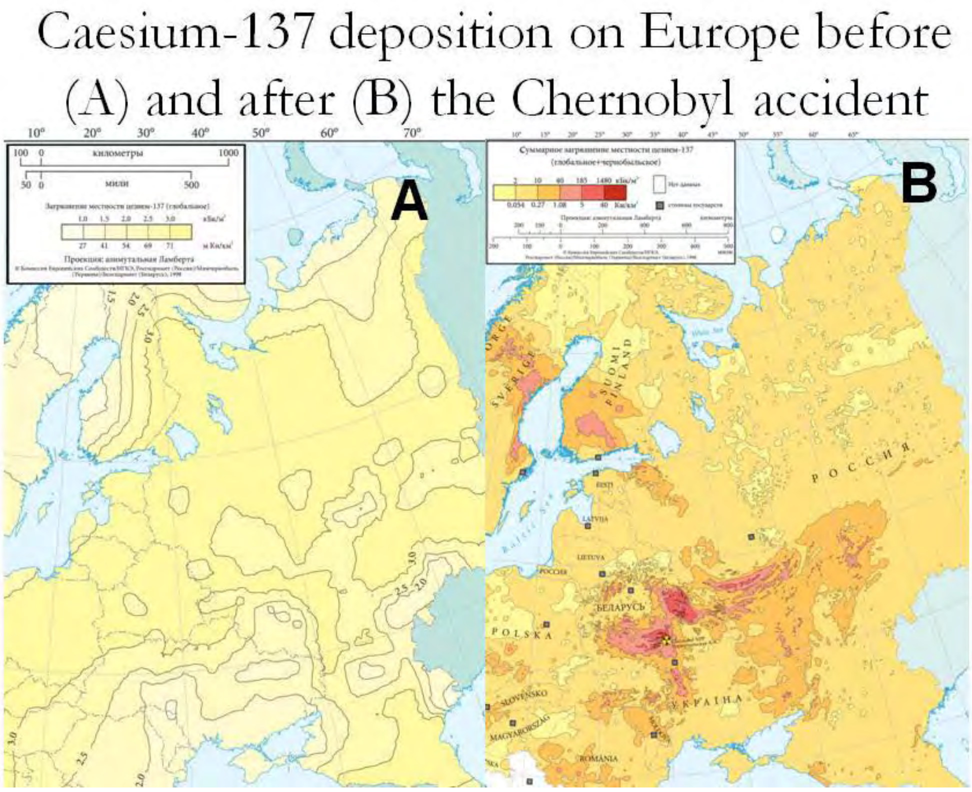
Chernobyl radionuclide contamination of European Russia and transformation of initial contamination after 25 years

Valentin Golosov,
principal scientific researcher, Laboratory for Soil Erosion and Fluvial Processes, Faculty of Geography, Lomonosov Moscow State University, Moscow, Russian Federation,
Expert IAEA,
President of International Commission of Continental Erosion (ICCE) International Association of Hydrological Sciences (IAHS)
Federation

Thank you very much. First to all, I would like to say thank you very much Professor Yuichi Onda [ph] for the kind invitation to come to Japan and to give you a talk about Chernobyl contamination.

As I understand from Yuichi who already introduced myself, so it is not necessary to introduce once again.



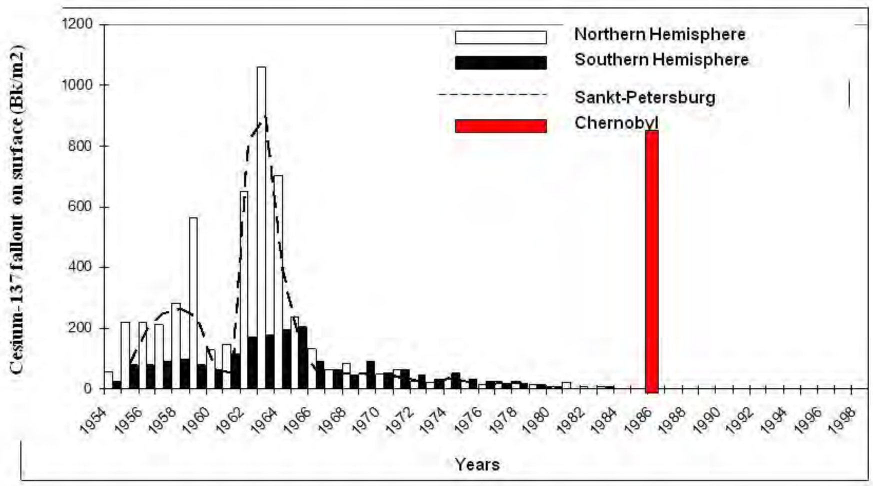
First of all, I would like to show you the two maps of caesium-137 deposition on Europe, before on the left side and after the Chernobyl incident, and you can see from these pictures the values of – I would say the contamination of Europe was maximum after 3 kBq per square meter, and after the Chernobyl, you see that most part of Europe was contaminated even more than 1500 kBq per square meter in the area nearby of Chernobyl but all other parts of Europe was also contaminated by caesium-137, and in particular high density of contamination was in Belorussia, Great Ukraine, and central part of European Russia but also somewhere in Europe like Scandinavia and also in Germany and Poland also was contaminated very seriously.

Features of ^{137}Cs Chernobyl-derived fallout

- Explosion on Chernobyl Power Station is happen 26 April 1986.
- Maximum of Chernobyl-derived ^{137}Cs fallout deposition in the most locations was observed during time interval 26 April – 11 May 1986 and it was connected with one rain
- In the result initial fallout is characterized by high variability for the vast areas. Most part of Europe had received Chernobyl fallout

Features of caesium-137 Chernobyl-derived fallout: First of all, I would like to remind you that explosion on Chernobyl Power Station happened on 26 April 1986, so it's already about 28 years come past since this explosion. The maximum of Chernobyl-derived caesium-137 fallout deposition in most locations was observed during the time interval between 26 April until May 11, 1986 and most cases except, of course, areas that surrounded Chernobyl Power Plant, it was connected with only one rain. In the result, the initial fallout is characterized by high variability for the vast areas and, again, I should repeat that the most part of Europe had received Chernobyl fallout probably except Spain and Portugal.

Bomb-derived and Chernobyl Cs-137 deposition for period 1954-1998



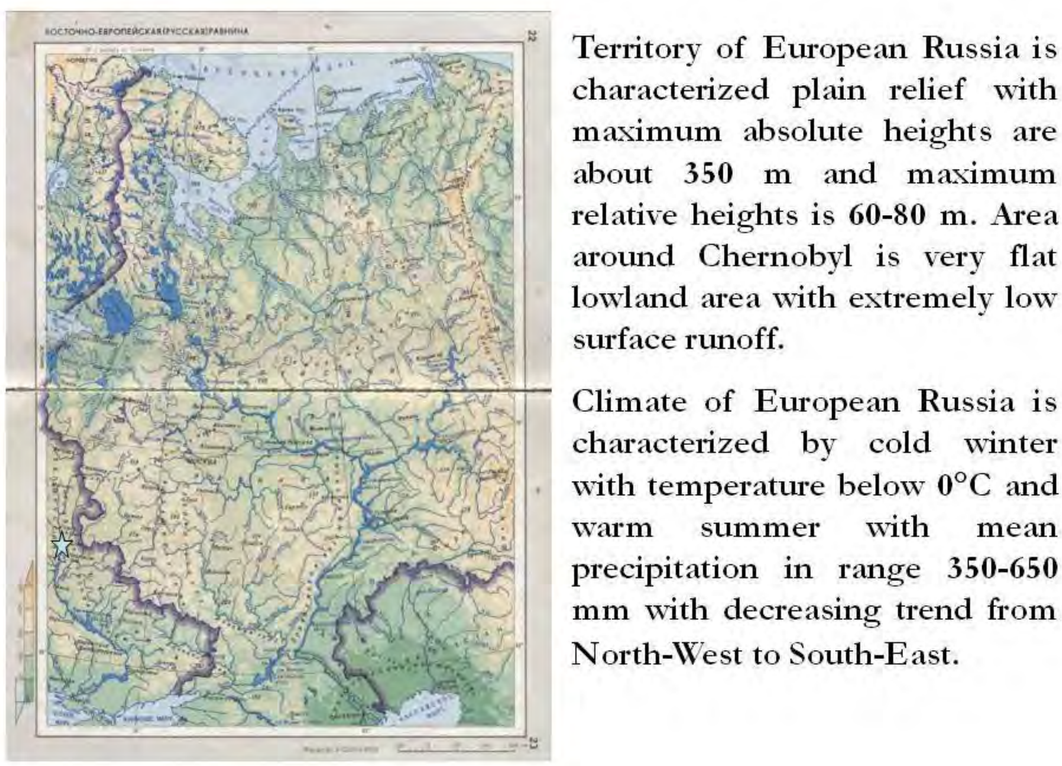
Therefore, explanation which means bomb-derived caesium-137 and Chernobyl-derived caesium-137, I would like to show you this graph which gives you some idea about when a bomb-derived caesium appear in atmosphere and appear on the ground as a fallout. The fallouts started just, of course, shortly, unfortunately, after the bombing of Hiroshima and Nagasaki in the end of Great War II in 1945 but the most essential contamination started after the testing of bomb – nuclear bombs in our atmosphere which started in the beginning of 50s' and both Soviet Union and USA started this testing. As you can see during period until 1963, where intensity of fallout increased and the maximum was that immediately after the agreement about of course when bomb testing in our atmosphere was signed by Soviet Union and USA. After that, there was a sharp decrease of fallout and in the beginning of 80s' this had already became very small.

For the Southern Hemisphere, as you see, the level contamination was considerably low because only France was testing nuclear bomb in Southern Hemisphere, in the Pacific Ocean. The Chernobyl input was very considerable and, of course, this is just only to show the time when it had happened and for different area the level of contamination was very different as you saw on the previous slide.

Contaminated territories with different conditions

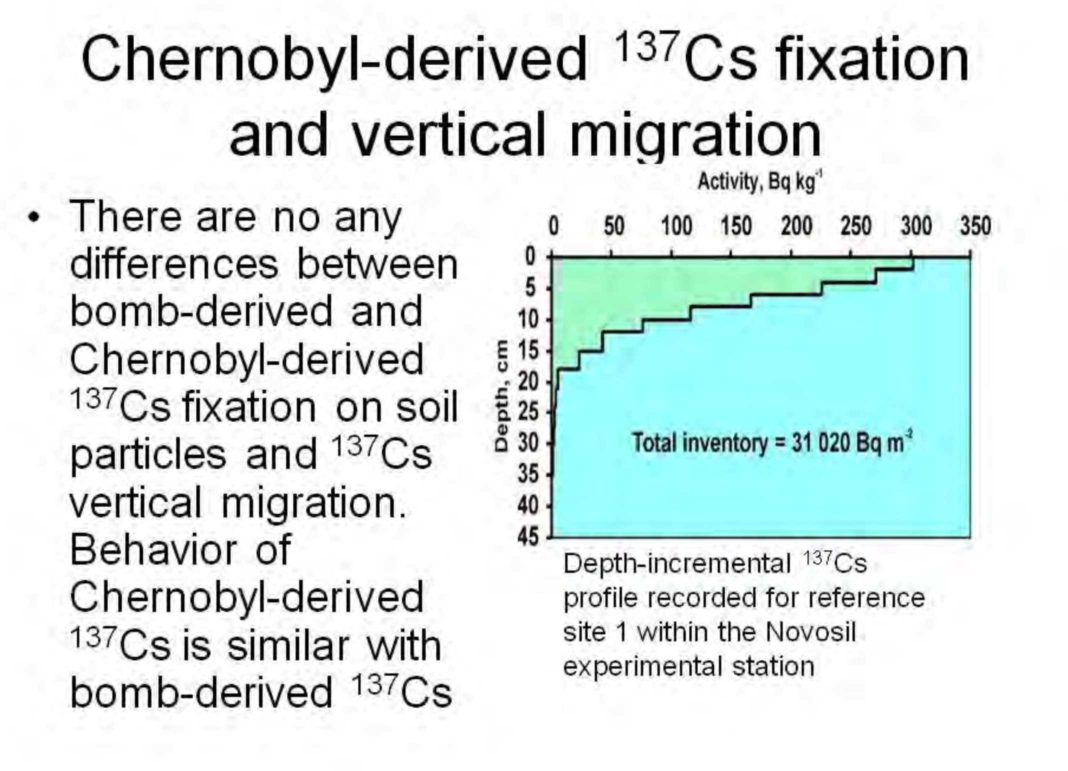
- Exclusion zone - >1480 kBq m^{-2} (>40 Ci km^{-2})
- Evacuation zone 555 -1480 kBq m^{-2} (15-40 Ci km^{-2})
- Partial evacuation zone 185-555 kBq m^{-2} (5-15 Ci km^{-2})
- Control zone with special social-economic status - 37 – 185 kBq m^{-2} (1-5 Ci km^{-2})

Immediately after Chernobyl incident, a detailed survey of contaminated area was done, and four different zones were divided across the country – I mean the Soviet Union in this time. First of all, it was exclusion zone with extremely high areas of contamination, evacuation zone, partial evacuation zone, and the control zone with special social-economic status. During next years, the people who were living in these zones received special medical support and they also received some additional money each month because they were living in area which was under contamination.



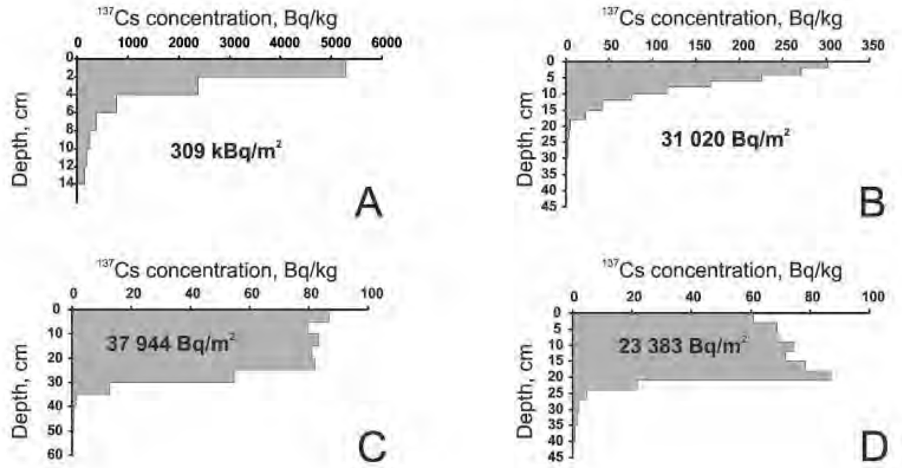
Very shortly, I would like to introduce to you the feature of European part of Russia. Territory of European Russia is characterized as plain relief with maximum absolute heights of about 350 meters and maximum relative heights is 60-80 meters, which was considerably different with Japan's situation, of course. Area around Chernobyl is very flat lowland area with extremely low surface runoff.

Climate of European Russia is characterized by cold winter with temperature below 0ºC and warm summer with a mean precipitation in range of 350 up to 650 millimeters with decreasing trend from North-West to the South-East. It's again considerable difference of your situation where you have more than 1500 millimeters per year.



Very shortly, just I would like to say that Chernobyl-derived caesium fixation and vertical migration is very similar which we found for bomb-derived caesium fixation on soil particles and you can see the typical depth distribution of caesium-137 which is typical for both bomb-derived caesium and Chernobyl-derived caesium-137 and so the following behavior of Chernobyl-derived caesium is absolutely similar with bomb-derived caesium-137.

Types of Chernobyl-derived ^{137}Cs depth distribution at reference sites



Just a few depth distribution curves in reference sites. The reference sites which are the sites where there are no any disturbance of caesium, so there is no any erosion on deposition. On the top, you can see and completely understood site, which is usually meadows and here you can see the maximum, of course, on the top 5 centimeters even after the 20 years after fallout and usually it's distributed up to about 20 centimeter of the depth and sometimes less, which depends from chemical features of the soils.

For cultivated flat area, you can find, of course, very different distribution because of regular cultivation. It's some mix of these curves but anyway, the most part of caesium in site of cultivated lands is only a small part, maybe just under the cultivated lands. At least, if it's only once cultivated field as here, you can see this churn with curves so the maximum previously was here but now it's here and also you can see that anyway it can be as deeper at maximum up to 30 centimeters.

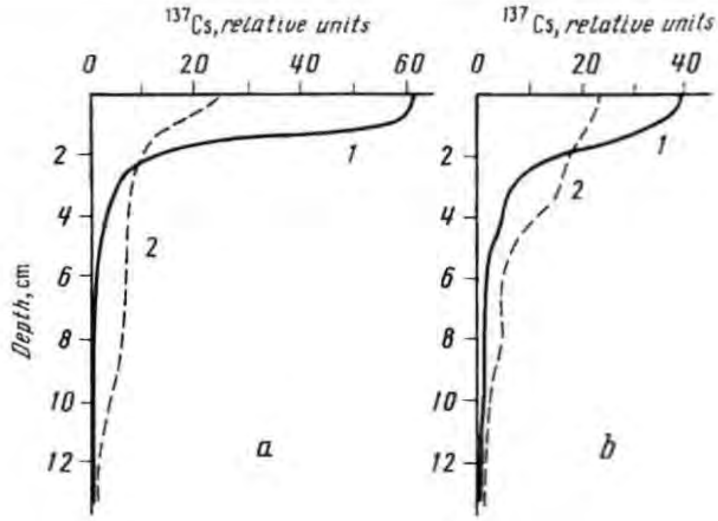
Evaluation of initial Chernobyl-derived ^{137}Cs variability in reference locations for areas with different level of Chernobyl-contamination

One of the very essential things that you need to know – this is initial variability of Chernobyl contamination. We've done a lot of work for variation of initial Chernobyl-derived caesium-137 variability for different reference location for areas with different levels of Chernobyl contamination.

