30 years of exposure to Chernobyl originating radionuclides: two case studies on food and wood contamination in the Ukraine

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1. Introduction

The explosion of the 4th reactor at the Chernobyl nuclear power plant (ChNPP) contaminated vast areas of agricultural land and forest with a range of radionuclides (De Cort et al., 1998; Kuriny et al., 1993). According to the latest radiological surveillance data, the average annual dose to population of a number of settlements in Ukraine is still above the dose limit of 1 mSv/year established for individual members of public (Lihtarov, 2013, 2012). In these settlements, the primary route of exposure to radioactive elements is by consumption of locally produced foodstuffs contaminated by radionuclides. Among those radionuclides, ^{137}Cs and ^{90}Sr are the most important long-lived elements in terms of widespread contamination and their potential to enter the food chain by, for example, accumulating in grain crops (Krouglov et al., 1997) and in milk (Belli et al. 1989; Fesenko et al. 2007). It has been reported that cow's milk, wild mushrooms and wild berries are the main contributors (70 – 90%) to the internal dose of people residing on ^{137}Cs contaminated territories.

There are two regions in Ukraine that have ongoing problems with locally produced food being contaminated with ^{137}Cs, including milk and beef (Lihtarov, 2013; UIAR, 2015) – the Rivne region (area: 20047 km^2, population: about 1.2 million) and the Zhytomyr region (area: 29832 km^2, population: about 1.3 million) (see Fig. 1). The most critical situation has been observed in the Rokytne district of Rivne region (area: 2350 km^2, population: 56 276), in which soil contamination is accompanied by particularly high soil-to-plant transfer coefficients for ^{137}Cs, resulting in abnormally high bioavailability of radioceasium (Maloshtan et al., 2015; Prister et al., 1993). A Greenpeace research team visited Rokytne district in 2011 in order to investigate contamination of foodstuffs by radionuclides in the region. Our data (Labunska et al., 2011) showed that, even 25 years after the Chernobyl catastrophe, most of the local milk (93%) from Drozdyn village in Rokytne district exceeded Ukrainian norms for ^{137}Cs in milk products for children by factors ranging between 1.2 and 16.3.

In addition, trees growing on radioactively contaminated areas appear to play an important role in redistribution of radionuclides by 'pumping' radionuclides back to the surface soil through root uptake and subsequent leaf litter fall (Kashparov et al., 2012; Thiry et al., 2009). Moreover, the latter study estimated that a maximum in ^{90}Sr cycling can be expected to occur around 40 years after trees are planted. This can result in substantial ^{90}Sr transfer to the surface soil (12%) as well as accumulation in tree biomass (7%) as was found for trees at the Red Forest waste site in Chernobyl Zone (Thiry et al., 2009). Currently, the activity concentration of ^{90}Sr in firewood (Otreshko et al., 2015) and locally grown grains (Otreshko et al., 2014) in Ivankiv district of the Kyiv region, which is adjacent to the Chernobyl Exclusion Zone, may exceed permissible levels established by the Ukrainian government of 60 Bq/kg and 20 Bq/kg respectively (Ministry of Health of Ukraine, 2006, 2005).

At the same time, the usage of forest trees as a fuel in rural private households is commonplace in Ukraine. Furthermore, due to current economic difficulties, particularly with shortage of oil and gas, a thermal power plant (TPP) utilizing wood sourced from local forests has been built in the Ivankiv district of the Kyiv region in Ukraine (see Fig.1). As this area has a known legacy of forest tree contamination with ^{90}Sr after the Chernobyl accident (Otreshko et al., 2015), the local public are very concerned about potential for this TPP to enhance the spread of radiation in the surrounding area.

Fig. 1 Location of Rivne, Zhytomyr, and Kyiv regions on the map of the Ukraine. ChNPP – Chernobyl Nuclear Power Plant.

It is important to note that, due to various restructuring issues, governmental monitoring of goods for radionuclide content in the Ukraine has rarely been performed during the last few years. The last large-scale investigations of radionuclides from Chernobyl in milk and potato were conducted in the Ukraine in 2012 (Lihtarov, 2013). Some selective monitoring of agricultural products and forest goods is currently undertaken for the ^{137}Cs content, and then only in the most critical regions in the Ukraine (UIAR, 2015). Moreover, the measurement of ^{90}Sr in goods has completely stopped in Ukraine due to various factors including the complexity and duration of the analysis as well as its cost.

The aims of the current study were therefore to:

- Re-visit Rokytne district in Rivne region of Ukraine and conduct a more detailed investigation of locally produced milk and mushrooms for ^{137}Cs content in order to evaluate the current situation and estimate temporal trends (30 years after the Chernobyl accident);
- Investigate food grains grown in Ivankiv district, Kyiv region, Ukraine, for ^{90}Sr content;
- Investigate trees grown in Ivankiv district, Kyiv region, Ukraine, and used as firewood, for their ^{90}Sr content;
- Compare obtained data with existing Ukrainian legislation.

The sampling program, including field–work, was conducted jointly by a team from Greenpeace International and scientists from the Ukrainian Institute of Agricultural Radiology (UIAR), part of the National University of Life and Environmental Sciences of Ukraine. The participation and assistance provided by scientists from the UIAR is very much appreciated.

