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Age and gender related dietary dose from ^{90}Sr in fallout from nuclear tests and the Chernobyl accident in Finland

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Abstract. Annual intake of ^{90}Sr trough foodstuffs and drinking water was assessed for eleven age categories of Finnish females and males in 1955–2010. Maximum intakes were received by young men in 1963–64. Cereals and milk contributed more than 80% to the dietary dose then. *Per capita* dose from ingestion of ^{90}Sr corresponded to the dose for a boy 13 years of age and a man older than 65 years. Lifetime committed effective dose from ingestion of ^{90}Sr for a newborn male was 0.49 mSv and for a 20 years old male 0.32 mSv, when the exposure of 70 and 50 years started in the beginning of 1955. For females the doses were 0.39 and 0.25 mSv, respectively. The activity concentrations of ^{90}Sr in milk varied in the whole country by a factor of two in the years of maximum fallout and decreased towards the 1980s. Also other than soil related factors have contributed to the variation in human exposure to dietary ^{90}Sr.

1. INTRODUCTION

Radioactive fallout from atmospheric nuclear weapons tests dispersed worldwide since early 1950s. In April-May 1986 the releases caused by the Chernobyl accident reached also Finland via atmospheric transport and deposition. The long-lived fission product nuclide ^{90}Sr ($T_{1/2} = 28$ years) was regularly monitored in dry plus wet deposition in Finland since 1961 [1, 2]. ^{90}Sr decays via beta emission, without gamma radiation, and is important for internal radiation of people. Because of the long lasting availability of radioactive strontium to terrestrial and aquatic food chains ^{90}Sr can contribute significantly to the dietary burden of man. Radio-ecological conditions in food production area have effect on the uptake of ^{90}Sr to human food, and on radiation doses received by population particularly via milk, cereals and certain vegetables. In the human metabolic system strontium and other alkaline earths (Ca, Ra, Th) are predominantly transferred from the blood plasma to bones where their removal is slow.

Dietary ^{90}Sr in Finland originates mainly in global atmospheric fallout since the 1950s and to a lesser degree in the releases caused by the Chernobyl accident. Studies quantifying ingestion of ^{90}Sr by age and gender are scarce, and they are needed to clarify the exposure to ^{90}Sr in various groups of population.

The aim of this study was to provide age and gender related dietary intake of ^{90}Sr, based on activity concentrations of ^{90}Sr in Finnish foodstuffs in 1960–2010 completed with European data for 1955–1959. Examples on the lifetime committed effective dose from ingested ^{90}Sr were provided. Areal long term variation in activity concentration of ^{90}Sr in milk was presented to illustrate its significance to ingestion dose from ^{90}Sr.

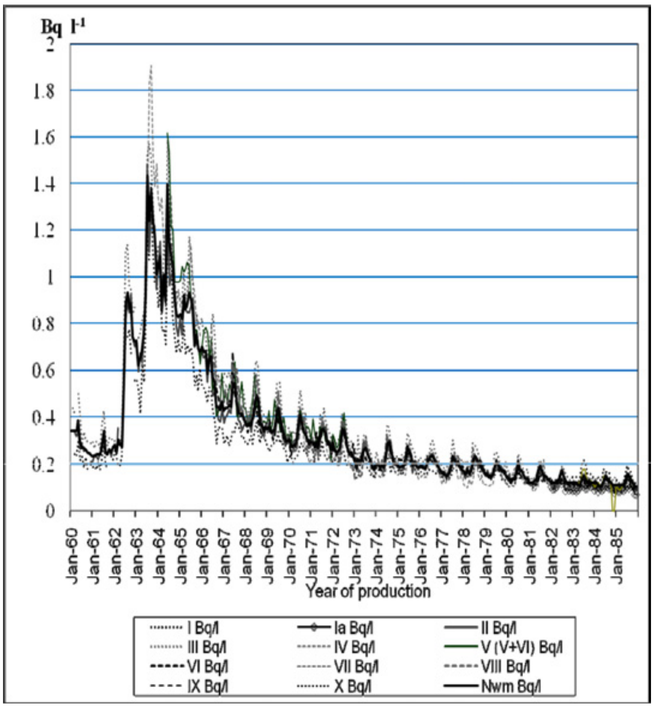

Figure 1. Monthly ^{90}Sr concentration (Bq l^{-1}) in Finnish milk. Data for eleven production areas and the nationwide production weighted mean (Nwm). Sources of data in [3].