60 km zone around Chernobyl Nuclear Power Plant
*It is located in the Ukraine

- Area around Chernobyl is characterized by extremely high spatial variability, because of ash particles. Until now there are no any detail study of lateral casium-137 redistribution was undertaken in this zone. Only immediately after Chernobyl incident runoff observation was undertaken. It was found that surface runoff
- It is lowland and it is unlikely, that some lateral migration of radionuclides is occur

First of all, very shortly, about 60 kilometers zone around Chernobyl Nuclear Power Plant, which is the most seriously contaminated area, with extremely high level of variability so there's even no sense to check initial variability here because a lot of hot particles fell on the ground nearby and the level of different – the concentration of radionuclide in these particles were extremely different, which is extremely high variability here. However, immediately after Chernobyl incident, runoff observation was undertaken in this area, and it was found that surface runoff was very low, and because it's lowland, it is unlikely that some lateral migration of radionuclides has occurred here. It is, of course, fortunately for us.



Vertical distribution of ^{137}Cs in the mineral layers of forest soils (% of the total inventory in the mineral layers):

(a) exclusion zone (key sites D-1 and D-3); (b) "remote" zone" (Bryansk Region, key sites Kl-1 and Kl-2)

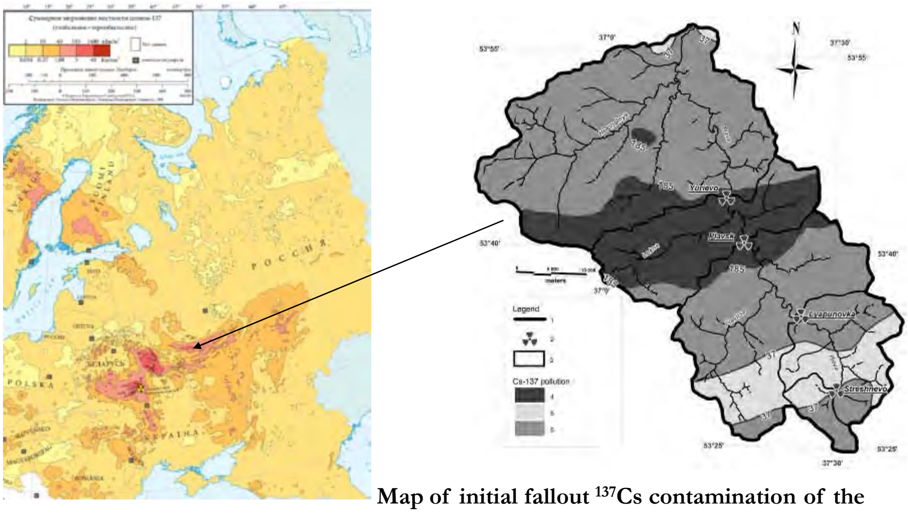
(After Shcheglov et al., 2001)

Also, some study of vertical distribution of caesium-137 was done, which was published in this book, and you can see it is for forest soils but it is also very typical curve, which are relative units here. However, the maximum, again, in the top layers where all caesium mostly were top 10 centimeters.

Locations of reference sites, where detail study of initial variability were undertaken

We re-studied initial variability in four different sites across Europe with different level of contamination. These are two areas with very high level of Chernobyl contamination, Orel and Kursk region with mean value of Chernobyl contamination and Stavropol region with low level of Chernobyl contamination.

Area with very high level of contamination



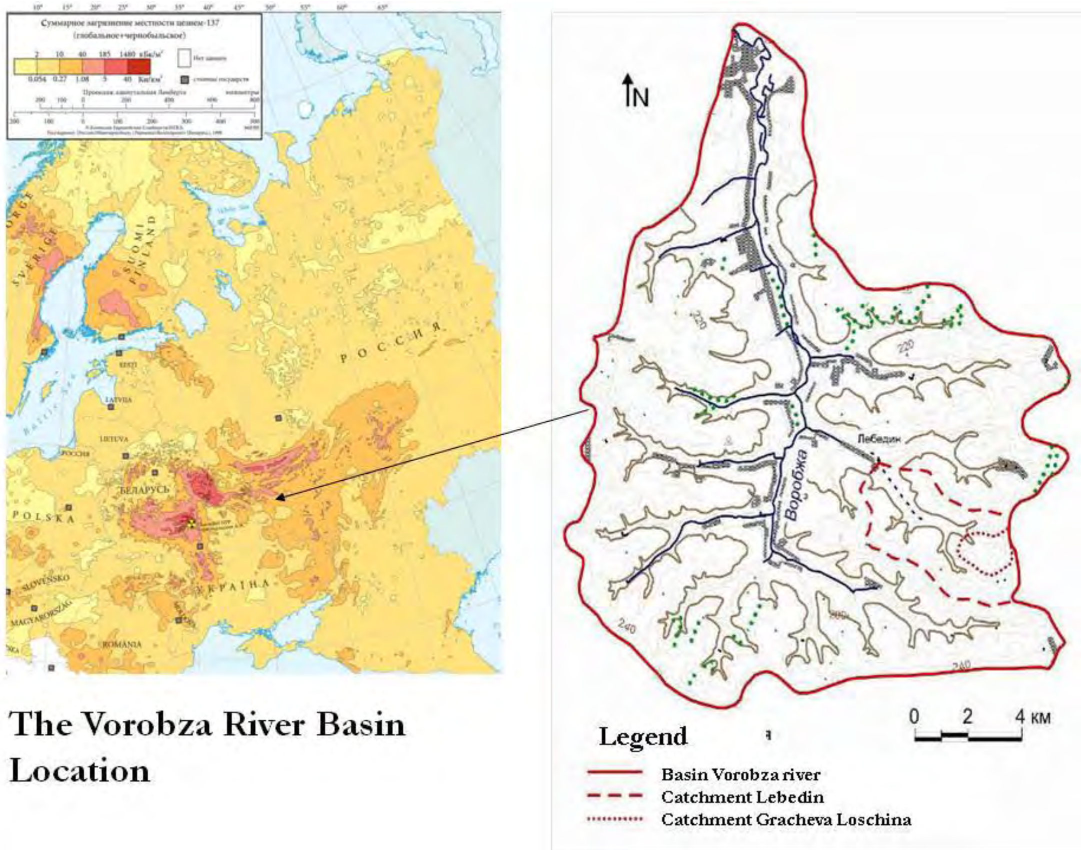
Map of initial fallout ^{137}Cs contamination of the Plava river basin (Atlas..., 1998) Levels of the initial ^{137}Cs fallout: **4) >185 KBq m^{-2}**. 5) <37 KBq m^{-2}; 6) 37-185 KBq m^{-2};

First, this is area with high level of contamination. This is located here. It is about 250 kilometers to south from Moscow and here the level – this is Plava River Basin, which is the most seriously contaminated and the highest level of contamination in the middle part of basin with some tributary of Plava river and Lokna river located.

General characteristics and ^{137}Cs concentration (Bk/kg) statistics for the reference sites Lokna river basin (Tula region) Area with very high level of contamination

Reference site	Number samples	Mean value, KBq m^{-2}	Range, KBq m^{-2}	Cv, %	Type of measurements
1	6	315±20	274-363	9	laboratory
1	19	379±23	288-507	16	field
2	28	563±28	380-828	16	laboratory
2	22	435±12	379-479	7	field
3a	7	357±16	314-422	12	field
3б	20	344±14	298-440	11	field
3б	9	378±41	296-505	20	laboratory
3в	20	291±21	209-404	17	laboratory
4	12	350±16	295-402	10	laboratory

Because of a large investigation, here you can see several reference sites and we use both measurement laboratory evaluation of caesium concentration and field evaluation using portable detector. You can see for all of the sites, we found that percent variation for reference sites is not so high. It is in the same range which we found for mostly which was only contaminated by bomb-derived caesium-137. That means that it is possible to study later on following redistribution of caesium-137 for these particular areas.



The next area which is the mean value of Chernobyl contamination located in Vorobza River Basin which is nearby Kursk Regional Center, which is about 550 kilometers from Moscow.

GENERAL CHARACTERISTICS AND ^{137}CS INVENTORY STATISTICS FOR THE REFERENCE

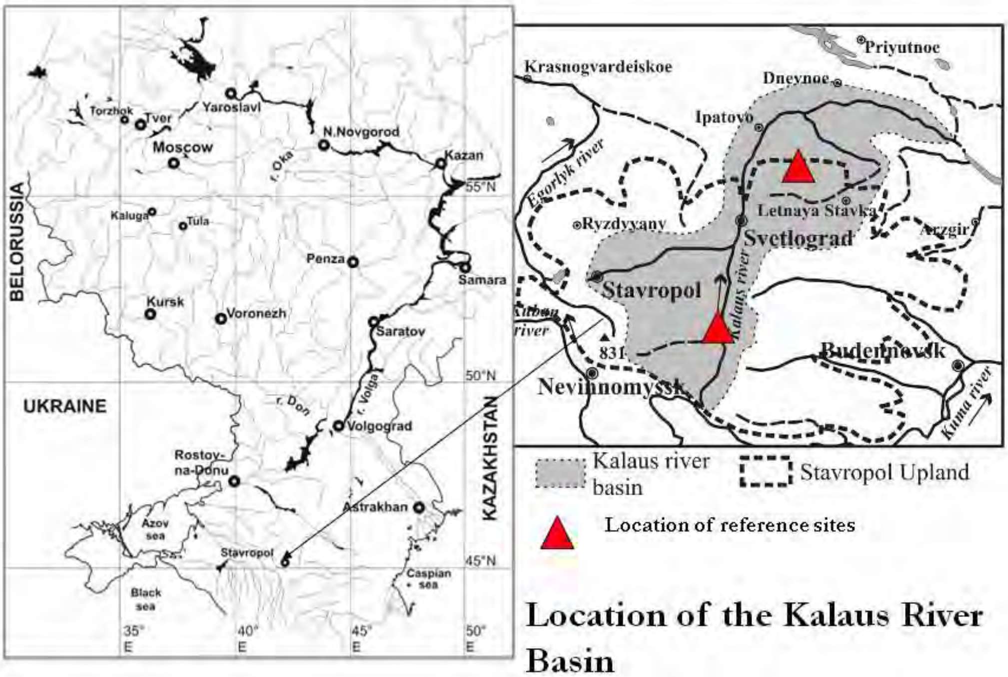
Vorozba site

Area with mean values of Chernobyl contamination

Reference site	Land use	^{1}N	The ^{137}Cs inventory (kBq m^{-2})		CV, %	$^{2}N_0$
			Range of values	Average ± 90% confidence interval		
Ref-1	**Arable land**	12	5,4- 11,8	9,5±1,2	**22**	24
Ref-2	**Arable land**	12	6,3-10,3	7,6±0,7	**16**	12
Ref-3	**Arable land**	12	7,2-11,1	9,1±0,7	**13**	8
Ref-4	**Arable land**	12	6,4-10,2	8,6±0,6	**13**	8

1 – actual number of samples; 2 – requested number of sample for such variability

Here also take for references. Unfortunately, it was very difficult to find here at these two sites so we used arable land but it was really very flat area with possible very slow erosion on this flat area. As you see here, we also found a relatively small initial variability of Chernobyl-derived caesium-137, and you can see again here where Chernobyl contamination involved was higher if compared with bomb-derived caesium-137. We don't take into consideration of previous contamination by bomb-derived caesium-137.



Location of the Kalaus River Basin

At least, one more territory with low value of Chernobyl contamination, which is located in the southern part of European Russia, and it is Kalaus River Basin. Here, we have two locations where we take samples on reference sites

GENERAL CHARACTERISTICS AND ^{137}CS INVENTORY STATISTICS FOR THE REFERENCE Kalaus site
Area with low values of Chernobyl contamination

Reference site	Land use	^{1}N	The ^{137}Cs inventory (KBq m^{-2})		CV, %	$^{2}N_{0}$
			Range of values	Average ± 90% confidence interval		
Ref-1	Pasture	12	3,3- 6,5	4,9±0,4	28	25
Ref-2	Pasture	11	2,2-4,6	3,6±0,4	23	17
Ref-3	Pasture	13	0,5-4,5	2,1±0,6	60	116

1 – actual number of samples; 2 – requested number of sample for such variability

and you can see that here the level of contamination after Chernobyl was approximately equal with the previous bomb-derived caesium contamination and here we found very high initial variability of caesium-137. That means that for such area it is very difficult to arrange for fallout redistribution in the large scale because initial fallout was very irregular.

Assessment of Chernobyl-derived ^{137}Cs initial fallout variability in reference locations

with different levels of Chernobyl contamination

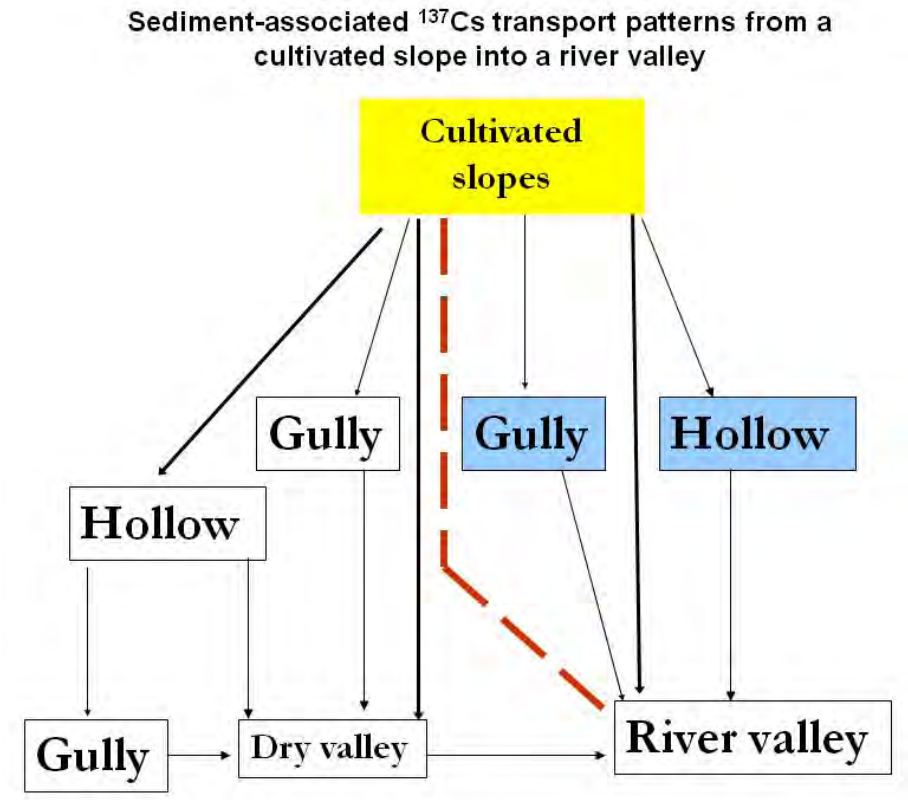
- Initial fallout variability of Chernobyl-derived ^{137}Cs fallout is low (10-20%) in areas where Chernobyl-derived ^{137}Cs fallout exceed bomb-derived ^{137}Cs fallout in about 10 times
- Initial fallout variability of Chernobyl-derived ^{137}Cs fallout is high (30-60%) in areas where Chernobyl-derived ^{137}Cs fallout is relatively equal to bomb-derived ^{137}Cs fallout
- So it is possible to study Chernobyl-derived ^{137}Cs post-fallout redistribution on slopes only in areas with mean and high values Chernobyl-contamination

To conclude this part of the talk, we can say that initial variability of Chernobyl-derived caesium-137 fallout is low, about 10% to 20%, in area where Chernobyl-derived caesium-137 fallout exceeded bomb-derived caesium fallout in about 10 times. Initial fallout variability of Chernobyl-derived caesium-137 is high at about 30% to 60% in areas where Chernobyl-derived caesium-137 fallout is relatively equal to bomb-derived caesium-137 fallout. It is possible to study Chernobyl-derived caesium-137 post-fallout redistribution on slopes only in areas with mean and high values of Chernobyl contamination. It is why it is not so often Chernobyl caesium method applied in Europe because most parts of Europe have relatively small contamination after Chernobyl.