2. Sampling programme

Milk, mushrooms and hay samples from Rokytne district, Rivne region, Ukraine

In September 2015, fifty milk samples were collected from private households in three villages of Rokytne district, Rivne region, Ukraine: Vezhytsya, Stare Selo, and Drozdyn, located about 200km to the west from ChNPP. Cows are still grazing on pastures around villages at that time of the year. The locations of the villages are presented in Fig. 2, and a description of the sampling areas in Table 1. In general, the specific activity of ^{137}Cs in milk from these villages has previously been found to exceed several fold the Ukrainian permissible level (PL) for milk of 100 Bq/kg during the whole post-Chernobyl period (UIAR, 2015). Over the same period, soil contamination by ^{137}Cs in these villages has not been found to exceed 185 kBq/km^2 (see Fig. 2). The elevated activity concentration of radiocesium in cow's milk in such areas of Ukraine is caused by a specific properties of peat-bog soils (types 131 – 138, see Fig. 3), which are typical for Ukrainian-Belarusian Polissya, and characterized by the abnormally high soil-to-plant transfer coefficient for ^{137}Cs (Maloshtan et al., 2015).

Traditionally for the studied area, people regularly include wild mushrooms and berries in their diet, foods which grow abundantly in the forests surrounding the villages of Drozdyn, Stare Selo and Vezhytsya. However, the lack of rainfall in the Ukraine during summer-autumn period of 2015 caused droughts and a very limited growth of mushrooms. Therefore, only six dry mushroom samples (collected in 2014) were obtained from Vezhytsya village in addition to one fresh mushroom sample collected on the edge of Stare Selo village during the current sampling program.

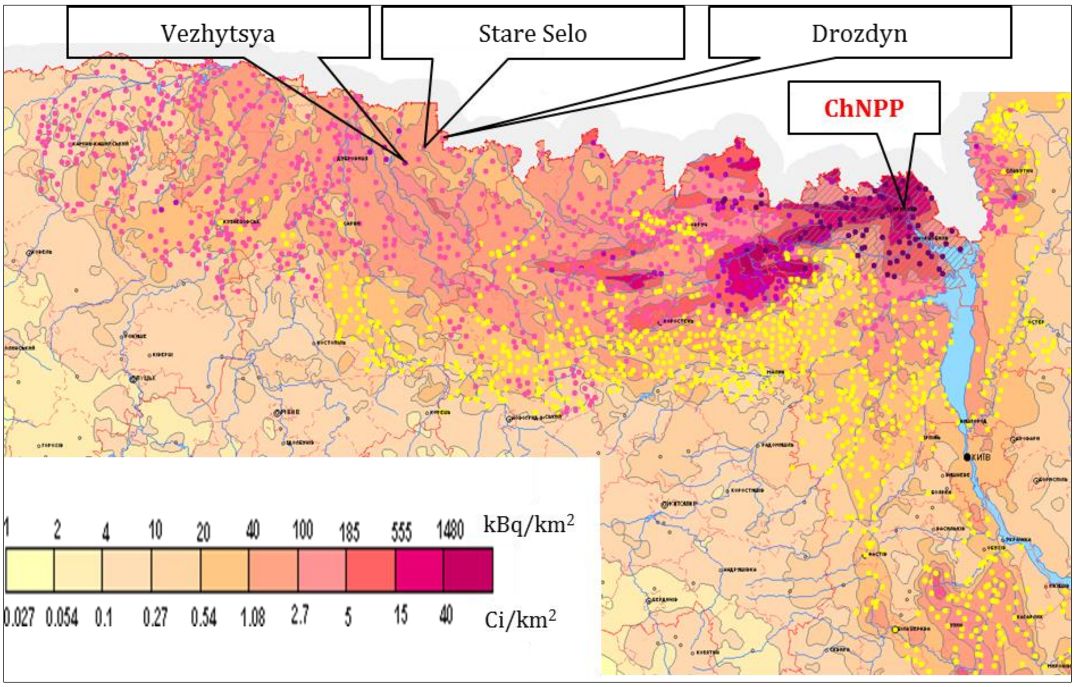

Fig. 2 Location of Vezhytsya, Stare Selo, and Drozdyn villages on the map showing the density of contamination of the territory of the Ukraine by ^{137}Cs.

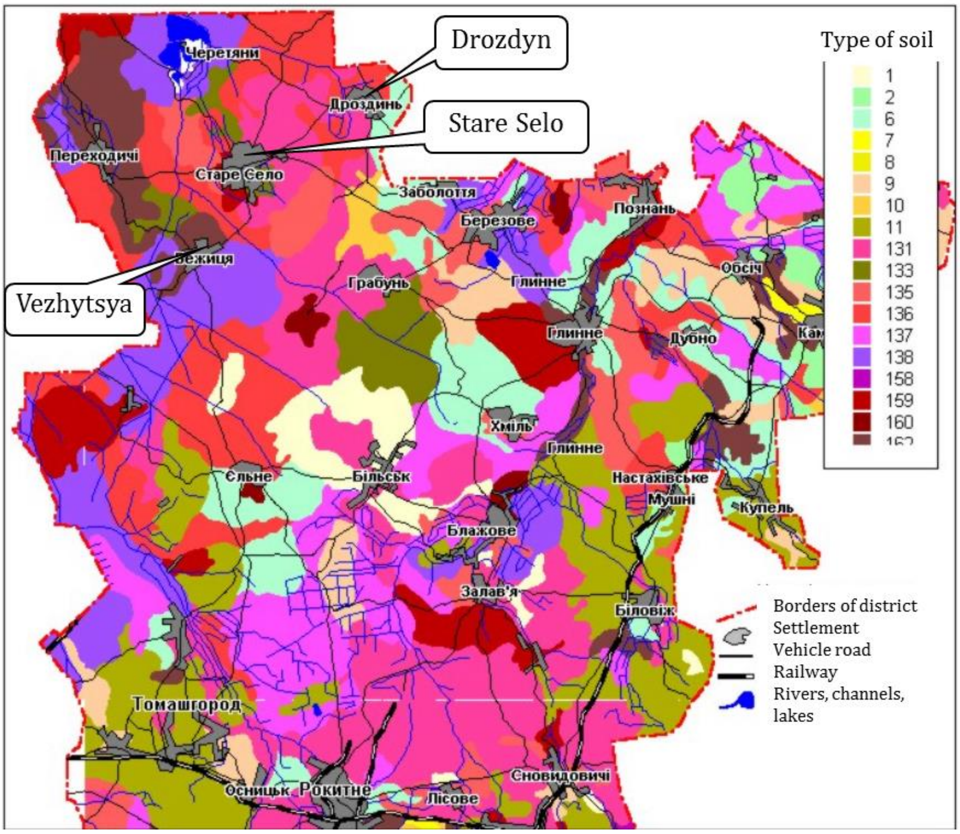

Fig. 3 Types of soil in Rokytne district, Rivne region, Ukraine:

1	***Soddy pseudopodzolic sandy soils (pine forest sands)***
2	***Soddy-light and middle podzolic sandy and clay-sandy soils***
6	***Soddy pseudopodzolic and light podzolic gleyic sandy soils***
7	***Soddy-light podzolic gleyic sandy sand soils***
8	***Soddy- middle podzoilc gleic sandy sand soils (in complex only)***
9	***Soddy-light podzolic clay sandy and loamy sand soils***
10	***Soddy-middle and heavy podzolic clay sandy and sandy loam soils***
11	***Soddy-podzolic heavy gleic soils***
131	***Meadow bog soils***
133	***Bog soils***
135	***Peat-bog soils***
136	***Peaty-bog soils***
137	***High moor and transition peats***
138	***Low moor peats***
158	***Soddy developed sandy soils***
159	***Soddy gleyish sandy and clay sandy soils***
160	***Sands turf-covered light humified and non-humified soils***
162	***Soddy gleyish sandy sand and sandy loam soils***

Name of village	Total number of residents	Number of children (% of total residents)	Number of cows in village*	Number of milk samples collected in current study
Drozdyn	2419	1077 (44%)	565	15
Stare Selo	3847	1627 (42%)	800	20
Vezhytsya	1131	460 (41%)	330	15

Table 1 Description of milk sampling areas in Rokytne region, Rivne region, Ukraine. * - data from 2014.

Additionally, one hay sample was obtained from one of the households of Drozdyn village, which was harvested from the Luchych pasture where all cows from this village are grazing. About 250ml of fresh milk was obtained directly from the farmers and stored in pre-cleaned plastic bottles. Mushroom and hay samples were obtained in various quantities – as kindly donated by village residents - and collected into plastic bags. All samples were transported to the UIAR laboratory for ^{137}Cs analysis.

Wood and grain samples from Ivankiv district, Kyiv region, Ukraine

In total, twelve grain samples were collected from fields in Ivankiv district, Kyiv region, Ukraine, located in the vicinity of the Chernobyl Exclusion Zone (see Fig. 4, Fig.5 & Table 2). Most of the grain samples (G01-09, see Table 2) were collected directly from fields during harvesting time in August 2015. A further three samples of wheat (G10 – 12) of known provenance (a field near Fedorivka village) were collected in September 2015 from a farmer's grain storage facilities in Bolotnya village.

Grain sampling was conducted in accordance with the standard procedure established by the Ministry of Agricultural Policy and Food of the Ukraine (Kashparov et al., 2006). In brief, about 1 kg of ears of grains was manually collected at a location within a field at least 100 m away from the field edge. At each sampling point, the equivalent dose rate was measured at 1 m height using dosimeter PKC-01 "CTOPA-TY» (ECOTEST, Ukraine). The dose rate ranged from 0.09 to 0.13 μSv/h at the time of sampling. Sampling coordinates were determined utilizing GPSmap (Garmin, USA).