2. MATERIAL AND METHODS

2.1 Activity concentrations of ^{90}Sr in foodstuffs

Activity concentrations of ^{90}Sr in Finnish foodstuffs were compiled earlier for the period 1960–2005. Annual p*er capita* doses from ingestion of ^{90}Sr were derived for the period 1955–2005. For the years 1955–1959 the doses were derived using simple modeling approach and data for ^{90}Sr in wet plus dry deposition, milk and average diet in Finland, Russia and United Kingdom in the 1950s and early 1960s [3]. For the present study the foodstuff data for 2005–2010 were completed using the results for milk from the recent years [2]. For the future years until 2025 the dietary intakes were extrapolated from the existing data for previous years considering only radioactive decay. Food processing losses of radionuclides were the same as in the earlier ingestion dose study [3].

The regional variation of ^{90}Sr concentration in milk was based on analysis of samples from up to eleven production areas in 1960–1985 (figs. 1 and 2). The activity concentrations in milk differed at maximum by a factor of two during the highest deposition rate of ^{90}Sr and the following increase in activity concentrations of ^{90}Sr in milk in 1963–1964. Later the variation in the ^{90}Sr concentration of milk from various production areas decreased [4].

In 1967 a survey of ^{90}Sr in milk samples from all dairies in Finland showed clearly that low concentration of exchangeable Ca in agricultural soil correlated with enhanced transfer of ^{90}Sr from soil to milk (fig. 3) [5].

2.2 Consumption of foodstuffs

Extensive mobile clinic campaigns were carried out to survey the consumption of foodstuffs by Finns in the 1960s and the 1970s. Males and females 15 to 64 years of age and also older persons were

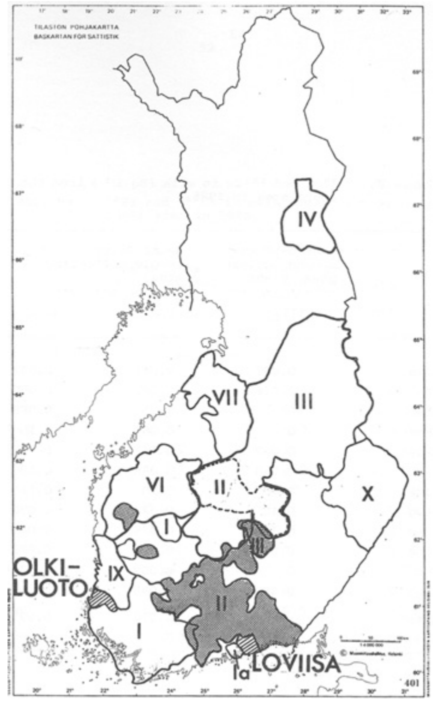

Figure 2. Sampling areas of milk analyzed for ^{90}Sr in 1960-1985 [4].

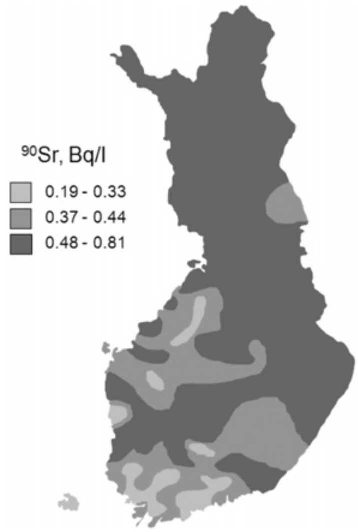

Figure 3. ^{90}Sr in milk from all Finnish dairies in winter 1967 [5].

invited to interviews where nutrition experts demonstrated the composition of a diet and estimated the interviewee's daily consumption of foodstuffs [6–8]. The intake of twenty types of food was reported for six age groups, based on ten year intervals from 15 to 24 until 64 years of age and a group of persons older than 64.