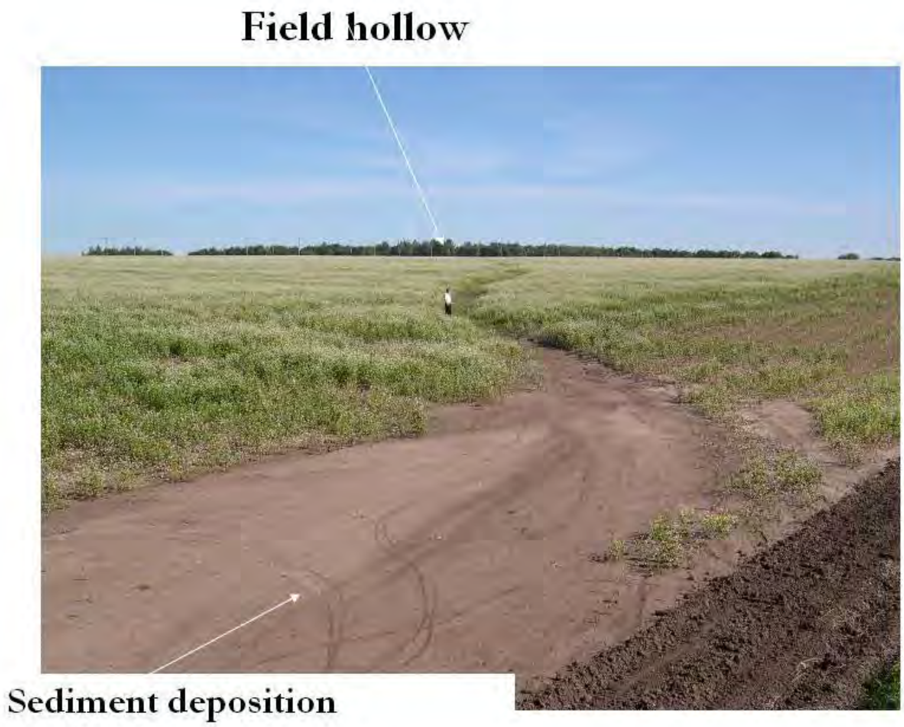
^{137}Cs lateral redistribution in the river basins

- It was found that surface runoff under natural meadow, pasture and forest is very low and soil losses are close to zero. So after ^{137}Cs fixation on soil particles there are no any lateral migration of ^{137}Cs. During first two years some dissolved ^{137}Cs percolate to the ground water
- Intensive lateral ^{137}Cs migration on Russian Plain is mostly observed on cultivated lands because of water and wind erosion and further along the different chains if fluvial system

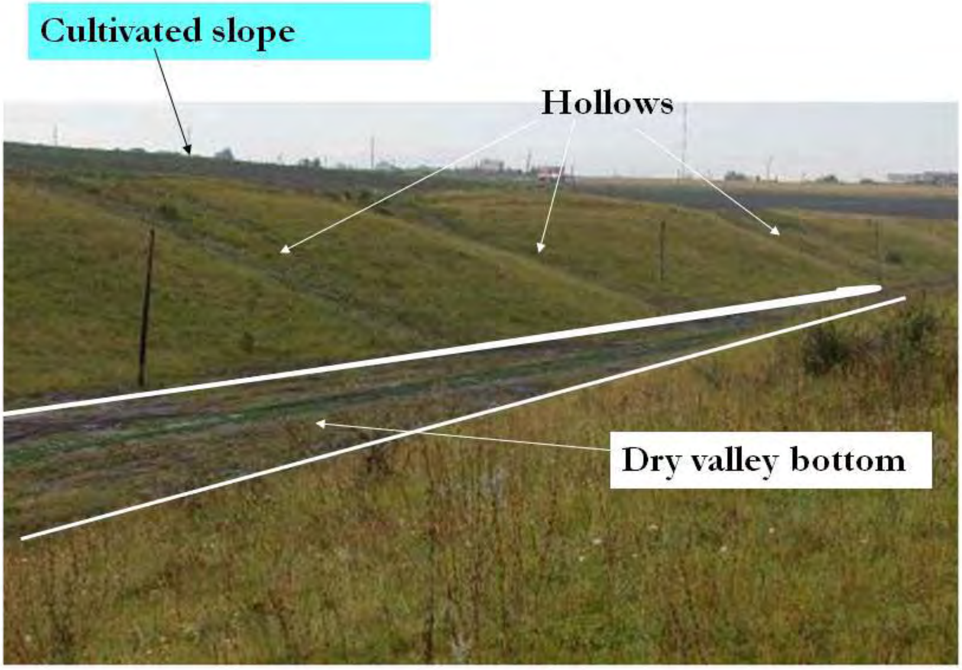
The next part of the topic is the caesium lateral redistribution in river basins. It was well known even, of course, before Chernobyl that the surface runoff under natural meadow, pasture, and forest is very low in our case for European parts of Russia and so losses are close to zero. After caesium-137 fixation on soil particles, there are no any lateral migration of caesium-137 mostly from this land use, meadow, pasture, and forest. Of course, except where pasture, let's say, very high pressure and only during the first 2 years, some dissolved caesium-137 percolated to the ground water. But intensive lateral caesium-137 migration on Russian Plain is mostly observed on cultivated lands because of water and wind erosion and further moving along the different chains of fluvial system.



We need to understand how it's going in the river system as this graph shows you, first of all, direction of sediment-associated caesium-137 transport patterns from a cultivated slope into the river basin. We can divide it to two groups; one group where we have very simple system, from cultivated slopes, sediments can come into the gully and directly to the river valley or it can be also through a hollow which is also concentrated with runoff. The other system which is more complicated in our case, in addition to gully and hollow, we have long system of dry valleys where no constant flow for most part of the area and this system working in a different way and I'll show later what we have here.



To some idea what means hollow which is cultivated slope and then some, let's say, this is like channel because it is an area with low concentration. Here you can see some erosion from the field with deposition in the bottom part of the slope.



Also, the other type of hollows, which is on the bank of this dry valley. This is uncultivated part of valley bank and the reason here is you see the cultivated slope and this is a dry valley with slope like this. You can see there’s a lot of grass here and, of course, the most part of sediment which is entering to the bottom of such dry valley are deposited there.

Typical dry valley with incision in the valley bottom

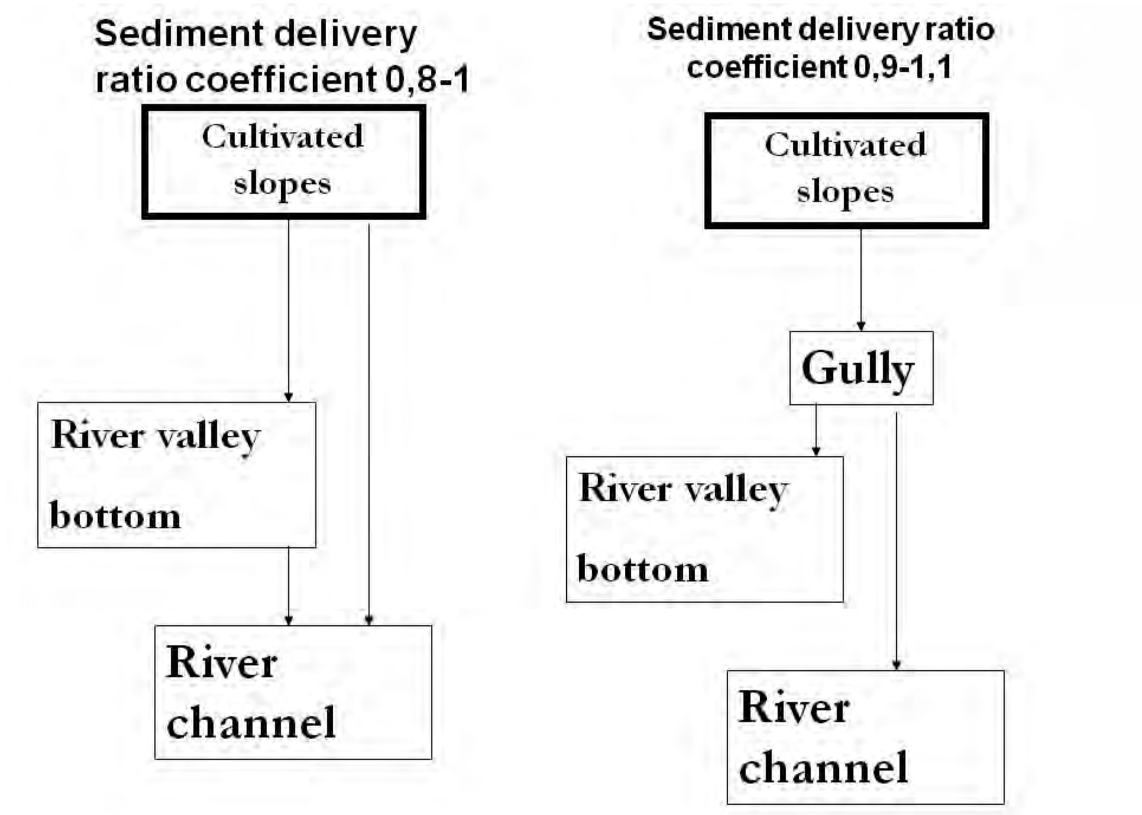
Following remobilization of sediments from such type of dry valley usually occur because of retreat of bottom gully in the retreat of knick-point to bottom gully and it is remobilized the already re-deposited sediments and caesium.

SEDIMENT DELIVERY RATIO COEFFICIENT

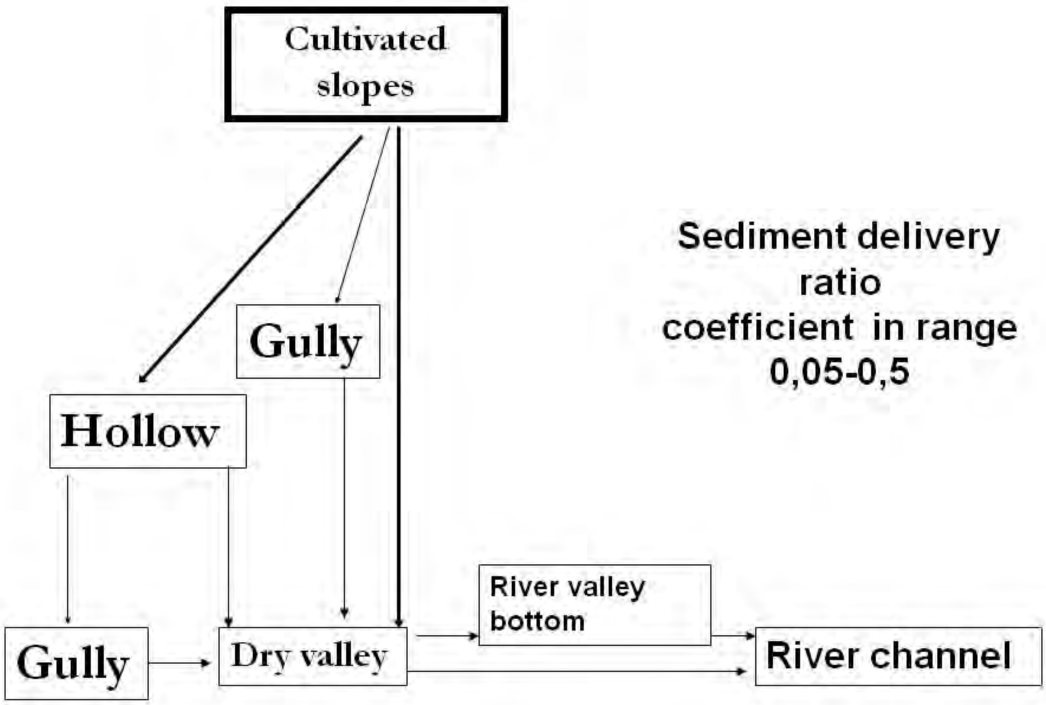
- The sediment delivery ratio is defined as the ratio of sediment delivered at a location in the stream system to the gross erosion from the drainage area above that point.

- SDR = SY / E
- where SDR = the sediment delivery ratio
- SY = the sediment yield
- E = the gross erosion per unit area above a measuring point.

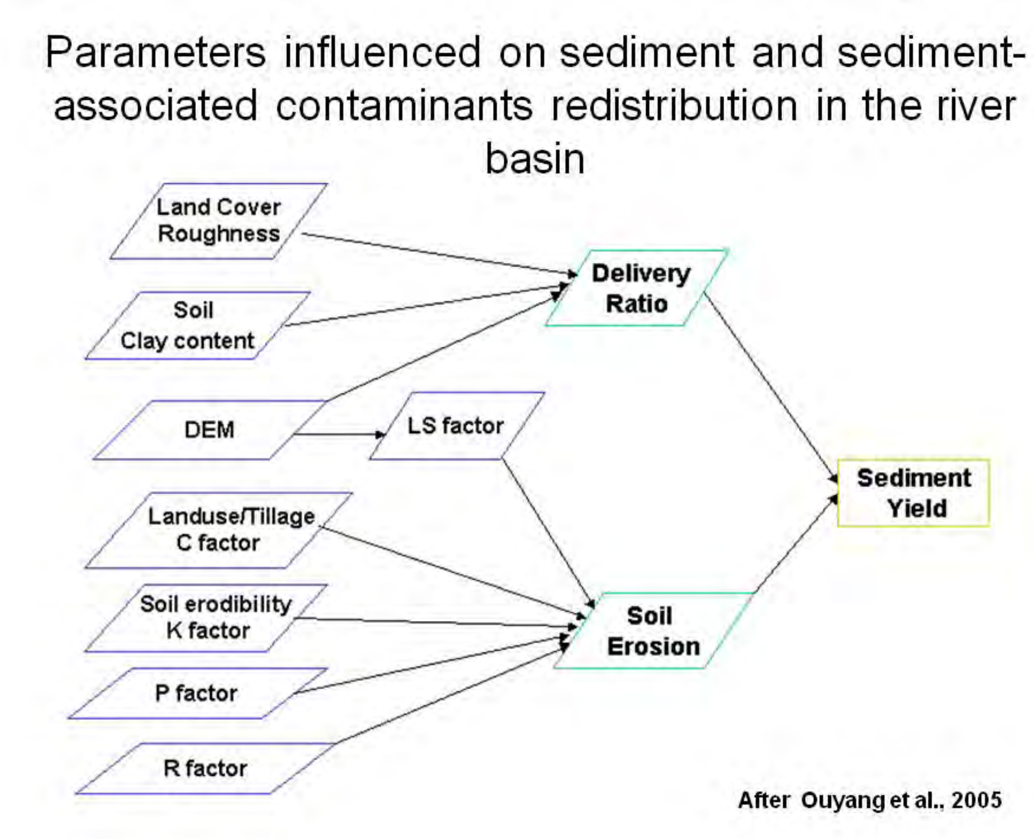
We need to evaluate the sediment delivery ratio coefficient for different types of sediment transport of the fluvial system. The sediment delivery ratio is defined as the ratio of sediment delivered at a location in the stream system to the gross erosion from the drainage area above that point. This is the formula which is very simple how you can calculate sediment delivery ratio coefficient.



Firstly, the system which has very high sediment delivery ratio coefficient, which is more simple. In fact, it is cultivated slopes where directly sediments can come into the river valley bottom or directly to the river channel. In this case, according to our even previous observation, the coefficient delivery rate can reach 1, that means that all sediments coming from the slope to the river channel. If you we have the gully in addition that even, of course, sediment delivery ratio coefficient may be even more than 1 because you have additional inputs of sediments from gully.



The other system which is more typical for Russian Plain is this system where we have in addition to hollow and gully, we have a dry valley which is what in case a sediment sinks and because of the sediment delivery ratio coefficient for different type of such system can change from 0.05 up to 0.5, so it is a completely different system, which is what influence over the whole system.



This graph shows you the main parameters which influence on sediment and sediment-associated contaminants redistribution in the river basins. I hope that most of you, of course, know what does this parameter means and one of the main things, of course, it is relief parameters and land use parameters and, of course, rainfall factor which is influenced considerably of formation of surface runoff.

Assessment Chernobyl-derived ^{137}Cs redistribution on cultivated slopes

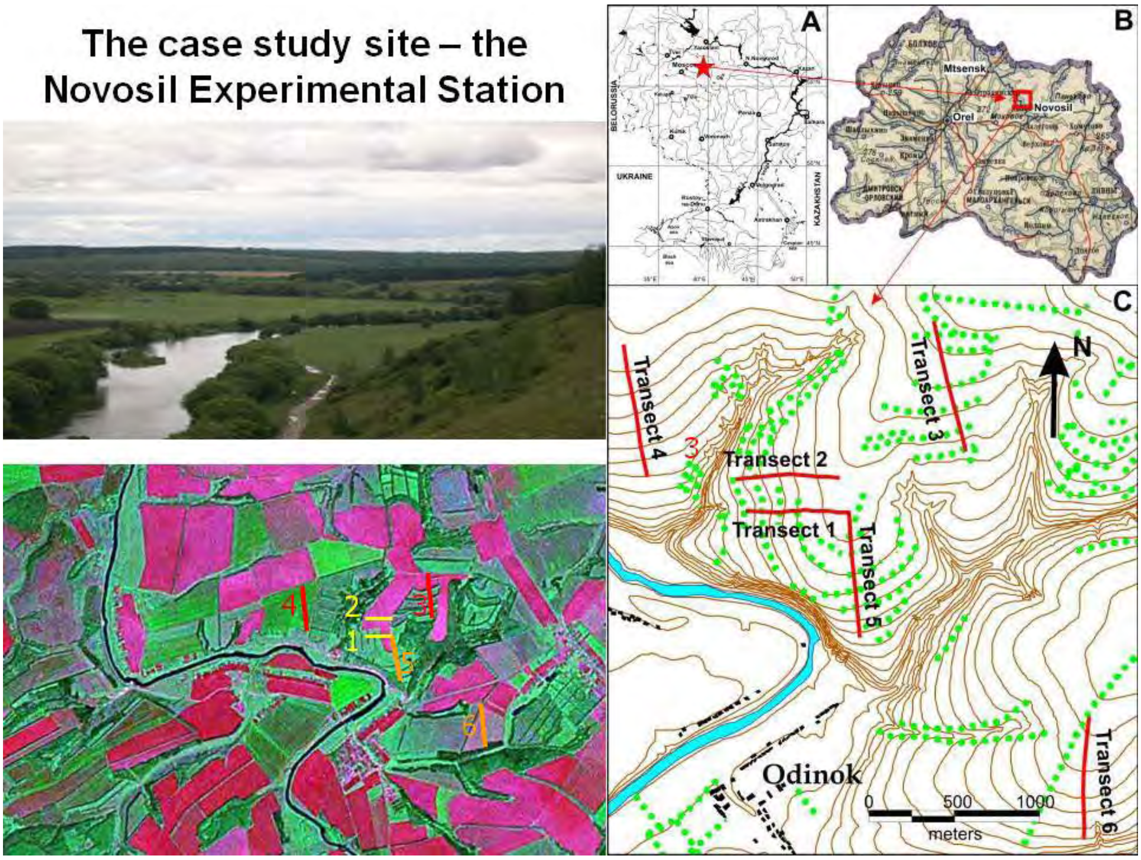
- Water soil erosion is the main processes responsible for ^{137}Cs redistribution on cultivated slopes of Russian Plain. There are two types of water soil erosion on Russian Plain: erosion during snow-melting (March – April) and during rain-storms (May – October)
- Wind soil erosion is observed mostly in Southern part of Russian Plain, in area with low level of Chernobyl contamination

Let me show you shortly some of our results for different chains of fluvial system.