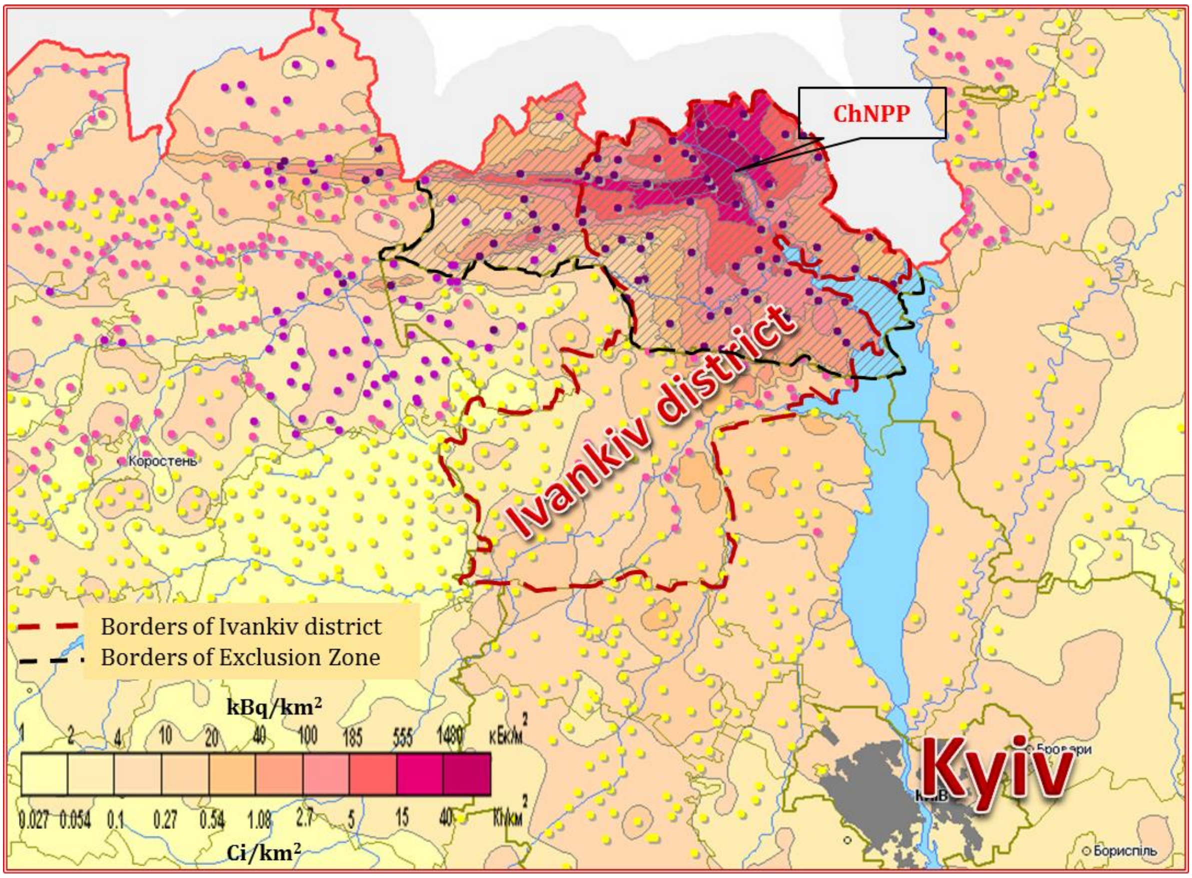

Fig. 4 Location of Ivankiv district, Kyiv region, on the map of territory of the Ukraine contamination by 90Sr.

Fig. 5 Sampling points for wood (W01-12) and grain (G01-12) samples in Ivankiv district, Kyiv region, Ukraine.

Code	Plant type (*Latin name*)	Settlement	Latitude	Longitude
G01	wheat (*Tríticum*)	Prybirsk	51.007N	29.953E
G02	oat (*Avéna*)	Dytiatky	51.112N	30.127E
G03	oat (*Avéna*)	Dytiatky	51.111N	30.126E
G04	rye (*Secále cereále*)	Gornostaypil'	51.076N	30.241E
G05	rye (*Secále cereále*)	Gornostaypil'	51.081N	30.263E
G06	rye (*Secále cereále*)	Pisky	51.097N	30.022E
G07	rye (*Secále cereále*)	Domanivka	51.082N	29.983E
G08	oat (*Avéna*)	Pyrogovychi	50.990N	29.953E
G09	oat (*Avéna*)	Pyrogovychi	50.986N	29.955E
G10	wheat "Stolichna" (*Tríticum*)	Fedorivka	50.982N	29.903E
G11	wheat "Favorit" (*Tríticum*)	Fedorivka	50.986N	29.896E
G12	wheat "Yasochka" (*Tríticum*)	Fedorivka	50.984N	29.892E

Table 2 Location of sampling points for grain samples, Ivankiv District, Kievska Oblast, Ukraine, 2015.

Code	Plant type (*Latin name*)	Trunk diameter, cm (mean±STD, n=5)	Latitude	Longitude
W01	pine (*Pinus sylvestris L.)*	36±1	50.815N	30.066E
W02	pine (*Pinus sylvestris L.)*	36±4	50.861N	30.043E
W03	pine (*Pinus sylvestris L.)*	31±8	50.874N	29.993E
W04	pine (*Pinus sylvestris L.)*	29±6	50.896N	29.961E
W05	pine (*Pinus sylvestris L.)*	38±1	50.895N	29.939E
W06	pine (*Pinus sylvestris L.)*	32±7	50.895N	29.93E
W07	pine (*Pinus sylvestris L.)*	33±4	50.894N	29.917E
W08	pine (*Pinus sylvestris L.)*	22±4	50.908N	29.938E
W09	pine (*Pinus sylvestris L.)*	34±5	51.027N	30.053E
W10	birch (*Bétula péndula*)	28±5	50.964N	29.853E
W11	pine (*Pinus sylvestris L.)*	27±6	50.962N	29.906E
W12	pine (*Pinus sylvestris L.)*	27±5	50.897N	29.962E

Table 3 Location of sampling points for wood samples, Ivankiv District, Kievska Oblast, Ukraine, 2015.

Sixty wood samples were collected at twelve sampling points from the forests of Ivankiv district (see Fig. 4, Fig 5 & Table 3). Five mature standing trees were sampled at each of the twelve points and their diameters were recorded. Distance between sampled trees at an individual sampling point varied from 2m to 10m.

Fig. 6 View of a sample collected from a single tree.

At each sampling point, the equivalent dose rate was measured at 1 m height using dosimeter РКС-01 "СТОРА-ТУ» (ECOTEST, Ukraine). The dose rate ranged from 0.09 to 0.12 μS/h at the time of sampling. Sampling coordinates were determined utilizing GPSmap (Garmin, USA).

Each sample was taken by drilling through a tree trunk at 1.3 m height with a special hole bore (diameter 0.5 cm) obtaining a cylindrical wood sample as shown on Fig. 6. Samples from five trees were then combined to form a pooled sample from each sampling location. Environmentally friendly sealant was applied to each sampled tree for its protection.

3. Methodology

The analysis for ^{137}Cs in milk, mushrooms and hay samples was conducted using gamma-spectrometer with High Purity Germanium detector (GEM-30185) coupled to a multi-channel analyser (ASPEC-927) and interfaced with GammaVision 32 (ORTEC, USA). For measurements, samples were placed into a 100 cm^3 cylindrical container.
For ^{90}Sr analysis, samples of ears of grains were dried and de-seeded manually in the UIAR laboratory. Both wood and dried grain samples were subject to calcination at 450°C followed by a radiochemical analysis according to the standard procedure (Pavlotskaya, 1997) utilizing beta-spectrometer СЕБ-01-70 (АКП, Ukraine).