For decades the food balance sheets compiled annually by the Ministry of Agriculture and Forestry [9] have provided consumption data for *per capita* doses [3]. Consumption surveys of the food consumption of children covered boys and girls from five to thirteen years of age [10] and of children one-to-two year old (11). Infants younger than six months received 800 ml mother's milk per day during six months of exclusive breast feeding on average [12]. For children at an age without reported dietary data the intake of foodstuffs was interpolated from existing values.

For the present study the intake of vegetables and fruit was divided into agricultural and garden produce and wild foods to allow species specific consumption rate for wild foodstuffs differing from cultivated species concerning ^{90}Sr. The need for drinking water by age and gender was derived from the ICRP Publication 89 [13].

2.3 Dietary intake and committed effective dose

All food types and species of relevance to ingestion of ^{90}Sr were considered in the calculation of annual dietary intake. Food processing data and consumption of wild foods by species were based on domestic studies designed for assessments of radionuclide intake [3, 14]. The activity concentration of ^{90}Sr in mother's milk was derived from results of a study on breast feeding, based on environmental ^{90}Sr in the diet of mothers [15].

Lifelong committed effective doses were assessed from the annual intakes in calendar years related to the lifetime age categories. The conversion coefficients from intake to dose (Sv Bq^{-1}) by age were from Basic Safety Standards of the IAEA [16].

3. RESULTS

3.1 Dietary intake

Cereals and milk were the main dietary sources of ^{90}Sr for most age groups in 1960–1964 and several years thereafter. Their contribution to *per capita* intake exceeded 80% in the years of maximum fallout and decreased slowly towards the late 1980s [3]. After maximum fallout the annual intake by males and females increased temporarily after atmospheric nuclear tests in China (fig. 4). Chernobyl accident caused a clearly detectable, low increase in the dietary intake in 1986–1987.

The consumption trend towards more meat and vegetables and less milk, cereals and potato [9] was clear since the first years of the study period until the late 1970s and early 1980s. The trend was not easy to trace in the intake history (fig. 4) because of simultaneous decline of ^{90}Sr activity in most foodstuffs.

3.2 Committed effective dose

The lifetime committed effective dose from ingestion of ^{90}Sr for a newborn and an adult of 20 years of age differed clearly since the year 1955 (Table 1). The doses for males and females differed because of higher consumption rates of men and boys. The higher dose conversion coefficient for children increased their doses. The longer exposure time of the newborn naturally increased his or her dose. However, the intake period of an adult included most of the years of the highest food intake by males and females.

4. DISCUSSION

The assessment of annual intakes and committed effective dose from ingestion of ^{90}Sr, by age and gender, was based on historical representative data for radioactivity, food production, processing of foodstuffs and food consumption. The results for annual intakes during the first half of the study