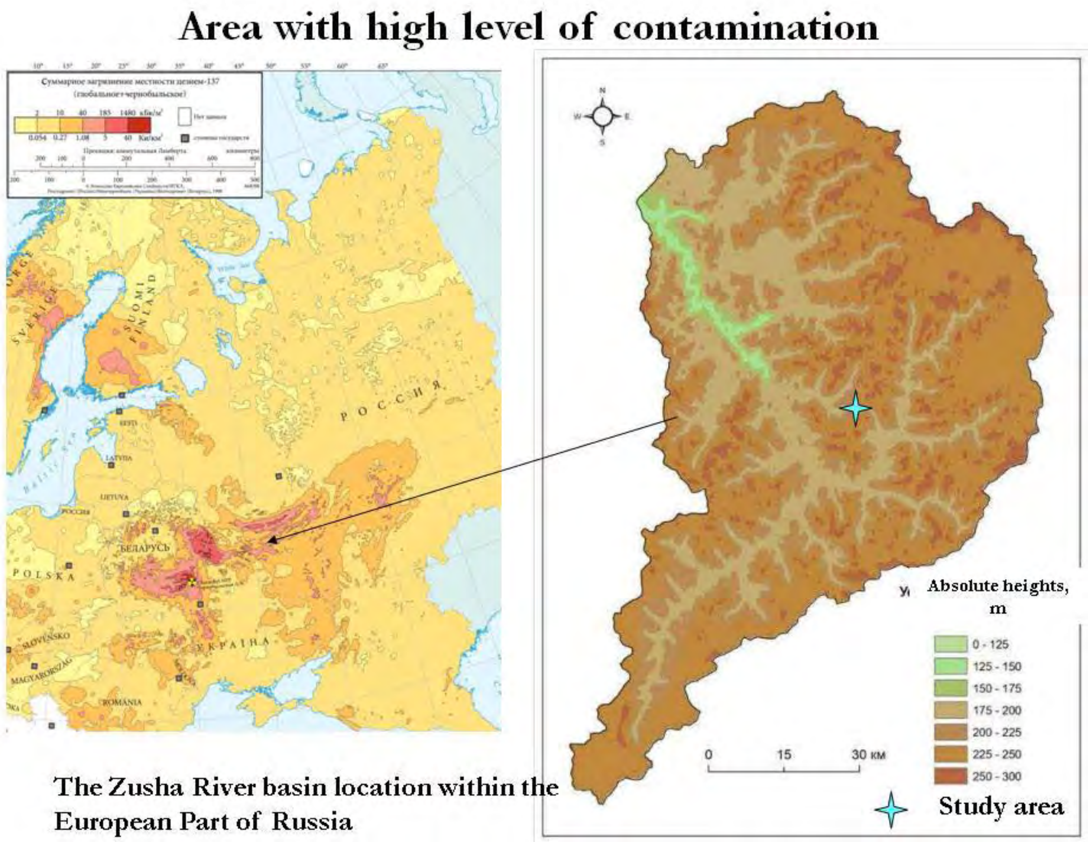
First of all, assessment of Chernobyl-derived caesium-137 redistribution on cultivated slopes. As I did talk before, water soil erosion is the main process responsible for caesium-137 redistribution on cultivated slopes of Russian Plain. There are two types of water erosion on Russian Plain: Erosion during snow-melting, which usually happens in March and April, and erosion during rainstorm, which usually occurs between May and October. We have also wind erosion but it is mostly observed only in southern parts of Russian Plain, here, and it's an area with low level of Chernobyl contamination.

Evaluation of Cs-137 redistribution along slope

This is one example of our case study site in Novosil Experimental Station.



This is one example of our case study site in Novosil Experimental Station. It is located not so far from the region of Central Orel and Orel location is about 350 kilometers from Moscow to the south. Here, you can see we have an area which has in addition to traditional cultivation, without soil conservation measurement. We have a system of forest shelter belts, which was constructed already about 8 years ago and it was not started to use the soil erosion on heavily eroded slope which is typical for this particular area. We choose for our operation two parts of transect, one with similar configuration of slope. One of them which is through system for soil conservation measures and the other with traditional cultivation.



So, it’s again the soil where it is located and you can see this is the level of contamination here.

GENERAL CHARACTERISTICS AND ^{137}CS INVENTORY STATISTICS FOR THE REFERENCE Zusha site (Orel region)

Area with mean values of Chernobyl contamination

Reference site	Land use	^{1}N	The ^{137}Cs inventory (Bq m^{-2})		CV, %	$^2N_0$
			Range of values	Average ± 90% confidence interval		
Ref-1	Open meadow	12	30470-33038	31754±1284	9	2
Ref-2	Abandoned (>10 years) arable with tree shootings	11	18164-37128	27699±2573	19	12
Ref-3	Permanent pasture with adjacent trees	9	23209-32051	27573±1688	11	4
Ref-4	Meadow with adjacent trees	12	31696-52512	42289±3431	16	8
Ref-5	Arable land	4	30175-37944	34654±1942	10	6

1 – actual number of samples; 2 – requested number of sample for such variability

First, let's possibly characterize the initial variability of caesium-137 in the reference location and we have five reference locations here and again you can see that the level of variability on the reference locations are relatively low but you can see that values of inventory for different locations are very different.

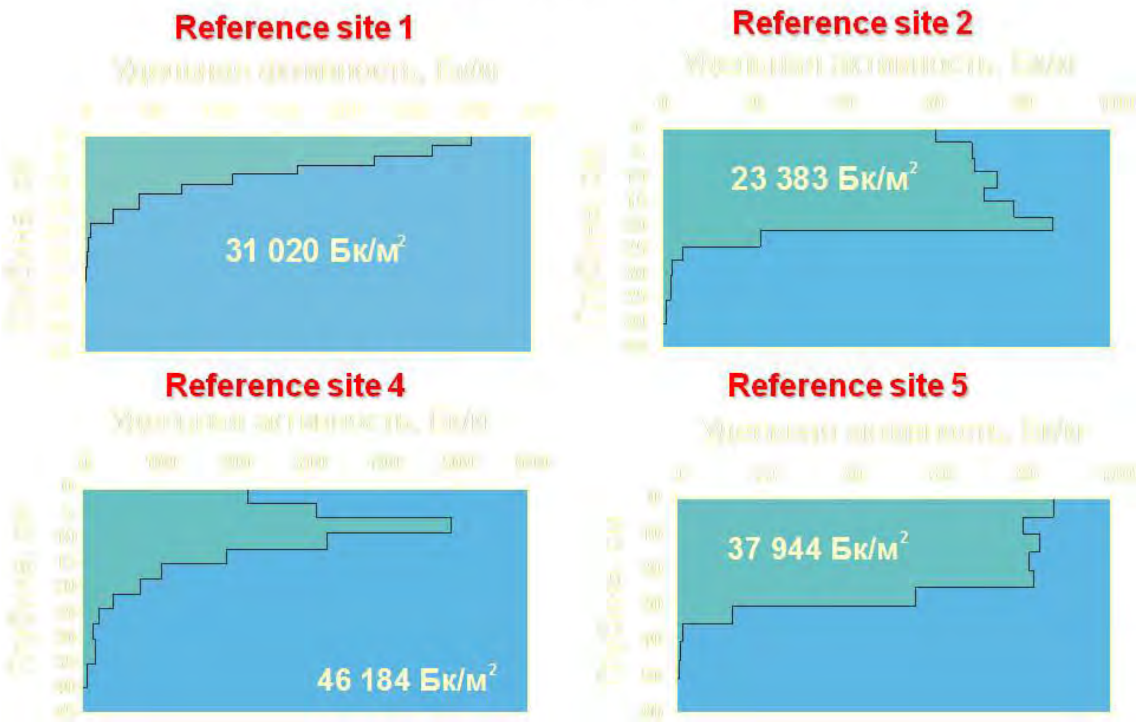
General characteristics of the case study slope transects

Pairs of slopes	Slope transects	Documented cultivation period, years	Aspect	Relative height, m	Length, m (entire transect / upper gentle part)	Gradient, degrees (upper part/ average/ lower part)
1	[1]Transect 1	300	west	17	460/110	0.8/2.2/3.2
	[2]Transect 2	300	west	18	490/100	0.8/2.2/3.2
2	[1]Transect 3	300	south	25	800/230	1.0/1.7/2.3
	[2]Transect 4	100	south	30	770/250	1.3/2.2/3.0
3	[1]Transect 5	300	southeast	31	750/280	1.0/2.3/3.7
	[2]Transect 6	300	southeast	28	730/300	1.0/2.2/4.3

[1]Slope transects with contour terraces and forest shelter belts;
[2]Conventionally cultivated slope transects.

This table gives you some idea about the morphological characteristics of case study slope transects. You can see most of them were cultivated during about 300 years and there's the aspect of slope and relative heights and [Unclear] but, in general, we are not so different but it is typical for this particular landscape.

Depth distribution of ^{137}Cs in soil profiles at reference locations



Here, you can see the depth distribution of caesium-137 for different reference sites. This is for cultivated. The previous was for uncultivated and this is also uncultivated.

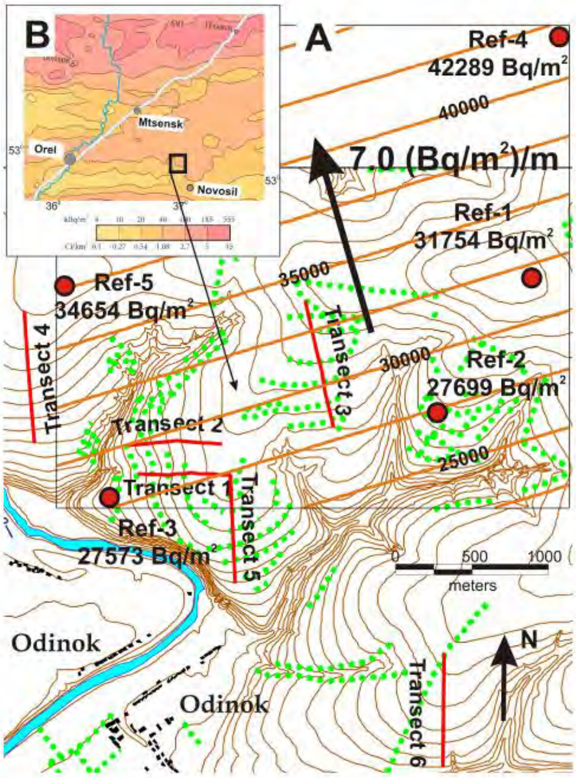
Incremental sampling in the pit, located at reference location

This is how we take samples – incremental samples. This might be more simple that what you have done but, in any case, we have repeat and we are looking closely. We have no any disturbance and after which, we get from a regular area. Layer by layer, we take samples for analysis.

Morphological characteristics of studied slopes

№	Site	Slope configu-ration	Slope aspect	Length, m	Mean/maximum gradient, degree
1	Diktatura Tula region	convex	South	700	2/5
2	Gracheva Locshina Kursk region	convex	South-west	470	3,3/5
3	Gistischevo Belgorod region	convex	South	550	1,4/2,4

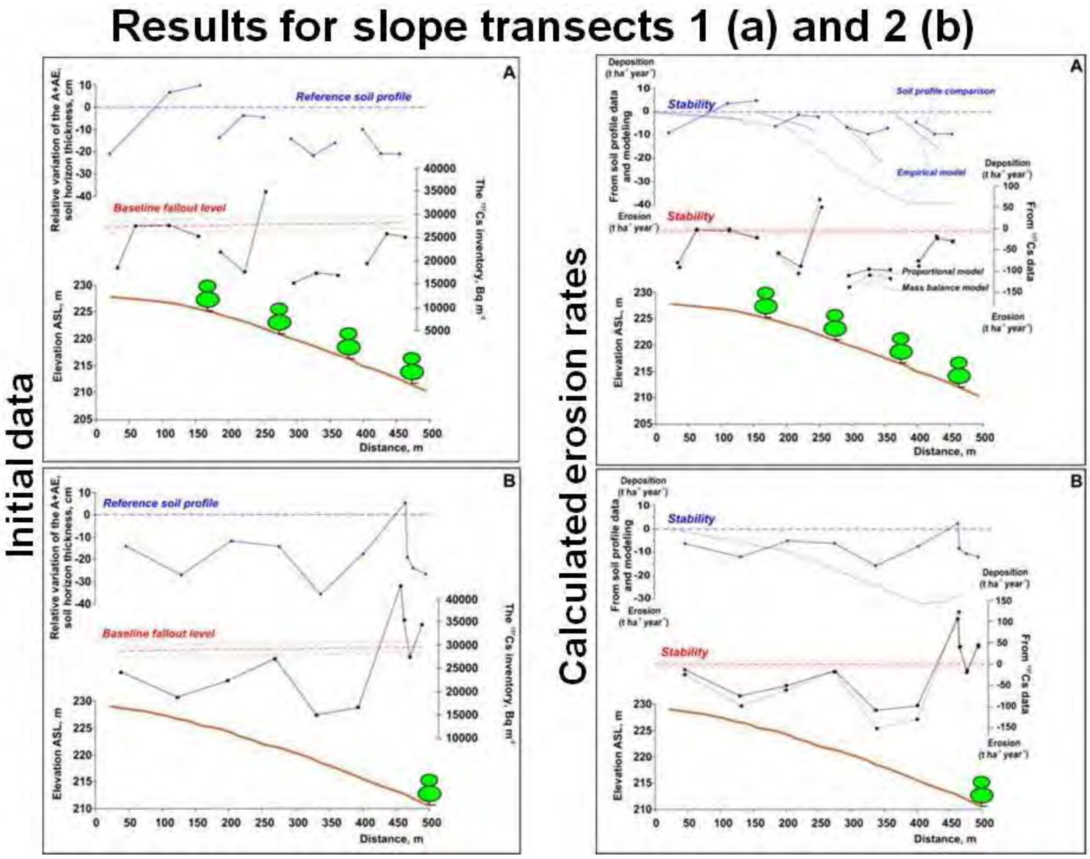
This is the result we received for different transects and, in addition, we use soil-morphological method for variation soil erosion here and each graph shows the differences of caesium and the soil redistribution along the slope.



It is necessary to have few reference locations surrounded the study site for evaluation of possible initial trend of Chernobyl-derived

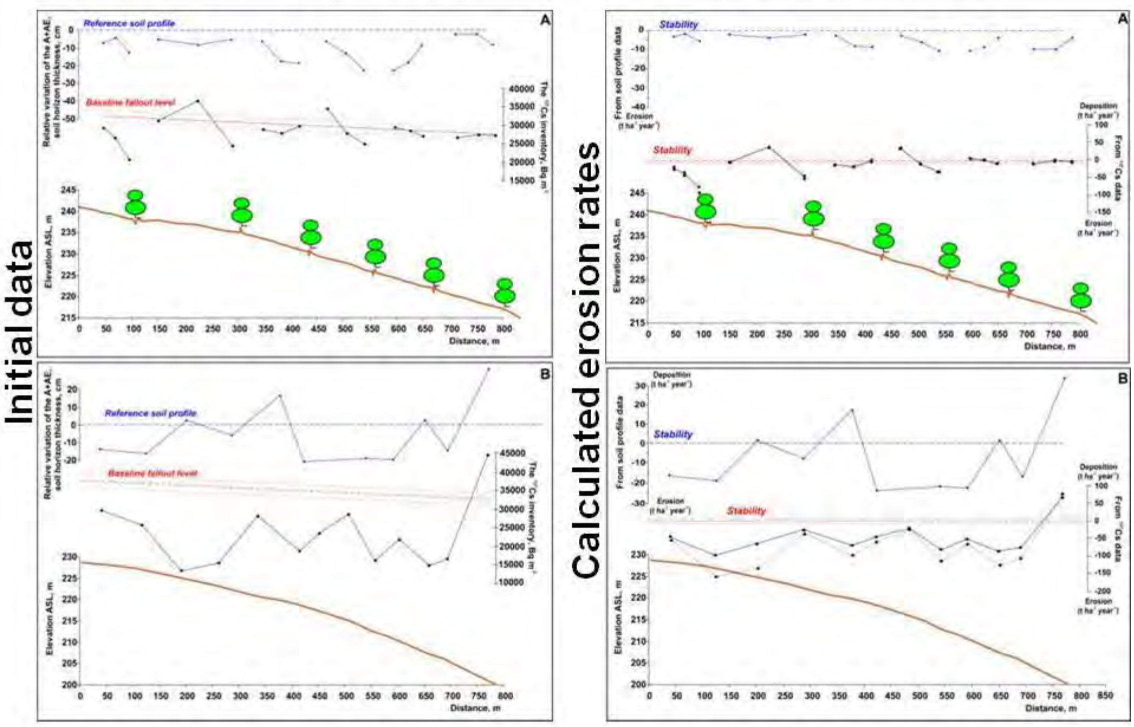
The ^{137}Cs inventory ^{137}Cs spatial trend established from field data (a) and published information (Atlas., 1998; b).

We need to find the trend of initial contamination in this case so it is – here, you can see this is our reference location and when we put this value on the map, we found very regular trend of initial fallout which is here and so, of course, we took into consideration this trend for evaluation of the following caesium redistribution. It is very essential points for study of caesium distribution on slope in area affected by the Chernobyl contamination.



This is for slope with soil conservation measurement and [Unclear] and this is with traditional cultivation. You can see that this is reference value for caesium and this is reference value for soil-morphological method. You can see that it has very similar changes along the slope. In fact, there is some more strong erosion on the first part of slope with possible decreasing of erosion later on and again increasing. It is very typical for any erosion process along the slope because erosion and deposition coincide along all pathways and when there is concentration of sediment increasing the flow, there is some deposition material already and later again erosion and again deposition. Of course, there are more serious deposition in the bottom part of a cultivated slope because here it is already uncultivated part of slope. It is the same we found for other transects.