Regular calibrations of gamma- and beta-spectrometers were performed using a certified mixed radionuclides source containing ^{137}Cs and ^{40}K (density 1g cm^{-3}) (Odessa Research and Production Center for Ecological Safety, Ukraine) and Standard Radionuclide Solution of ^{90}Sr (D.I. Mendeleyev Institute for Metrology, Russia), respectively. Verification of the analysis was performed using Reference Material IAEA-375 “Radionuclides and Trace elements in soil” and IAEA-473 “Milk powder” (Austria).

4. Results and discussion

^{137}Cs in milk samples

The results of ^{137}Cs analysis in milk samples from Drozdyn, Stare Selo and Vezhytsya villages are presented in Tables 4, 5, and 6 respectively. The average ^{137}Cs activity concentration for these three villages ranges from 213 Bq/l to 375 Bq/l, which exceed several fold both adult (APL) and child permissible levels (ChPL) established in the Ukraine (Ministry of Health of Ukraine, 2006). The maximum ^{137}Cs activity concentration at 640 Bq/l was detected in milk from Drozdyn village, exceeding ChPL 16 times, which was very similar to our previous finding in 2011 for the same village (milk max: 650 Bg/l) (Labunska et al., 2011). Unfortunately, the situation has not changed significantly during the intervening years and children in the investigated area will therefore still be exposed to high levels of radiocesium through consumption of contaminated milk.

Village name	Pasture name	Code	^{137}Cs, Bq/kg	Uncertainty*, Bq/kg	Ratio to APL ^{137}Cs (100 Bq/kg)	Ratio to ChPL ^{137}Cs (40 Bq/kg)
Drozdyn	Lyuchych	Milk01	620	70	6.2	15.5
		Milk02	390	50	3.9	9.8
		Milk03	310	40	3.1	7.8
		Milk04	310	40	3.1	7.8
		Milk05	280	40	2.8	7.0
		Milk06	280	40	2.8	7.0
		Milk07	330	40	3.3	8.3
		Milk08	260	30	2.6	6.5
		Milk09	510	60	5.1	12.8
		Milk10	360	40	3.6	9.0
		Milk11	470	60	4.7	11.8
		Milk12	300	40	3.0	7.5
		Milk13	270	30	2.7	6.8
		Milk14	640	80	6.4	16.0
		Milk15	290	40	2.9	7.3
		min	260	n/a	2.6	6.5
		max	640	n/a	6.4	16.0
		Average for village	375	n/a	3.7	9.4
		SD	126	n/a	1.3	3.2

Table 4 Activity concentration of ^{137}Cs, in Bq/kg, in milk (n=15) from Drozdyn village, Rivnenska Oblast, Ukraine, 2015. (APL – adult permissible level; ChPL – child permissible level); * - 95% confidence interval.

Our current data are consistent with earlier observations conducted by Ukrainian scientific institutions (Lihtarov, 2013, 2012; UIAR, 2015) as can be seen from Fig. 7. The situation has not changed greatly, and differences in annual average ^{137}Cs activity concentration in milk from these three villages were within the range of standard deviation and expected seasonal variations. Despite decreasing soil ^{137}Cs activity concentration arising from radionuclide decay, contamination of milk from local cows may well persist for many decades to come.

A range of countermeasures have been proposed and conducted in Ukraine, including radical improvement of fields and treatment of cows with ferrocyn (Fesenko et al., 2013; Jacob et al., 2009), which is capable of significantly reducing the transfer of radiocesium from cow to milk resulting in reduction of ^{137}Cs activity concentration in milk below Ukrainian PL (Fesenko et al., 2013). However, this practice has been stopped since 2009, contributing to the ongoing radiation exposure of people residing on contaminated areas. It is therefore important to take urgent actions to prevent further unnecessary human exposure, children in particular, *via* locally produced milk.

Additionally, one hay sample was collected from Drozdyn village from the person who also provided milk sample № 9. The grasses for this hay were harvested from the local pasture where cows are grazing during the spring to autumn period. The activity concentration of ^{137}Cs in the hay sample amounted to 5290 Bq/kg. The activity concentration of ^{137}Cs in milk from cows consuming hay (or other feed) may be estimated using equation below (Lazarev, 1998):

$$C_{milk} = C_{hay} \times W_{hay} \times \frac{TC}{100}$$

where C_{milk} is activity concentration of ^{137}Cs in milk, in Bq/kg; C_{hay} is activity concentration of ^{137}Cs in hay, in Bq/kg; W_{hay} is daily intake of hay by a cow, in kg; and TC is hay-milk transfer coefficient (Lazarev, 1998).

