRACT

Variation of the stable iodine supply was evaluated in the soils of around more than 700 settlements in the regions (oblasts) of Belarus and the Russian Federation contaminated after the Chernobyl accident. It involved the use of regional information on iodine content in different types of soil cover, biogeochemical criteria of iodine deficiency in food chains, and the available soil maps.

The proposed method enabled to create overview maps that differentiated study areas by iodine supply level and to rank rural settlements according to iodine content in soil cover. The area-weighted concentration of stable iodine in the soil cover used for farming was estimated. Median iodine concentration was found to be highest in the settlements of Orel and Tula oblasts (3.6 mg/kg), lower in Gomel and Mogilev oblasts (3.0 and 2.3 mg/kg, respectively) and lowest in Bryansk and Kaluga oblasts (1.3 mg/kg). Estimates of iodine availability from different types of soils were corrected for volumetric weight and adjusted for the type of settlement in order to assign the stable iodine status for each subject in a case–control study of thyroid cancer risk following the Chernobyl accident. The epidemiological study found a significant modifying effect of iodine deficiency on the risk of thyroid cancer following exposure to radioiodines.

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1. Introduction

Iodine belongs to one of the most intrinsic chemical elements in the biosphere due to its multivalent nature (from -1 to $+7$) and corresponding ability to form gaseous, water soluble and refractory compounds with both mineral and organic matter (Fuge et al., 1986). Its mean concentration in the main geo-spheres equals to: 0.4 mg/kg in the Earth's crust (Voitkevich et al., 1977); 0.06 mg/kg in the hydrosphere (Mason and Moore, 1982); 0.05 mg/kg in the biosphere (fresh mass) (Whitehead, 1984). 97.78% of iodine in the atmosphere emerges due to the seawater evaporation (5×10^{11} t/y, Miyake and Tsunogai, 1963); 10% of this amount is annually transported to the continents and brought back by rivers (Kashin, 1987). Marine sediments and soils are the main reservoir of this element and serve as its secondary source. Surface soils worldwide contain on average 5 mg/kg of iodine (Vinogradov, 1957; Wedepohl, 1969; Bowen, 1979;

Fleming, 1980; Johnson, 2003b); the amount can vary in different areas from 0.1 to 98.2 mg/kg (Vinogradov, 1927, 1957; Lozovsky, 1971; Whitehead, 1984; Kashin, 1987; Shinonaga et al., 2001; Johnson, 2003b; Muramatsu et al., 2004).

Marine environment and marine biota play a key role in iodine transfer to food chains. Iodine concentration in soils results from the balance of several processes controlling its input, retention, leaching and dynamic redistribution rates. These are: sorption by the soil organic matter, iron and aluminium oxides and fine particles; iodine fixation and decrease of its mobility to iodate by oxidation in alkaline conditions; iodine mobilization by its reduction to iodide; its leaching by water enriched in water-soluble natural organic substances; release of iodine in gaseous phase as free iodine or volatile organo-iodides, like methyl-iodide and others (Vinogradov, 1946; Lozovsky, 1971; Bowen, 1979; Whitehead, 1984; Fuge et al., 1986; Shinonaga et al., 2001; Hou et al., 2003a,b; Johnson, 2003a; Michel et al., 2005).

Being involved in biological processes in the early history of the Earth this element plays an important role in human biochemistry. French physician J. Prevost was among the first who suggested in 1849 that iodine deficiency in soil may cause goitre. In Switzerland, in the

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areas where iodine concentration in soil ranged from 0.6 to 1.4 mg/kg, 56–61% of the population had goitre while in the areas containing 11.9 mg/kg – only 1% (Roche and Lissitzky, 1960).

Normal daily consumption of iodine ranges from 100 to 200 µg for adults; WHO recommended daily intake for adults is 150 µg (Shinonaga et al., 2001; WHO, 2001). The intake of 120 µg of iodine is provided mainly by vegetables (70 µg), meat (40 µg), air and water (5 µg each, continental zones) (Vinogradov, 1946). Seafood, milk and dairy products are significant contributors of iodine to diets (Shinonaga et al., 2001; Johnson, 2003a).

In the modern world with intensive exchange of foodstuff, local food chains still remain significant for rural and other areas where population mainly lives on local products. About one third of the global population has health problems related to iodine deficiency (Lidiard, 1995; Pouessel et al., 2003; Valentino et al., 2004; Lin et al., 2004). A number of geochemical factors can be responsible for the low iodine content in diets and subsequent endemic goitre. For instance, endemic goitre occurred in areas with low iodine in soils but high iodine in surface water (Fuge, 1989; Elwood, 1985), therefore iodine content in soils was likely to be a more significant factor. In some cases, the disease can be provoked by cobalt deficit (Blokhina, 1968), selenium (Fordyce et al., 2000), by presence of goitrogens in food, or by anthropogenic soil transformation (peaty soils drainage and liming) that leads to iodine immobilization (Lidiard, 1995). According to Vinogradov (1949), the main environmental factors contributing to the development of endemic goitre are podzolic (especially sandy) and peaty soils, mountain and internal continental areas, humid climate and limestone deposits, serving as a source of drinking water. Favourable environmental factors that protect from developing endemic goitre are chernozems and organic soils rich in colloids, seaside areas, semi-arid climate (with dominating evaporation) and deep artesian waters used for drinking.

In the former Soviet Union (FSU), in order to prevent thyroid diseases in animals and humans, the problem of low iodine content was widely discussed and studied in various state funded projects in the period from 1950s to 1980s. The problem of iodine deficiency was considered from both ends of the biogeochemical food chain.