Results for slope transects 3 (a) and 4 (b)



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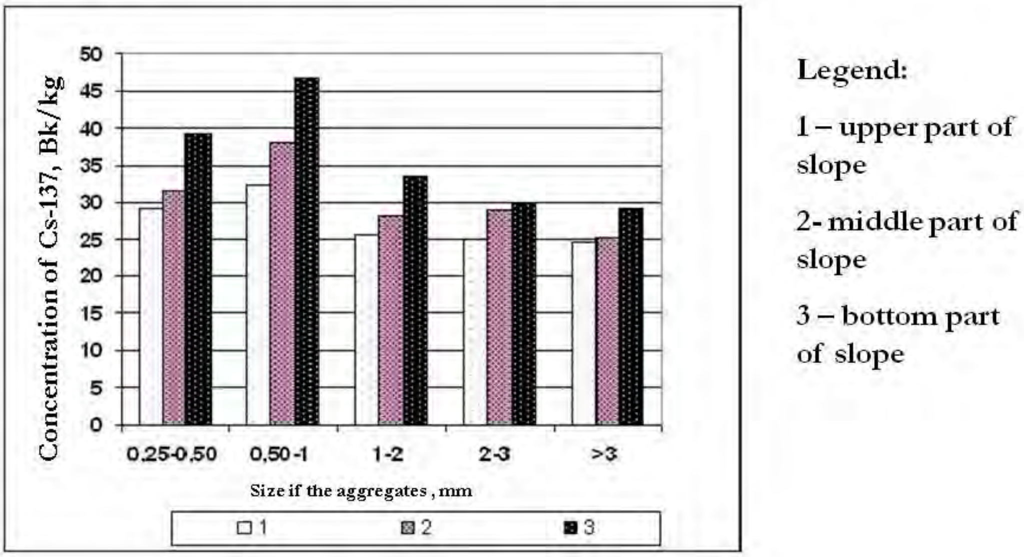
^{137}Cs concentration in different fractions of water-stable aggregates of soil for upper, middle and bottom parts of cultivated slope



Also, we studied caesium concentration in different fractions of water-stable aggregates of soil for upper, middle, and bottom parts of cultivated slope. This graph gives you some idea. I think it is not necessary to spend a lot of time for description of it but you can see - but anyway, in the bottom part, we have much more caesium in small particles. It is also because the aggregates are moving down slope where it destroys partly but the more small particles still in aggregates.

Mean values of soil loss/gain for studied cultivated slopes and net losses for two time intervals (t/ha per year)

Method	Site Diktatura		Site Gracheva Locshina		Site Gostischevo	
	^{137}Cs 1986-2009	Fly ash 1869-2009	^{137}Cs 1986-2009	Fly ash 1869-2009	^{137}Cs 1986-2009	Fly ash 1869-2009
Gross erosion	7,7	14,6	11.2	7,6	3,4	8,1
Gross deposition	2,8	0,1	7.5	1,3	2,2	1,0
Net erosion	4,9	14,5	3.6	6,4	1,2	7,2

This is some, shortly also, value results for some different sites which is located also in the European part of Russia. Here, we used caesium method for evaluation of erosion and deposition rate along the slopes and this a table give you some idea about the rate of soil erosion using different methods here, the fly ash method and caesium-137 method, and you can see that, in general, the mean rate of soil erosion is not so high. It is less than 10 ton per hectare.

Concluding remarks:
^{137}Cs redistribution on cultivated slopes

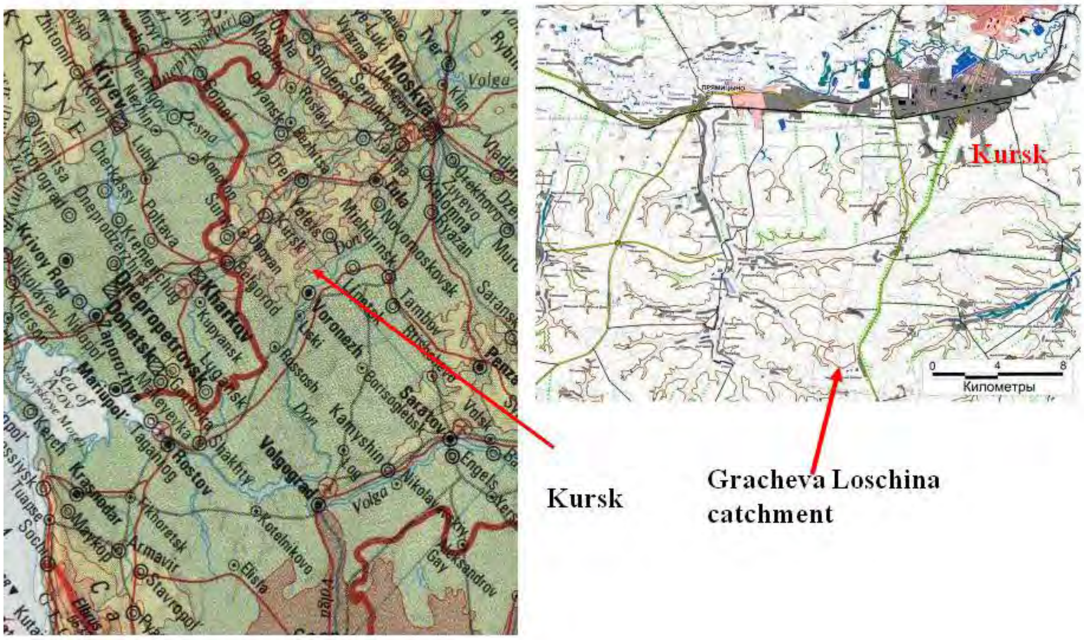
- It was found that rates of ^{137}Cs redistribution within cultivated slopes is relatively low, because of low erosion rates in the centre part of European Russia. Annually about 0,2-0,6% of ^{137}Cs eroded from cultivated slopes.
- It is found that ^{137}Cs migration along the cultivated slope has wave nature, because of re-deposition of sediment
- ^{137}Cs transfer to vegetation is extremely small and it is similar value with ^{137}Cs fallout.

Concluding remarks about caesium-137 redistribution on cultivated slopes. It was found that rate of caesium-137 redistribution within cultivated slopes is relatively low because of low erosion rates in the central part of European Russia. Annually about 0.2% to 0.6% of caesium-137 eroded from cultivated slopes, and it was found that caesium-137 migration along the cultivated slope has wave nature because of re-deposition of sediments along the slope. In general, caesium-137 transfer to vegetation is extremely small and it is similar value with caesium-137 fallout after Chernobyl incident.

^{137}Cs redistribution within the small catchment

The next part of topic is about caesium-137 redistribution within the small catchment. Here, you can see, this is typical small catchment which is a cultivated part of slope. Now, it's eventually grass but this may be also cultivated. This is the dry valley in the middle and the uncultivated steep slope of this valley. This is a flat bottom here and this particular catchment has the dam in outlet of the catchment, so it's a closed system. It is very convenient to study caesium redistribution in such type of system.

Location of Gracheva Loschina catchment



This catchment located nearby Kursk City which is about 550 kilometers from Moscow and this is the Gracheva Loschina catchment located here.

Study area characteristics

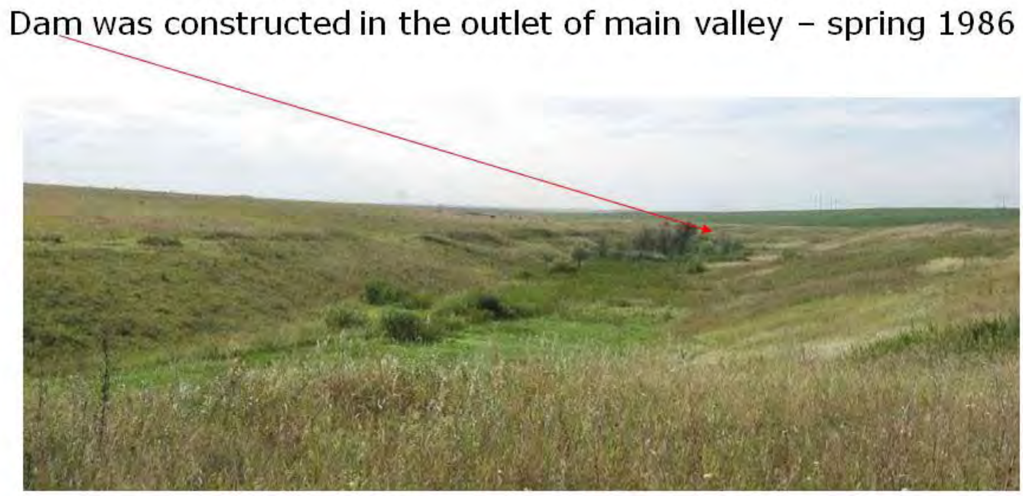
- Soil – chernozem formed mostly on loess deposits
- Precipitation 585 mm with 30% during cold months
- Relief amplitude 50-60 m with slope gradients in range 2-7° for cultivated slopes
- Erosion during snow-melting (frozen soil >40cm depth)
- Erosion during rain-storms - rain > 10 mm with maximum intensity 0,5-1 mm per min.

Very briefly, study area characteristics. Soil which is chernozem formed mostly on loess deposits. Precipitation about 600 millimeters with about 30% during cold months and relief amplitude of about 50 to 60 meters with slope gradients in range mostly between 2% and 7% regardless for cultivated slopes and erosion happened during both, during snow-melting if frozen soil of more than 40 centimeters depth and erosion during rainstorms if rain – have rain of more than 10 millimeters with maximum intensity more than 0.5 to up 1 millimeter per minute.

History of cultivation within study site

- Period 1930-1958 – mostly grain crops
- Period 1958 – 1964 – high increase of maize in crop rotation
- Period 1964 – 1992 – increase of sugar beats in crop rotation
- Since spring 1986 complex of soil conservation measures was created on the 70% cultivated slopes
- Period 1992 – 2006 – reduction of row crops in crop rotation

We have a detailed history of cultivation within the study sites. The one most useful things for us that since the spring 1986, just before Chernobyl fallout, the complex of soil conservation measures was created on the 70% cultivated slopes within the study catchment so it gives us a possibility to relate the influence of this soil conservation measures on caesium redistribution within the catchment.

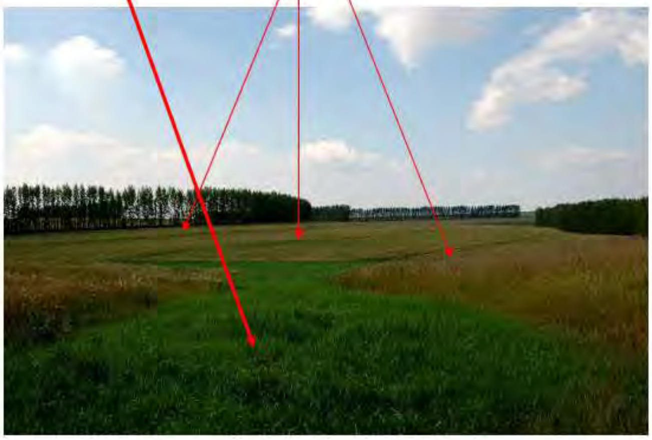


Chernobyl-derived Cs-137 fallout – May 1986.

This is once again the picture. It is more close, we can see here the dam.

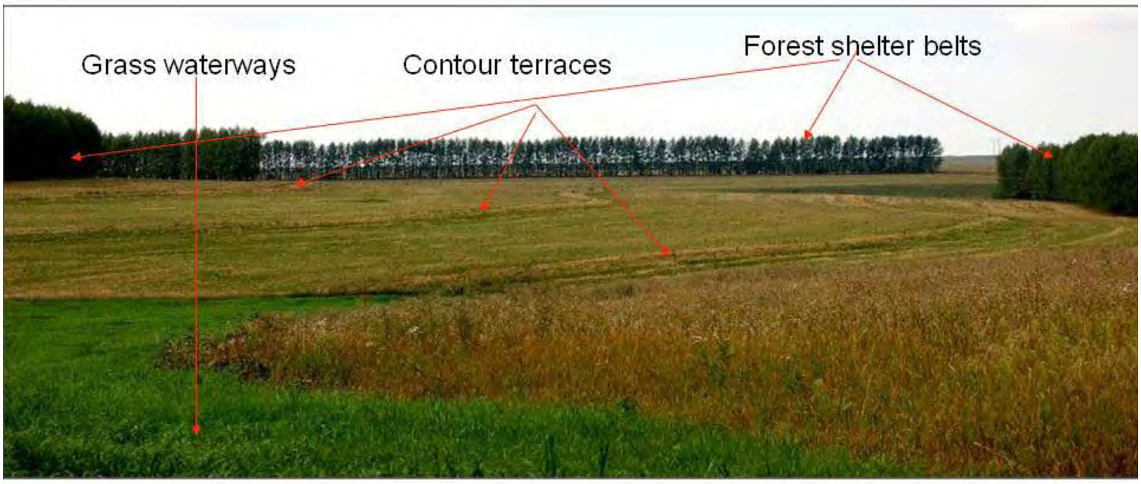
Types of conservation measures since 1986

Forest shelter belts with ditch between tree lines, contour earth terraces and grass ways.



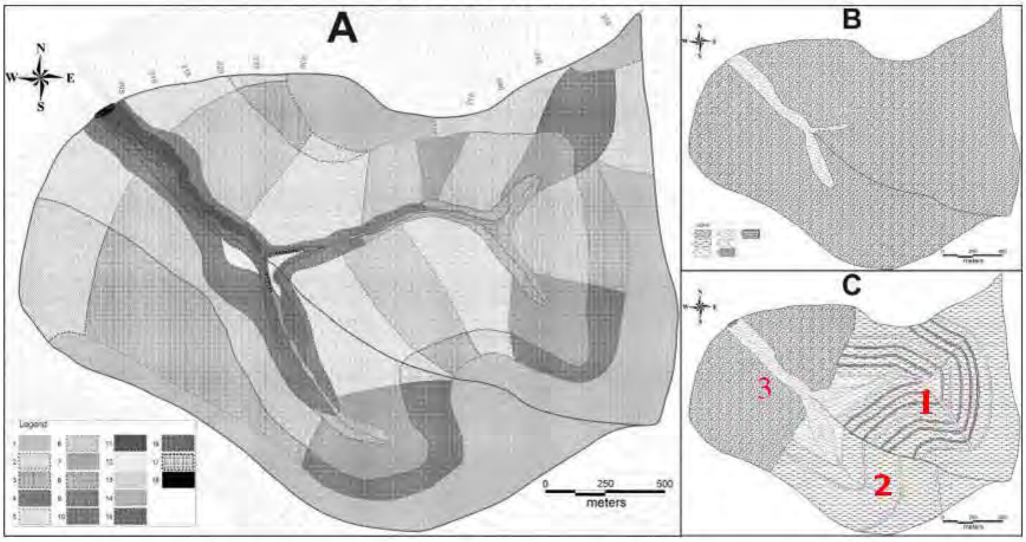
This shows you how the different type of soil conservation measures look like. This is the forest shelter belts with ditch in the middle which collects all water and sediments inside. This is also the slope terraces, here you can see, which is the contour earth terraces, which also reduce sediment redistribution and erosion rates, and there also are grass ways along the hollows also collect the possible sediments coming from eroded part of the slope.

General view of sub-catchment 2



This is the same with more detail. You can see here contour terraces, forest shelter belts, and the distance between the forest shelter belts is about 100 meters.

A: Geomorphic map of the case study catchment



B: Land use before 1986. C: Land use after 1986

This is the whole study catchment and you can see it can be divided on three parts. Two sub catchment with different type of soil conservation measures and the rest of the catchment with traditional cultivation. Here it is where the uncultivated important part of valley. It is here you can see.

What we did, first of all, we made a very detailed geomorphologic map of core study catchment. We selected different type of slopes, different configuration, and also different deposition zone

Legend for geomorphologic map

1) Rolling interfluve surfaces with dominant gradients <2° ;

2-4) Gradual slopes, 2-3° (2 – divergent, 3 – straight, 4 – convergent);

5-7) Moderate slopes, 3-5° (5 – divergent, 6 – straight, 7 – convergent);

8) Moderately sloping sides of tributary hollows, 3-5° ;

9) Relatively steep slopes and sides of tributary hollows, 5-10° ;

10) Moderately sloping main valley sides, 5-10° ;

11) Relatively steep main valley sides, >10° ;

12) Main valley terrace surfaces, 2-5° ;

13) Bottoms of slope depressions;

14) Bottoms of tributary hollows;

15) Main valley bottom;

16) Aggraded reservoir bottom;

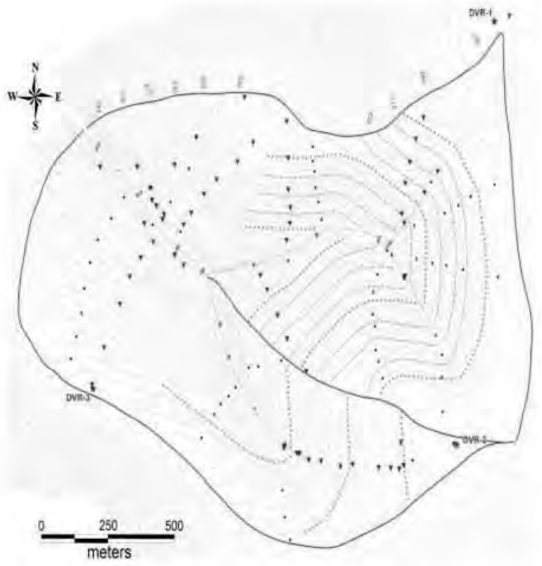
17) Concrete troughs at sites of former gauging stations at outlets of tributary hollows;

18) Earthen dam.

and this is the legend for geomorphologic map, and I think it is not necessary to stop and pinpoint but you understand the different type of geomorphologic units were divided.

Location of sampling points within the Gracheva Loschina catchment

4 reference locations were sampled for determination of initial ^{137}Cs fallout
Each morphological type of slopes was characterized by several transects
6-7 samples for determination of ^{137}Cs inventory were taken along the each transect



We have four reference locations in different corners of the catchment. This gives you some idea about initial trend, but in this case, there are no initial trend of caesium-137 fallout and each morphological type of slope was characterized by several transects with 6 or 7 samples for determination of caesium-137 inventory and so each unit was characterized by caesium-137 concentration.

Stage of evaluation of ^{137}Cs budget for each sub-catchment

- Area of each morphological unit was defined
- Several sampling points for radionuclide analysis were located within each morphological unit
- Total storage of ^{137}Cs were calculated for each morphological unit

Just more detail to show the stage of evaluation of caesium-137 budget for each sub-catchment. First of all, we measure the area of each morphological unit and also we sample several points for radionuclide analysis within each morphological unit and so we are able to evaluate the total storage of caesium-137 for each morphological unit. Actually, it is a simple but very useful approach for such system.