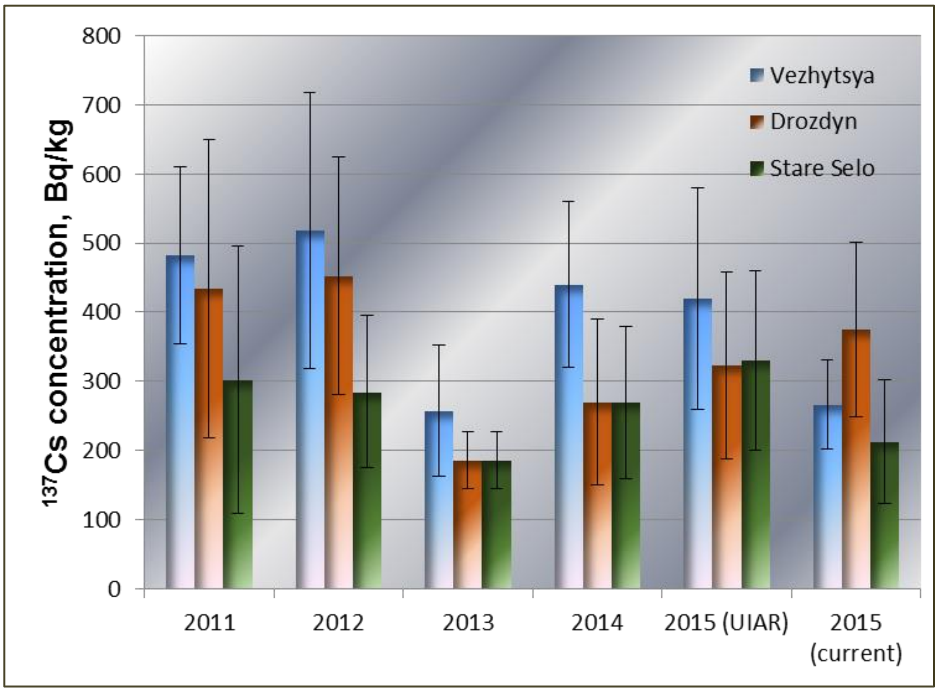

Fig. 7 ^{137}Cs activity concentration in milk from Vezhytsya, Drozdyn, and Stare Selo villages. Data for 2011 – 2013 from Lihtarov 2013 & 2012; for 2014 – UIAR, 2015.

Typical daily intake of hay for a cow during winter period is 10kg. Therefore, the estimated ^{137}Cs activity concentration in milk from a cow consuming hay containing ^{137}Cs at 5290Bq/kg would be 529 Bq/kg, which is very close to the value measured in the current study for milk (510

Bq/kg) from cows known to have been fed the contaminated hay. Milk from cows fed on contaminated hay or pasture can be expected to have elevated ^{137}Cs activity concentration throughout the year. In contrast, as we reported in our study in 2011 (Labunska et al., 2011), feeding cows with hay sourced from radiologically clean areas resulted, in most cases, in ^{137}Cs levels in milk below Ukrainian PL.

It is important to note that these villages have a relatively high number of children (3164 in total – see Table 1) comprising from 41% to 44% of the total population of a village. Chronic exposure to radioactive elements is known to cause a number of diseases and pathologies in children residing on radioactively contaminated territories, including disorders of the immune system (Sheikh Sajjadieh et al., 2011; Stepanova et al., 2010), haematological effects (Stepanova et al., 2008), respiratory disorders (Svendsen et al., 2015), functional abnormalities of the cardiovascular system (Stepanova et al., 2011), among others. A recent epidemiological study conducted among children in Rivne region (Wertelecki et al., 2014) has shown that rates of conjoined twins, teratomas, neural tube defects, microcephaly, and microphthalmia were among the highest in Europe.

Village name	Pasture name	Code	^{137}Cs, Bq/kg	Uncertainty*, Bq/kg	Ratio to APL ^{137}Cs (100 Bq/kg)	Ratio to ChPL ^{137}Cs (40 Bq/kg)
Stare Selo	Lebid	Milk20	320	40	3.2	8.0
		Milk41	240	30	2.4	6.0
		Milk42	280	30	2.8	7.0
		Milk25	340	40	3.4	8.5
		Milk35	340	40	3.4	8.5
		Milk43	300	40	3.0	7.5
	Voronyache	Milk17	290	40	2.9	7.3
		Milk19	290	40	2.9	7.3
		Milk34	230	30	2.3	5.8
		Milk18	260	30	2.6	6.5
		Milk40	140	20	1.4	3.5
		Milk16	220	30	2.2	5.5
	Terenovka	Milk44	110	20	1.1	2.8
		Milk49	99	16	1.0	2.5
	Pogonya	Milk45	100	20	1.0	2.5
	Before Vezhytsya	Milk39	160	20	1.6	4.0
	Before Perehodychi	Milk46	170	20	1.7	4.3
		Milk47	220	30	2.2	5.5
	Melechova	Milk48	68	14	0.7	1.7
		Milk50	90	17	0.9	2.3
		min	68	n/a	0.7	1.7
		max	340	n/a	3.4	8.5
		Average for village	213	n/a	2.1	5.3
		SD	90	n/a	0.9	2.2

*Table 5 Activity concentration of ^{137}Cs, in Bq/kg, in milk (n=20) from Stare Selo village, Rivne region, Ukraine, 2015. APL – adult permissible level, ChPL – child permissible level; * - 95% confidence interval.*

Village name	Pasture name	Code	^{137}Cs, Bq/kg	Uncertainty*, Bq/kg	Ratio to APL ^{137}Cs (100 Bq/kg)	Ratio to ChPL ^{137}Cs (40 Bq/kg)
Vezhytsya	Dovga	Milk30	170	20	1.7	4.3
		Milk26	250	30	2.5	6.3
		Milk29	170	20	1.7	4.3
		Milk23	230	30	2.3	5.8
		Milk24	240	30	2.4	6.0
		Milk38	310	40	3.1	7.8
		Milk32	240	30	2.4	6.0
		Milk36	340	40	3.4	8.5
		Milk27	230	30	2.3	5.8
		Milk31	310	40	3.1	7.8
		Milk37	280	30	2.8	7.0
		Milk22	390	50	3.9	9.8
		Milk33	140	20	1.4	3.5
		Milk28	320	40	3.2	8.0
		Milk21	380	50	3.8	9.5
		min	140	n/a	1.4	3.5
		max	390	n/a	3.9	9.8
		Average for village	267	n/a	2.7	6.7
		SD	75	n/a	0.8	1.9

Table 6 Activity concentration of ^{137}Cs, in Bq/kg, in milk (n=15) from Vezhytsya village, Rivne region, Ukraine, 2015. APL – adult permissible level, ChPL – child permissible level; * - 95% confidence interval.

^{137}Cs in mushrooms samples

The results of the analysis for ^{137}Cs in mushrooms are presented in Table 7.