Studies of natural and ploughed soils, as well as experiments with radioactive isotopes of iodine, demonstrated a relationship between the iodine content and key physical and chemical properties of soil that affect iodine sorption and transformation, such as: amount of organic matter, soil reaction, size of soil particles and the type of the soil-forming rocks (Vinogradov, 1957; Seleznev and Tyuryukanov, 1971; Lozovsky, 1971; Zyrin and Zborishchuk, 1975; Kalmet, 1975; Tikhomirov et al., 1980; Kashin, 1987; Korobova, 1992). Data on the factors responsible for iodine concentration in topsoils were used for regional soil grouping and mapping of iodine supply (Tyuryukanov and Shamaeva, 1964; Sitdikov, 1970; Lozovsky, 1971; Kalmet, 1975; Korobova, 1992; Protasova et al., 1992). Iodine mapping of particular regions was performed on the basis of existing rock, soil and landscape maps, which contained information on composition of the soils, their texture and organic content (Tyuryukanov and Shamaeva, 1964; Protasova et al., 1992). Data available for the soils of the European part of the FSU were summarized in a schematic map of iodine content (Zyrin and Zborishchuk, 1975). The map also reflected a spatial distribution of both rocks and soils with different capacity for iodine sorption.

The soil-based approach of evaluation of shortage, excess and imbalance of chemical elements in live organisms was proposed and applied in the FSU by Kovalsky (1974). He established threshold levels ensuring normal regulation of biological processes for several essential trace elements in Russian soils, fodder, or foodstuffs. The lower limit of iodine in soil that can sustain normal thyroid function was considered 5 mg/kg. It was used as a key ecological criterion to demonstrate different levels of iodine supply in soils of various natural zones and regions of the FSU. According

to Kovalsky, soils in non-chernozem areas were poorer in iodine, compared to chernozem.

A schematic map of the endemic goitre in the FSU was first generated by Kovalsky on the basis of zonal and regional principles in 1957 (Kovalsky, 1957). Numerous studies later showed that iodine deficiency was an important environmental risk factor provoking goitre and thyroid gland malfunctioning in animals and humans in the vast areas of the Russian plain and Siberia, and recommendations on iodine supplementation were developed (Nikolaev, 1955; Vinogradov, 1946; Kovalsky, 1974; Kovalsky and Blokhina, 1974; Rish, 1964; Antonov, 1965; Blokhina, 1968; Meshchenko, 1968; Kolomijtseva, 1968; Lozovsky, 1971; Golubev, 1973; Aidarkhanov et al., 1978; Komrakova, 1988).

However, the validity of using iodine content in soil to estimate iodine transfer into food chain could be argued, since it was shown that: 1) iodine can be easily bound to refractory organic substances and immobilized (Santschi and Schwehr, 2004; Oktay et al., 2000); 2) iodine transfer can be negatively associated with the clay content in soils (Shinonaga et al., 2001).

On the other hand, recent experiments with ^{125}I have proved that after being fixed, iodine can hardly be lost to gaseous phase in a considerable amount (Kashparov et al., 2005). Despite the stronger iodine fixation in the heavy and organic soils, the higher iodine concentration in these soils itself provides higher iodine content in soil water and its transfer to plants, compared to the sandy soils (Korobova, 1992). Moreover, in hydromorphic and anoxic environments, typical for peaty soils, iodine is more mobile due to its presence in the form of iodide and is therefore more transferable to plants. An approximate evaluation of iodine availability in the local food chain based on the total iodine content in dominating soils is therefore possible.

The Chernobyl accident in April 1986 caused a considerable short-term release of radioactive ^{131}I to the atmosphere over vast areas (Izrael, 2006) characterized by different climatic conditions and large variety of soils. An important accidental exposure of thyroid gland due to the uptake of radioactive isotopes of iodine, mainly ^{131}I , occurred in populations residing in large territories with considerable variation of stable iodine concentration in soils, plants and water (UNSCEAR, 2000). Some studies (Zvonova, 1989) indicate that for adults doses to the thyroid from radioiodines are independent of the level of stable iodine in diet, as the variation in the thyroid uptake is compensated by the variation in the thyroid mass. The models of thyroid dose estimation after the Chernobyl accident use therefore the reference values recommended by the International Commission on Radiological Protection (ICRP, 1993), which do not account for the level of stable iodine in the diet. The available data, however, mainly refer to adults; information on the relationship between the thyroid dose from ^{131}I and the level of stable iodine intake in diet for children is scarce.

Iodine deficiency affects not only the level of dose received by the thyroid gland at the moment of exposure but also, if continued, thyroid function in the years after exposure (Baverstock and Cardis, 1996; Gembicki et al., 1997; Yamashita and Shibata, 1997). Experimental studies indicated that iodine deficiency may be an important modifier of the risk of radiation-induced thyroid cancer (Thomas and Williams, 1991; Kanno et al., 1992). In humans, the modifying effect of stable iodine in diet on the risk of radiation-induced thyroid cancer was unknown.

Stable iodine status of the areas where the residents received substantial doses to the thyroid resulting from intake of radioactive isotopes of iodine is therefore important at least because of two reasons: 1) intake of radioactive isotopes of iodine by the thyroid gland can be correlated with that of its stable isotope (Hou et al., 2003a,b); 2) lack of stable iodine in diet causes a prolonged stimulation of thyroid gland and affects the progression of subsequent radiation-induced cancer.

A very large population based case-control study of thyroid cancer in children and adolescents coordinated by the International Agency for Research on Cancer has been completed recently in regions of Belarus and the Russian Federation contaminated by the Chernobyl

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