Determination of deposition volume for different time intervals

- Incremental sampling was made for the several pits along the valley bottom
- Area of deposition zone was evaluated on the base of detail geomorphologic mapping
- Peaks of ^{137}Cs concentration for 1964 (bomb-derived ^{137}Cs) and for 1986 (Chernobyl-derived ^{137}Cs) were defined

As for deposition area, we take incremental samples for several pits in bottom valley and,

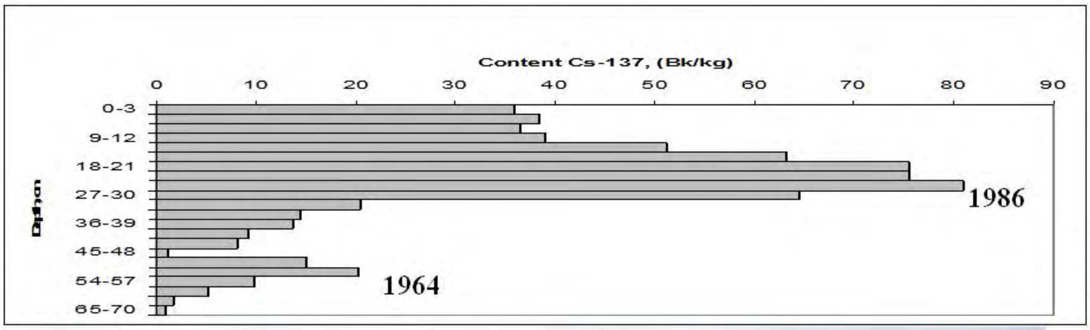
Section 2, middle part of the main valley bottom

Section location

Photo of section

for example, this pit is located in the middle part of the valley bottom.

Cs-137 vertical distribution for the dry valley bottom



Of course, we received a detailed vertical distribution of caesium-137 and we found how much sediments were deposited in each position since 1986. In addition, we were able to evaluate the other pit, which is connected with maximum fallout – bomb-derived caesium fallout.

^{137}Cs budget for sub-catchment with forest shelter belts and grass waterways

Total area, ha	^{137}Cs loss, KBq /Eroded area, ha	^{137}Cs gain, KBq /% from ^{137}Cs loss /Deposition area, ha		Residual KBq/%
		Within cultivated areas (including grassed waterways)	In tributary hollow bottoms and main valley bottom	
52.8	189606/42.3	154620/82%/55.2	7954/4%/0.3	-27032/14%

We just construct caesium-137 budget for each sub-catchment and, of course, for sub-catchment with soil conservation measures, the most part of sediment re-deposited within the catchment and only a small part reach the valley bottom

^{137}Cs budget for sub-catchment with forest shelter belts, grass waterways and contour terraces

Total area, ha	^{137}Cs loss, KBq /Eroded area, ha	^{137}Cs gain, KBq /% from ^{137}Cs loss /Deposition area, ha		Residual KBq/%
		Within cultivated areas (including grassed waterways)	In tributary hollow bottoms and main valley bottom	
88.1	926885/73.3	834195/90%/9.5	24650/3%/0.95	-68040/7%

and this is the same for the other sub-catchment with soil conservation measurement,

^{137}Cs budget for area without soil conservation measures and the main valley bottom

Total area, ha	^{137}Cs loss, KBq /Eroded area, ha	^{137}Cs gain, KBq /% from ^{137}Cs loss /Deposition area, ha		Residual KBq/%
		Within cultivated areas (including grassed waterways)	In tributary hollow bottoms and main valley bottom	
56.9	236786/48.6	22061/9%/1.4	200508/85%/1,4	-14217/6%

but the most part of sediments coming to the valley bottom from area where we have traditional cultivation, you can see that the most part of eroded sediments re-deposited later in the bottom part of the valley from this particular part of the catchment.

Sediment redistribution in the case study catchment according to ^{137}Cs budget

Time interval, year	Gross erosion, t/%	Deposition within cultivated field, t/%	Deposition within hollows and valley bottom, t/%	Output from the catchment, t/%
1986-2006	50989/100%	33778/82,8%	8766/17,2%	0

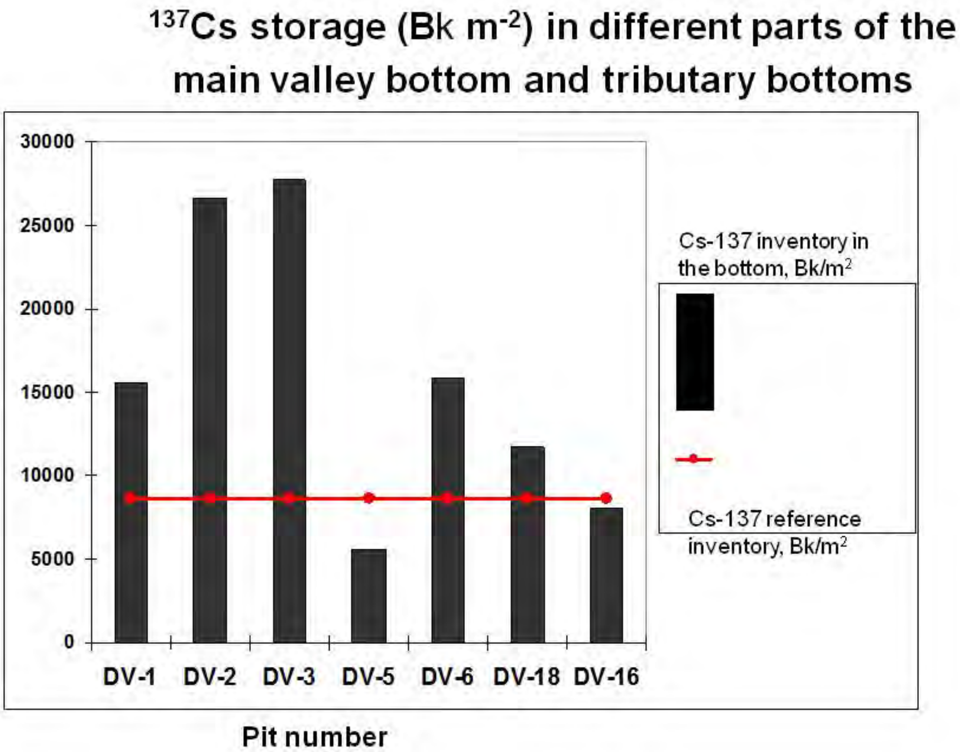
The total sediment redistribution budget according to the caesium-137 budget. You can see because of application of these soil conservation measures, the most part of eroded sediment are deposited within the cultivated group and only a small part entering the valley bottom.

^{137}Cs migration within Gracheva Loschina catchment

Part of agrolandscape	^{137}Cs fallout after Chernobyl incident	Transfer to vegetation	Lateral migration along the slope	Deposition in dry valley bottom
Flat interfluve area	**10 (~ 0,01)**	**8 (~ 0,01)**	**-**	
Slopes	**10 (~ 0,01)**	**12 (~ 0,02)**	**133–156 (0,2–0,6)**	
Valley bottoms	**10 (~ 0,01)**	**18 (~ 0,02)**		**27–111 (0,03–0,13)**

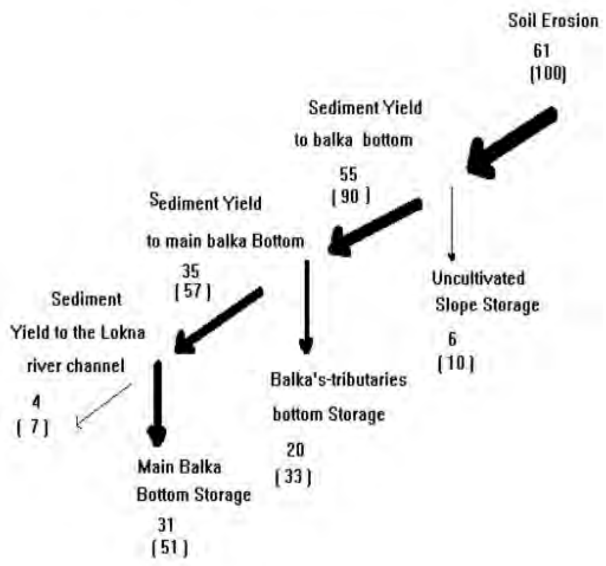
Here, we also studied the transfer to vegetation for different landscape position. You can see that the transfer of caesium to vegetation is relatively small and it is comparable with some caesium fallout already after the Chernobyl incident because later on we have some, of course, additional fallout. It was relatively small compared with initial Chernobyl fallout but anyway it was some fallout.

This is lateral migration along the slope and this is deposition in dry valley bottom. So, dry valley bottom which is the main sink of caesium in this case.



This graph gives you some idea about caesium storage in different parts of main valley bottoms and tributary bottoms. This part which is characterized by main valley bottom, you can see this is the reference value of caesium inventory for this particular catchment. You can see that the total storage in main valley is doubled up compared to initial fallout but for tributary, it depends from position. In some cases, there was some erosion because of the high gradient bottom but in most cases, it was more close to the reference values.

^{137}Cs and sediment redistribution within the Chasovenkov Verh Catchment (area 50 km^2, Tula region, very high level of Chernobyl contamination)

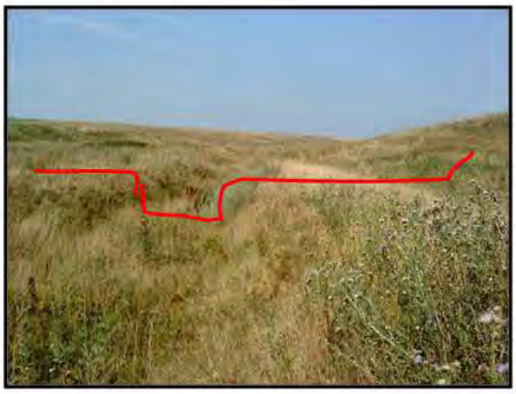


We have a same study for some Balka [ph] catchment. It is not necessary to go to some detail but this is only an example of such sedimented caesium redistribution budget for the Chasovenkov Verh Catchment with an area about 50 square kilometer in Tula region. You can see it here, the same situation, it’s the most part of sediment re-deposited in their valley bottoms which is about 84% and only about 7% of sediment and caesium entering to the river channel. It is the most typical situation for Russian Plain.

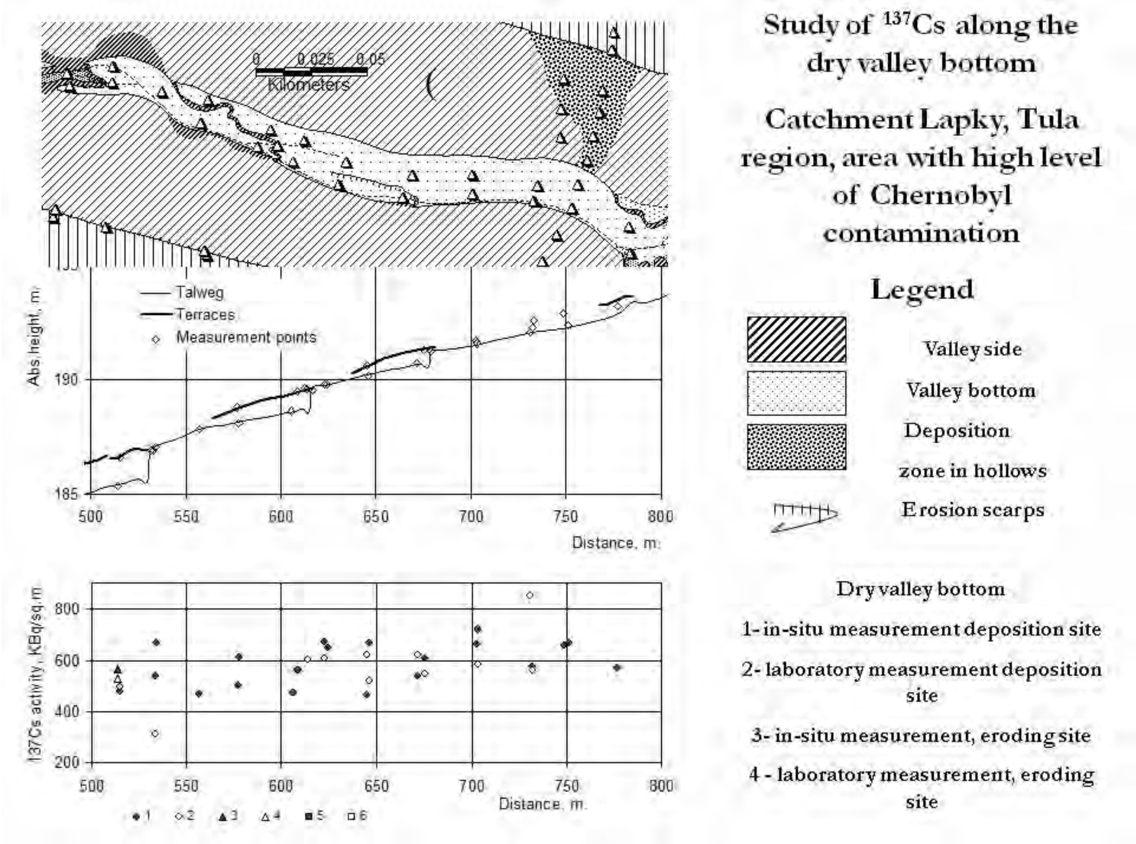
THE SEDIMENT AND SEDIMENT-ASSOCIATED 137CS REDISTRIBUTION IN DRY VALLEY BOTTOM

Active bottom gully

Aggradated bottom gully



Very shortly, some idea how sediment redistribute later on in the dry valley bottom. This is how the active gully bottom looks like. These are knick-points of this gully bottom if erosion happened, some retreat upstream happened and this is over the aggravated bottom gully. We have no erosion here.



This study - this graph is in more detail for one site. You can see this is also the bottom map of the dry valley bottom. This is the gully knick-points here and you can see this is profile. This is, again, aggravated points here and you can see this graph shows you the caesium concentration sample was taken just immediately after knick-points and on several methods downstream and the same. You can see after each knick-point, you have some increase in caesium, also the same. That means that eroded sediments are deposited immediately after the knick-points of the first few meters, and so it is not so active process recently because may be not so high intensity permanent runoff in this dry valley bottom.

Concluding remarks: ^{137}Cs redistribution in small catchments

- The most part of ^{137}Cs eroded from cultivated field re-deposited along pathways from arable land to the river channel. The main storage of ^{137}Cs is observed in the bottom of dry valleys, where total storage of ^{137}Cs became double if compare with initial Chernobyl-derived fallout and on bottom parts of cultivated slopes.
- Bottom gullies knick-point retreat is the main process of following remobilization of ^{137}Cs along the dry valley bottoms. However the most part of ^{137}Cs is re-deposited within 50- m stretch downstream. Dry valley bottom represents a long-term contaminant sink.

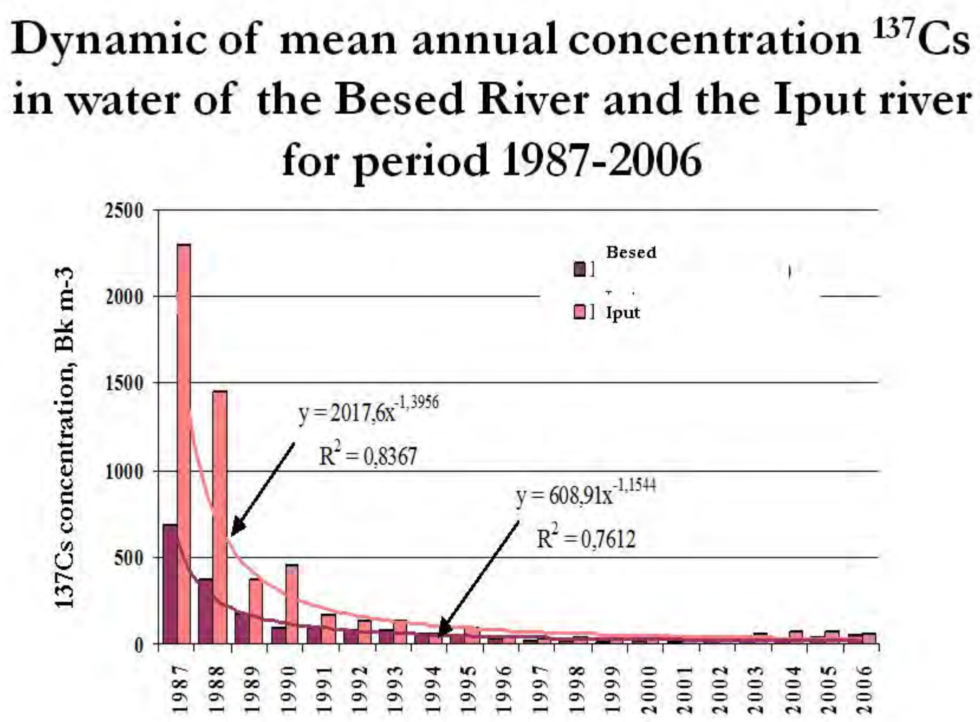
What do we say the conclusion for this part of the talk? We can say that the most part of caesium-137 eroded from cultivated field re-deposited along pathways from arable land to the river channel. The main storage of caesium-137 is observed in the bottom of dry valleys where total storage of caesium-137 became double if compared with initial Chernobyl-derived fallout and, of course, on the bottom parts of cultivated slopes.

Bottom gullies knick-point retreat is the main process of following remobilization of caesium-137 along the dry valley bottoms. However, the most part of caesium-137 is re-deposited within a 5-meter stretch downstream and so dry valley bottom represents a long-term contaminant sink nowadays.

^{137}Cs redistribution in river channels

- Immediately after Chernobyl incident few gauging station located down-stream from the most contaminated area began to monitor ^{137}Cs concentration in river water with suspended sediments
- Such observations were organized in the Dnieper River basin (few locations) and the Plava River
- It was found that maximum concentrations were observed during spring floods 1987 and 1988. After that ^{137}Cs concentration decrease considerably

The next part of topic is caesium-137 redistribution in river channels. Immediately after Chernobyl incident, a few gauging station located downstream from the most contaminated area began to monitor caesium-137 concentration in river water with suspended sediments. Such observations were organized in the Dnieper River basin at few locations and the Plava River. It was found that maximum concentrations were observed during spring floods in 1987 and 1988. After that, caesium-137 concentration decreased considerably.