Code	^{137}Cs, Bq/kg	Uncertainty*, Bq/kg	Ratio to PL
DM01	39000	3900	15.6
DM02	10400	1000	4.2
DM03	40200	4000	16.1
DM04	23000	2300	9.2
DM05	10300	1000	4.1
DM06	10900	1100	4.4
FM01	1100	130	2.2
min DM	10300	n/a	4.1
max DM	40200	n/a	16.1
Average DM	22300	n/a	8.9
SD	14250	n/a	5.7

Table 7 Activity concentration of ^{137}Cs, in Bq/kg, in dry mushrooms (DM, n=6) and fresh mushrooms (FM, n=1) from Vezhytsya village, Rivne region, Ukraine, 2015. PL – permissible level; * - 95% confidence interval.

Though it was possible to obtain only a limited number of mushrooms in our study, those available showed high levels of ^{137}Cs contamination, exceeding the Ukrainian PL in all cases. The average ^{137}Cs activity concentration in dry mushrooms (n=6) was almost 9 times of the Ukrainian PL (2500 Bq/kg), while the sample with maximum activity concentration of ^{137}Cs was 16 times the PL. A single sample of fresh mushrooms also had ^{137}Cs activity concentration exceeding the PL (500 Bq/kg). Mushrooms in Rokytne district are a very important traditional food and, being heavily contaminated by ^{137}Cs, likely contribute substantially to total internal radiation dose.

^{90}Sr in forest wood and grain samples

Among twelve wood samples collected in this study, nine had ^{90}Sr activity concentration exceeding Ukrainian PL for firewood of 60 Bq/kg (Ministry of Health of Ukraine, 2005), in the range of 1.1 to 4.6 times the limit value (Table 8). A previous study conducted in Ivankiv district (Otreshko et al., 2015) showed that activity concentration of ^{90}Sr in small brushwood (length ~ 20 cm, diameter ~5 cm) exceeded Ukrainian PL in samples collected from locations in around half of this district territory.

To investigate further, we collected three samples from mature standing trees growing in the same areas studied by Otreshko et al. 2015, additionally to those samples collected from areas that had not been studied previously. The comparison of the results for these three locations is presented in Fig. 8. For two of the locations (our samples W08 and W11), activity concentration of ^{90}Sr in standing trees were higher than those previously reported in brushwood. However, at a third location (our sample W03), ^{90}Sr activity concentration found in our study was lower than those reported for brushwood by Otreshko et al. 2015. Nevertheless, at all three locations in the current study, the levels of radioactive strontium in the wood samples exceeded the Ukranian PL by a significant margin.

Wood samples				Grain samples			
Code	^{90}Sr, Bq/kg	Uncertainty*, Bq/kg	Ratio to PL (60 Bq/kg)	Code	^{90}Sr, Bq/kg	Uncertainty*, Bq/kg	Ratio to PL (20 Bq/kg)
W01	43	18	0.7	G01	26.7	2.4	1.3
W02	75	18	1.3	G02	49.7	4.5	2.5
W03	113	15	1.9	G03	41.0	4.1	2.1
W04	103	12	1.7	G04	16	1.6	0.8
W05	67	17	1.1	G05	4.3	0.4	0.2
W06	57	21	1.0	G06	21	2.3	1.1
W07	51	19	0.9	G07	35	3.9	1.8
W08	278	12	4.6	G08	4.4	0.7	0.2
W09	101	14	1.7	G09	3.4	0.6	0.2
W10	90	14	1.5	G10	1.8	0.4	0.1
W11	108	15	1.8	G11	2.2	0.5	0.1
W12	207	11	3.5	G12	3.8	0.7	0.2

Table 8 Activity concentration of ^{90}Sr, Bq/kg, in forest wood (n=12) and grain (n=12) samples from Ivankiv district, Kyiv region, Ukraine, 2015. PL – permissible level; * - 95% confidence interval.

These data have shown that both brushwood and mature trees contain significant residues of radioactive strontium and are likely therefore to act as an important source of this radionuclide to the air and to ash in case these woods are used as firewood, in private households, for example. To investigate this, we collected one sample of ash from a local private house using brushwood as a fuel for the oven. This ash sample was analysed for both ^{90}Sr and ^{137}Cs and contained these radionuclides at activity concentration of 6950 Bq/kg and 650 Bq/kg, respectively.