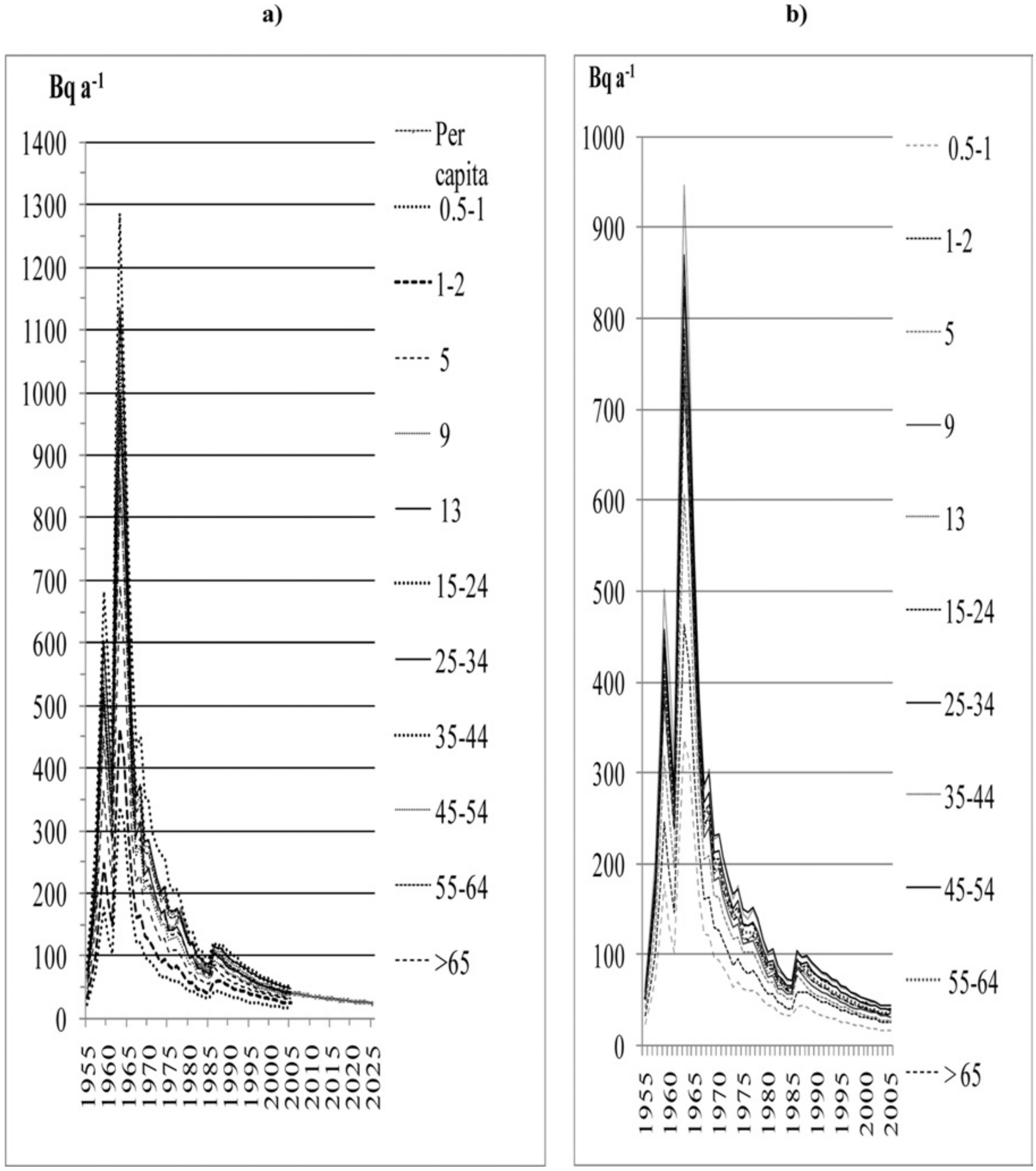

Figure 4. Annual intake of ^{90}Sr through food and drinking water by males (a) and females (b) of various ages. Age category in years is given in the legend.

period (Fig. 4) reflect relatively high intake of milk and cereals, the main sources of ^{90}Sr in the Finnish diet.

The assessment was based on nationwide production weighted means of activity concentrations. Therefore all production areas differing in growth conditions contributed to annual intakes in proportion to their fraction of annual production in the whole country. In individual intakes and committed effective doses the nationwide variation would be considerable, increased also by other than soil factors. The exposure to dietary ^{90}Sr was mainly received in Finland before the 1990s when availability of

Table 1. Lifelong committed effective dose (mSv) from dietary ^{90}Sr for a newborn and a 20-year old person. Exposure time was 75 years for a newborn and 50 years for an adult, starting in the beginning of 1955.

Period of exposure and the subject	Males by age category (a) of the dose conversion							Females by age category (a) of the dose conversion						
	≤ 1	1-2	2-7	7-12	12-17	>17	Life-long	≤ 1	1-2	2-7	7-12	12-17	>17	Life-long
1955-2025 Newborn	0.004	0.005	0.054	0.18	0.12	0.12	0.49	0.004	0.005	0.049	0.15	0.086	0.097	0.39
1955-2005 Adult	–	–	–	–	–	0.32	0.32	–	–	–	–	–	0.25	0.25

information about the regional origin of foodstuffs was better than after the great changes in the food supply chain in the 1990s. The availability of representative data facilitated the assessment and refers to the value of the data from the first decades of nuclear era for evaluation of health risks from dietary ^{90}Sr. The data compiled for this study allows further analysis of the population dose from ingestion of environmental ^{90}Sr through food and water in Finland.

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