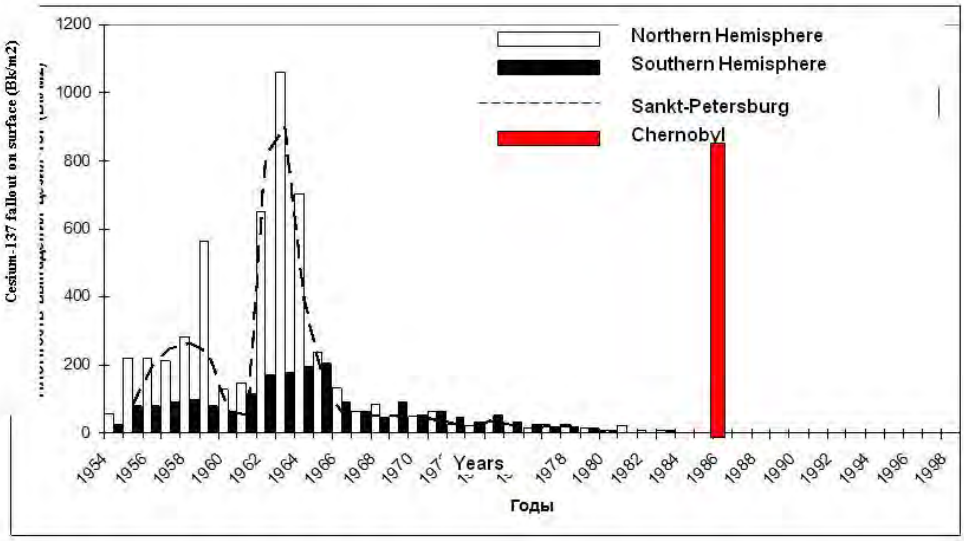


You can see the graph. This shows the dynamic of mean annual concentration caesium-137 in water of the Besed River, the Besed River drain mostly the Russian part of the contaminated area, and Iput River which is mostly drained the Russian part of contaminated area. Both of these basins located nearby from Chernobyl, not so far from Chernobyl. However, you can see that the relatively high concentration of caesium was observed only during this first year, varied afterwards, it was very sharp decrease in caesium-137 concentration in water. However, during the second part of 2000, there was some small increase observed probably just because maybe more stronger flooding and there may be some particles from wild [ph] land reached the river channel. However, it was very low.

Chernobyl ^{137}Cs deposition on river floodplains

We need to put much more attention, of course, in this case to Chernobyl caesium deposition on river floodplains because here we can see – we usually observed some sediment deposition.

Bomb-derived and Chernobyl Cs-137 deposition for period 1954-1998



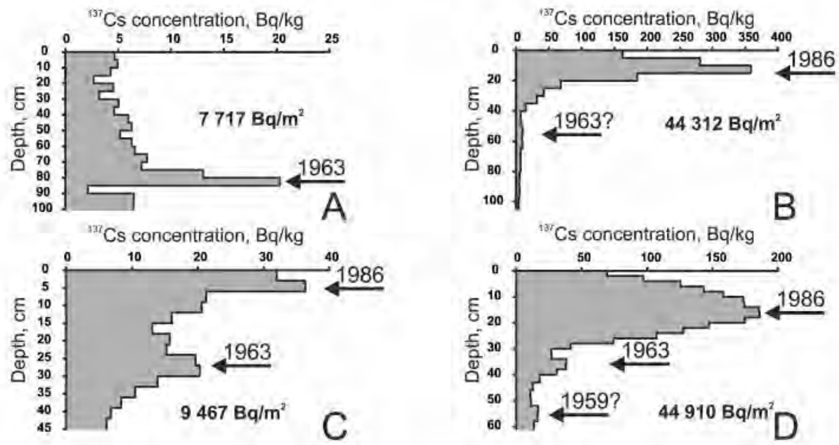
Once again, I just would like to remind you of how many peaks we have. We have one peak which belongs to 1958 and also the next which is 1963-1964, and Chernobyl and what have we found for – and again, you can see, it's very essential.

Initial bomb-derived ^{137}Cs deposition in Europe (according of Atlas of caesium deposition on Europe after Chernobyl Accident, 1998)

- Average level for latitudes 30-40°N – about 1,8 kBq m^{-2}
- Average level for latitudes 40-50°N – about 2,4 kBq m^{-2}
- Average level for latitudes 50-60°N – about 2,2 kBq m^{-2}

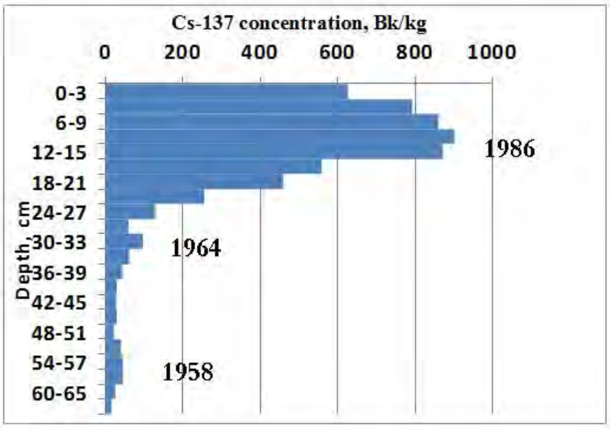
For Europe, we have average value of different latitudes in such range. This is the value of bomb-derived caesium contamination,

The ^{137}Cs profiles associated with the sediment cores collected from the floodplains of the rivers with different level of Chernobyl contamination:
A) Toshnya River; B) Zusha River;
C) Vorobzha River; D) Turdei River.



and if we are looking from depth distribution for different floodplains, what we found is that it is very similar values for 1963. You can see the two transects and for example this curve shows a distortion area, which is located in area of each was not contaminated by Chernobyl. There is more contamination here to even not evidenced on the graph but other graphs give it is for Zusha River, Vorobzha, Turdei River, all of them located in areas with different levels of Chernobyl contamination and here sometimes it is possible to identify even several peaks which belong to different time interval but for area with very high level of Chernobyl contamination, usually it is not possible to identify even a peak which belongs to 1963.

The ^{137}Cs profiles associated with sediment cores collected from floodplain of the River Plava (area with very high level of Chernobyl contamination)

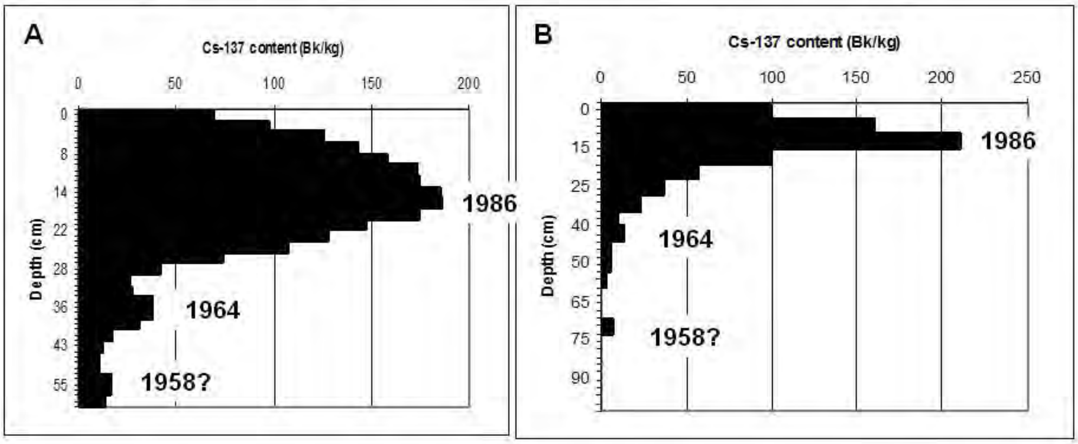


In some cases, it is possible but we are not absolutely sure if it is derived because, again, the differences between Chernobyl caesium contamination and the contamination after bomb-derived caesium fallout are considerably high.

The ^{137}Cs profiles associated with sediment cores collected from floodplain of :

A – the River Turdei; B – the River Zusha

(Area with high values of Chernobyl contamination)



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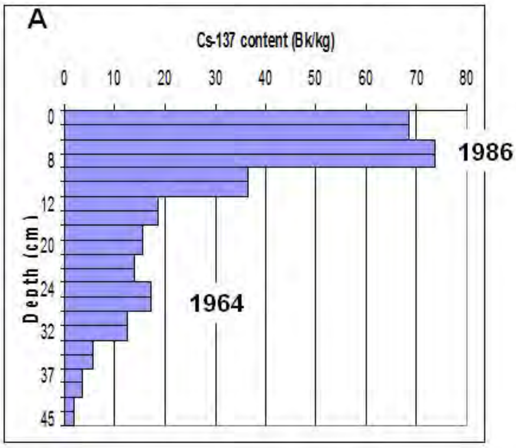
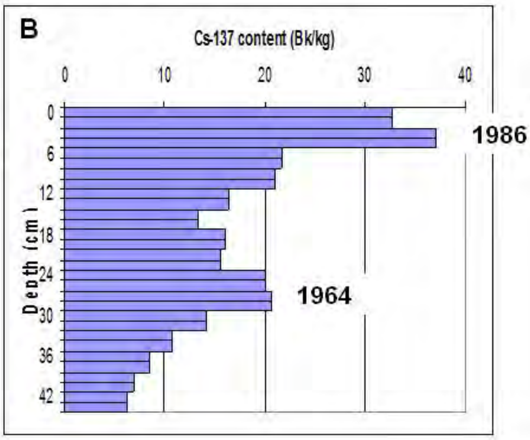
The ^{137}Cs profiles associated with sediment cores collected from floodplain of :
A – the lower Konopelka River; B – the lower Vorobza river

(Area with mean values of Chernobyl contamination)





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Concluding remarks:
^{137}Cs redistribution in river valleys

- ^{137}Cs concentration in river water (for area seriously affected by Chernobyl contamination) decrease considerably already after two years after Chernobyl incident
- However sediment-associated redistribution of 137Cs is continuing until now
- The most contaminated areas is the bottoms of reservoirs and low level floodplains.
- Fortunately in case of Russian Plain transport of contaminated sediment particles from cultivated slopes to the river channels is relatively low because of buffer zones (dry valleys) between cultivated fields and river valleys.

What you can see that the caesium-137 concentration in river water for areas seriously affected by Chernobyl contamination decreased considerably already after 2 years after the Chernobyl incident. However, sediment-associated redistribution of caesium-137 is continuing until now. The most contaminated area is the bottoms of reservoirs and low level of floodplains. Fortunately, in case of Russian Plain, transport of contaminated sediment particles from cultivated slopes to the river channels is relatively low because of buffer zones, dry valleys, between cultivated fields and river valleys.

Advantages in study Chernobyl-derived ^{137}Cs redistribution

- Short time of fallout (end of April – mid of May 1986), possibility to use more simple calibration models
- Available information about initial fallout (Atlas of Europe contamination after Chernobyl accident), possibility to check initial fallout, determine on reference location
- Additional marker for evaluation sedimentation rates for period since spring 1986
-

To summarize what we were talking about before, we have some advantages in study Chernobyl-derived caesium-137 redistribution. First of all, it is because the short time of fallout in this case, possibility to use the more simple calibration models for recalculation of values of caesium to erosion rate values. Also, we have very detailed available information about initial fallout because the Atlas of Europe contamination after Chernobyl accident is already published and it is possible to check initial fallout when you need to find some reference location in other words because we have such type of Atlas. Of course, it is additional marker for evaluation of sedimentation rates for period since spring 1986.

Advantages in study Chernobyl-derived ^{137}Cs redistribution

- Usually available information about crop-rotation for study field or study catchment
- Use ^{137}Cs budget approach for evaluation of sediment redistribution in close (with dam in outlet) catchments
- More short time of measurement concentrations if compare with bomb-derived ^{137}Cs (for areas with relatively high contamination)

Also, of course, it is usually available information about crop-rotation which is not so for bomb-derived caesium-137 because it's more long period of time. In this case also, we used caesium-137 budget approach for evaluation of sediment redistribution in close catchments. It's working very good. Of course, because of high concentration of caesium, which is more short time of measurement concentrations when compared with bomb-derived caesium-137 for areas with relatively high contamination.

Disadvantages in study Chernobyl-derived ^{137}Cs redistribution

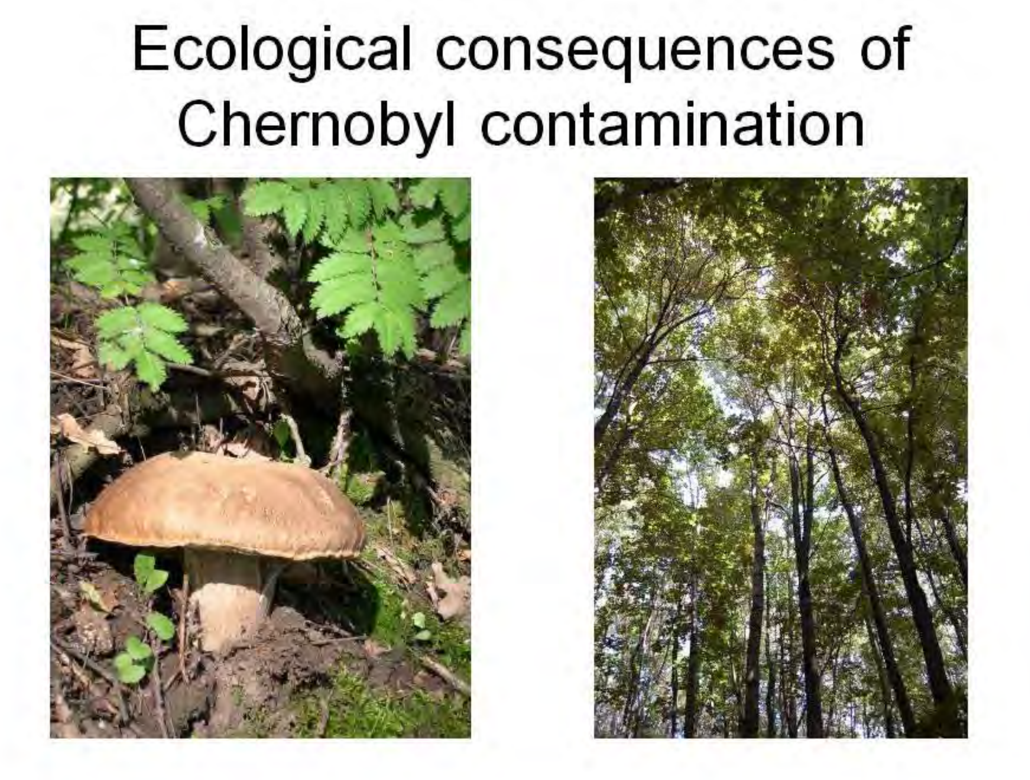
- Necessary to have few reference locations around study area for evaluation trend in initial fallout ^{137}Cs
- Problems with evaluation of soil losses in areas with relatively equal bomb-derived and Chernobyl-derived ^{137}Cs fallouts
- High initial spatial variability in areas surrounded Chernobyl Power station (distance about 0-200 km)

However, some disadvantages in study Chernobyl-derived caesium-137 redistribution. First of all, it is necessary to have few reference locations around study area for evaluation trend in initial fallout caesium-137. There are also problems with evaluation of soil losses in areas with relatively equal bomb-derived and Chernobyl-derived caesium-137 fallouts and, of course high, initial spatial variability in areas surrounded Chernobyl Power station.

Recommendations

- It is necessary to identify sediment sources areas for each river basin areas located in the radionuclide contamination zone for prevention ^{137}Cs transfer to the river channel.
- It is requested to evaluate sediment delivery ratio for different types of catchments for evaluation hot spots for each river basin.
- It can be done using both: for example, *LANDSOIL model*, which is allowed to received spatial-temporal assessment of soil redistribution rates including different processes affected on soil movement, and *fingerprinting technique*, which is allowed to identify the main sediment sources
- However any model calculations should be verified using field data

It is some just – probably very simple recommendations which is based on our study. It is necessary to identify sediment sources areas for each river basin areas located in the radionuclide contamination zone for prevention caesium-137 transfer to the river channel. It is requested to evaluate sediment delivery ratio for different types of catchments for evaluation of hot spots for each river basin. Note that it can be done using both for example LANDSOIL model which is allowed to receive spatial-temporal assessment of soil redistribution rates including different processes affected on soil movement and fingerprinting technique which is allowed to identify the main sediment sources. However, any model calculations should be verified using field data.



A few words about ecological consequences of Chernobyl contamination. In fact, it is not my topic but that’s all in general view.

Contaminated territories with different conditions

- Exclusion zone - >1480 kBq m^{-2} (>40 Ci km^{-2})
- Evacuation zone 555 -1480 kBq m^{-2} (15-40 Ci km^{-2})
- Partial evacuation zone 185-555 kBq m^{-2} (5-15 Ci km^{-2})
- Control zone with special social-economic status - 37 – 185 kBq m^{-2} (1-5 Ci km^{-2})

Now, once again, I would like to remind you of it, we have four different zones for different level of contamination

and for exclusion zone, first this area will not be used for life during long time because of very high level of radionuclide contamination and until now, it is not allowed to live there, only some tourist excursions start for this particular area for a very short time because, in fact, even now it is very high radioactivity there.