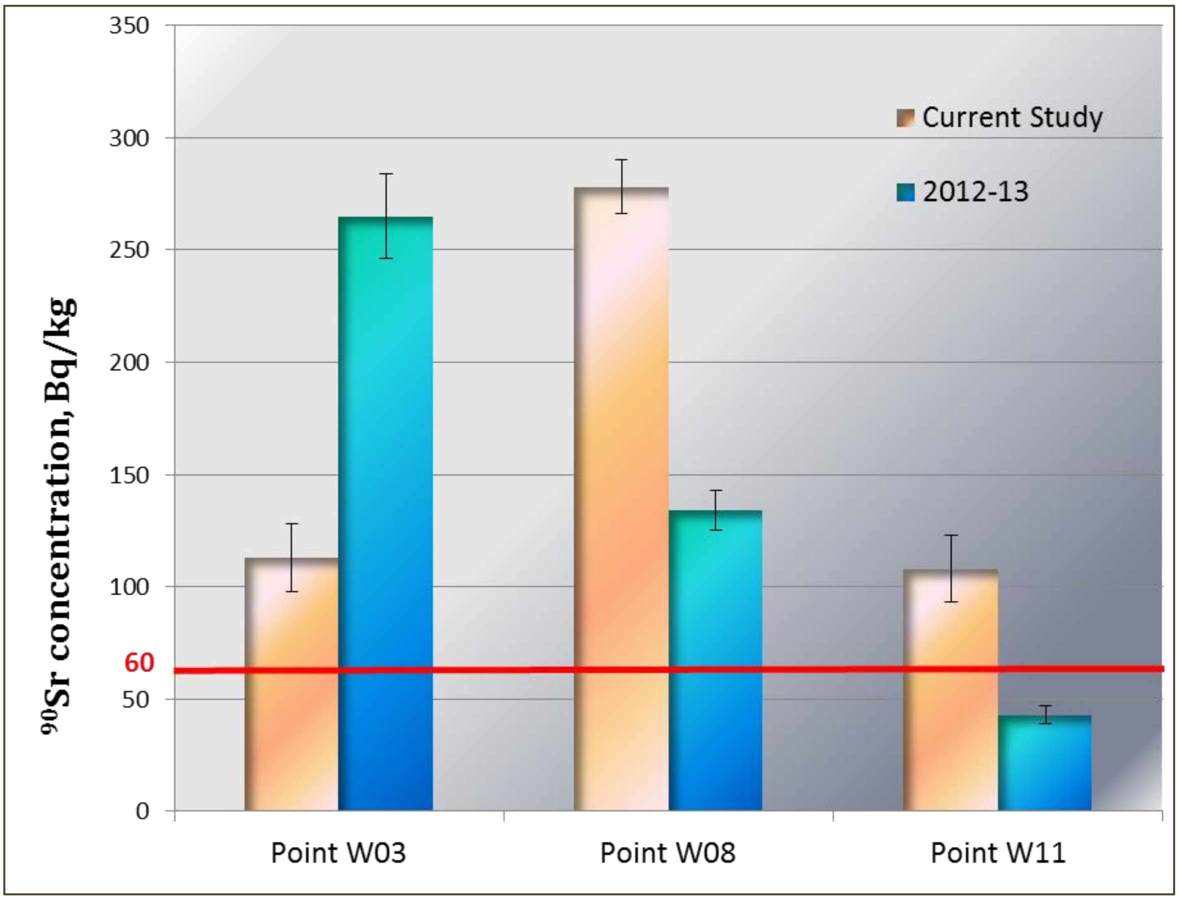

Fig. 8 Activity concentration of ^{90}Sr in brushwood (data from 2013 -2013, by Otreshko et al. 2015) and in wood from mature standing trees (current study). Error bar – uncertainty of measurement.

The activity concentration of ^{90}Sr recorded for the grain samples in our study exceeded the Ukraine PL of 20 Bq/kg) (Ministry of Health of Ukraine, 2006) in 42% of the samples (see Table 8). Our data are consistent with previous investigations for ^{90}Sr content in grains in Ivankiv district (Kashparov et al., 2013; Otreshko et al., 2014), confirming that the situation regarding grain contamination by ^{90}Sr in this region is not improving and, in some areas, appears to be getting worse, most probably due to the increased bioavailability of this radionuclide.

The first observations of increased ^{90}Sr accumulation in grains (three to eight fold) were reported for the 1988-1994 period (Krouglov et al., 1997), as the main part of the ^{90}Sr was released from the fuel particles, which deposited in the region after ChNNP explosion. This has subsequently become available for uptake by plants. Taking into account that the governmental monitoring of goods for ^{90}Sr in Ukraine has not been carried out for more than two decades

(Kashparov et al., 2001), the situation with ^{90}Sr contamination of the grains grown in the Ivankiv district remains of major concern and deserves further urgent investigation.

5. Conclusions

Analysis of milk, grain, mushroom, hay and wood samples collected from a number of villages located to the west and south-west of the Chernobyl nuclear power plant (ChNPP) in August-September 2015 has reconfirmed that high levels of radionuclide contamination, both caesium-137 (^{137}Cs) and strontium-90 (^{90}Sr), still persist almost 30 years after the accident.

- Of 50 milk samples collected from 3 villages located approximately 200 km from ChNPP, all but 4 contained ^{137}Cs at levels above the limit value set for consumption by adults in Ukraine, and all were substantially above the lower limit set for children
- A sample of the hay fed to cattle, collected from a farm in one of the villages, contained levels of ^{137}Cs that could readily explain the high activity concentration found in the milk
- Although mushrooms were scarce at the time of sampling due to dry weather, a single fresh sample had ^{137}Cs activity concentration more than twice the Ukrainian limit value for human consumption. Six samples of dried mushrooms, stored by local families after collection in 2014, contained levels of ^{137}Cs between 4 and 16 times the higher limit for dried products
- 42% of grain samples collected from fields in Ivankiv district, approximately 50 km from ChNPP, had ^{90}Sr activity concentration above limit values for human consumption, and in two cases more than double this limit
- Of 12 composite wood samples collected in the same district, 9 exceeded Ukrainian permissible limits for ^{90}Sr in firewood. In a single ash sample collected from a household oven using local brushwood as fuel, levels of ^{90}Sr were more than 20 times higher than in the most contaminated wood sample found in this study

The ongoing contamination of food and wood products in these regions to the west ans south-west of ChNPP raises very serious concerns regarding the pervasive and long-term exposure of local people to harmful radionuclides, including children born decades after the accident. Practical measures exist that could help reduce the presence of radionuclides in food products, such as sourcing hay and other forage from outside the contaminated areas and treatment of cattle with ferrocyn to reduce transfer to milk. To our knowledge, however, such measures have not been effectively maintained in recent years. Furthermore, continued operation of the recently constructed thermal power plant using locally sourced wood represents an additional pathway for the wider redistribution of harmful radiation.

The current lack of routine and comprehensive environmental and food monitoring programmes is a major omission, and one that continues to place severe limits on the assessment of radiological risk and on the design and implementation of measures that could otherwise help limit exposures to ^{137}Cs and ^{90}Sr in local communities. If areas of high contamination are to be identified and properly managed to avoid further spread of radionuclides, and if the burden of radiation-related disease in these impacted communities is to be reduced, it is vital that such scientific surveillance programmes are reinstated and properly financed into the future.

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