Evacuation zone

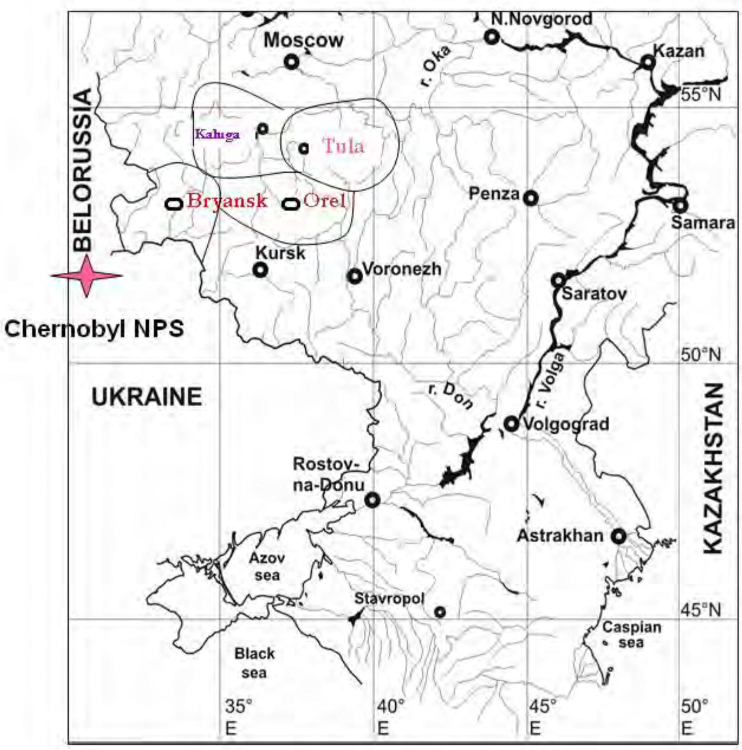
- High level of radionuclide contamination during first year after Chernobyl incident
- During long time high concentration of ^{137}Cs in wild mushrooms and wild berries.
- Special conservation measures for reducing radionuclide concentration in agricultural soils
- Problems with radionuclide redistribution because of forest fire (during first decade after Chernobyl)

For evacuation zone, we have high level of radionuclide contamination during first year, mostly during the first year after Chernobyl incident. During long time high concentration of caesium-137, it was found in wild mushrooms and wild berries and the Russians, they like to collect wild mushrooms and wild berries so in fact, it was dangerous and, of course, special conservation measures for reducing radionuclide concentration in agricultural zones were done for this particular area. Of course, even until now, some problems with radionuclide redistribution because of forest fire, which you need also to take into consideration this problem which can happen sometimes.

Partial evacuation zone and control zone with special social-economic status

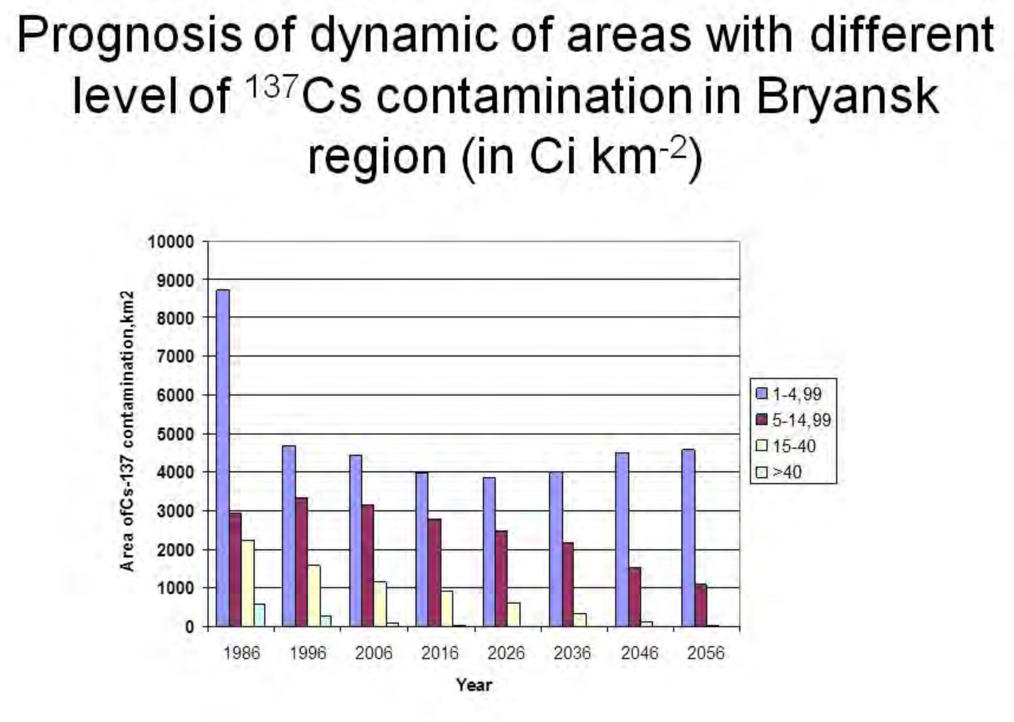
- The most serious influence on people health during first months after incident until the decay of short-live radionuclides
- Similar problems with wild mushrooms and wild berries, but during more short time interval
- Special conservation measures for reducing radionuclide concentration in agricultural soils (but more simple), if it was necessary

For two other zones, the most serious influence on people health was during first months after incident until the decay of short-live radionuclides. Similar problems with wild mushrooms and wild berries but during more short time interval and also some special conservation measures for reducing radionuclide concentration in agricultural soils was done but for more simple if it was necessary.

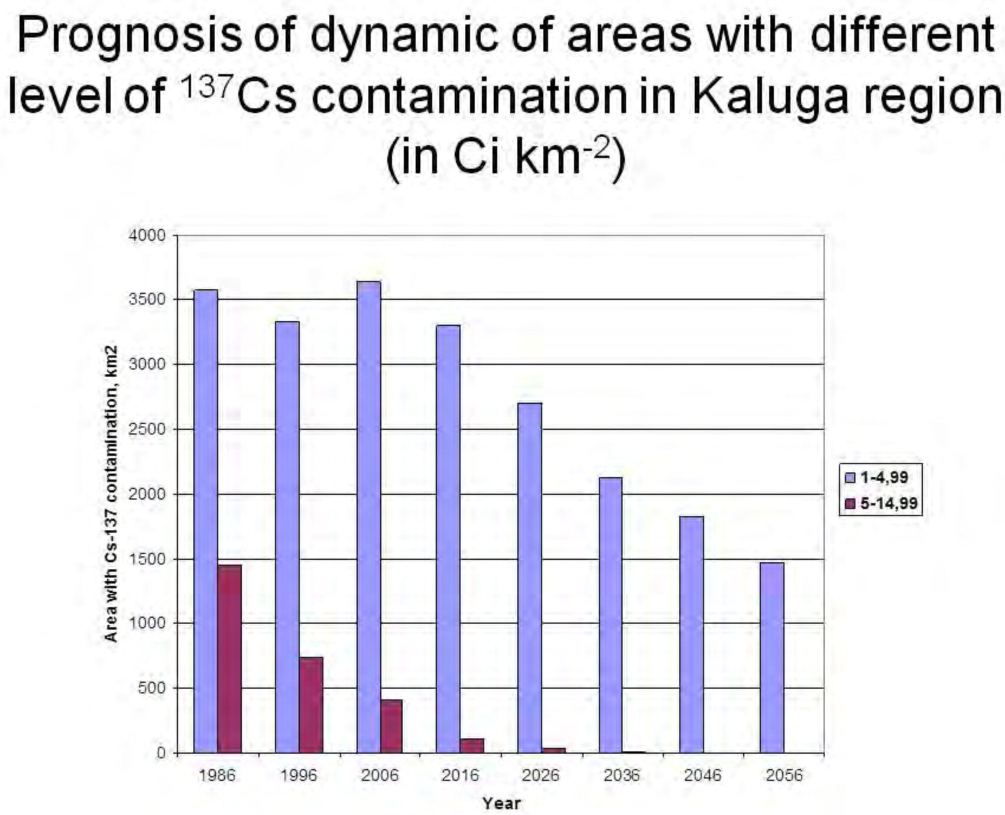


Regions with high level of Chernobyl contamination in Russia

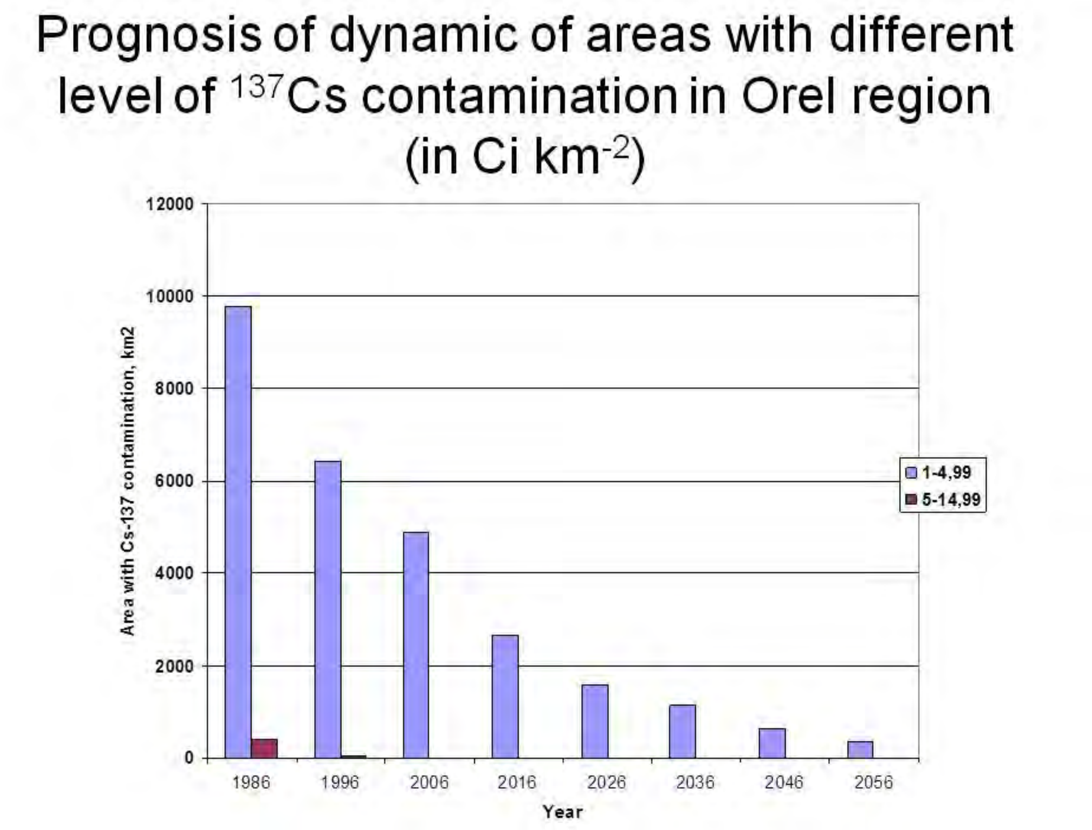
Just recently, a special prognosis was done how contaminated area will reduce for the coming clear. For this, the most contaminated area of Russia is Bryansk region, the most contaminated Tula region and Kaluga region and Orel region.



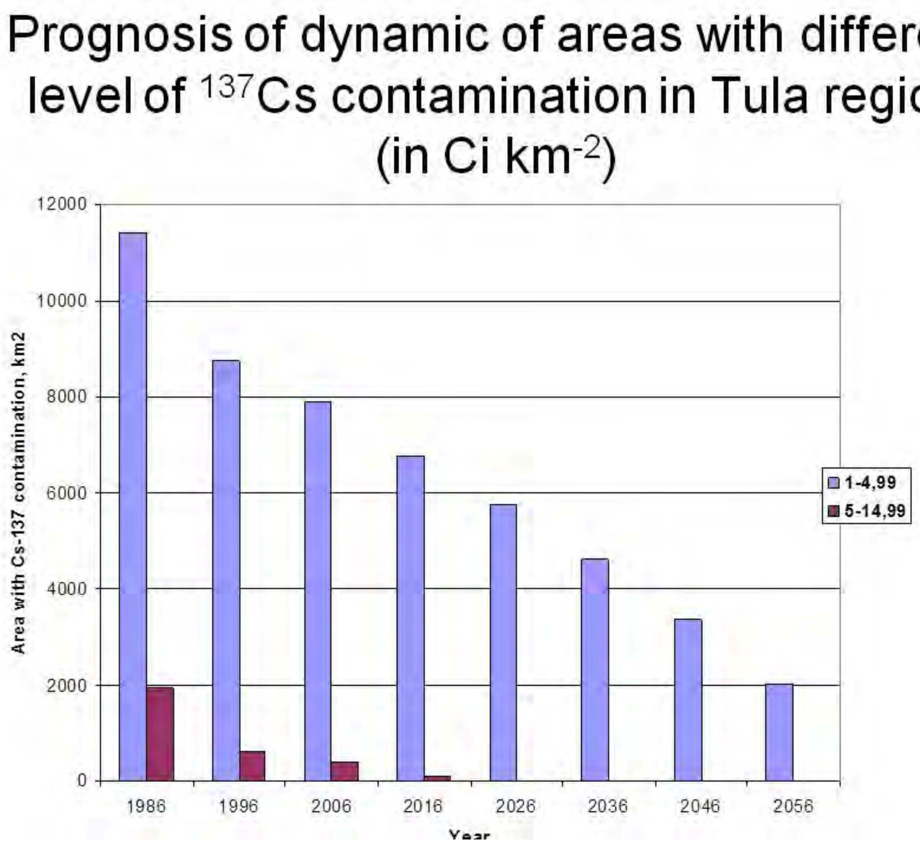
These graphs show you the prognosis of dynamic of areas with different level of caesium-137 contamination in Bryansk region. You can see initially that even area of very high value of contamination up to – in this case, it's curies per square kilometers was more 2000 kilometers and it is until 2056, some area will exist.



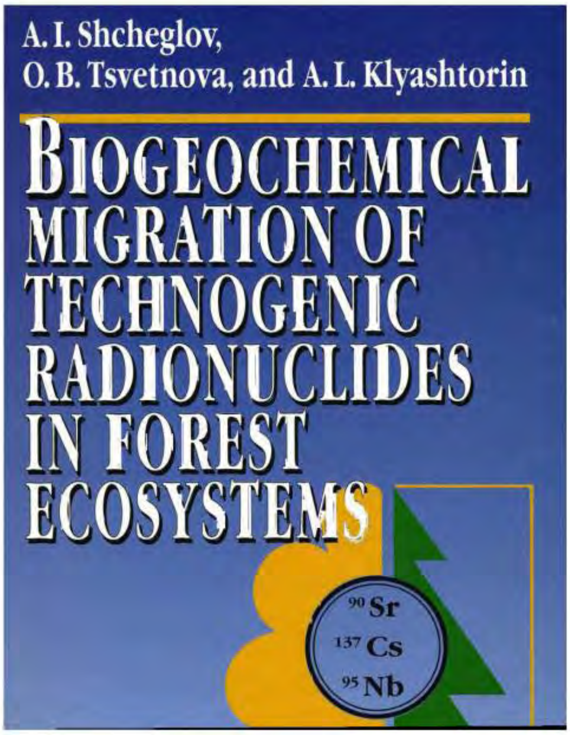
For our region, the situation initially was not so bad but still you can see, for example, for Kaluga region, we have until the middle of this century more than 1500 kilometers with such level of contamination.



This is for Orel region, which is not so heavily contaminated.



This is for Tula region, which also had some decrease of contamination.

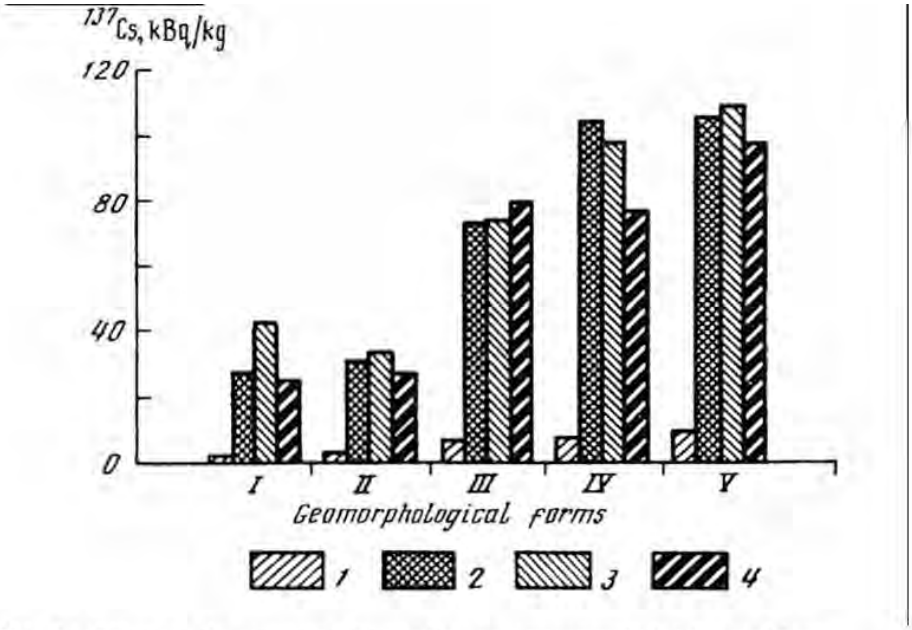


Also, I would like to say to you that I recommend you to read this particular book which was published in 2001, and it was written by Shcheglov, Tsvetnova, and Klyastorin. It is 'Biogeochemical Migration of Technogenic Radionuclides in Forest Ecosystems.'

The coefficients of radionuclide retention in the tree canopy depending on the climatic zone, age, and type of fallout [8]

Object	Type of fallout	Coefficient of retention, %
Young pine forest (6–10 years old), crown projection = 1.0	Experimental spraying of the tree crowns by water solution of ^{89}Sr	90–100
Old pine forest (60 years old), crown projection = 0.9	Fallout particles < 50 μm	80–100
Mature pine forest (25 years old), crown projection = 0.8	Fallout particles < 100 μm	70–90
Mature pine forest (30 years old), crown projection = 0.8	Secondary fallout (soil/fallout particles resuspended from the soil by wind)	40–60
Winter birch forest (40 years old), crown projection = 0.8	Secondary fallout (soil/fallout particles resuspended from the soil by wind)	20–25
Summer birch forest (35–40 years old), crown projection = 0.8	Global (weapon) fallout	20–60
Old pine forest (50–60 years old), crown projection = 1.0	Global (weapon) fallout	50–90
Tropical rainforest (Puerto-Rico, Central America)	Global (weapon) fallout	100

I think this is a very useful book for, in your case, because in Japan, a lot of forest area was contaminated and there are some examples what information you can find in this particular book. For example, the coefficients of radionuclide retention in the tree canopy depending on the climatic zone and the coefficient of retention for different type of forest



^{137}Cs in different pine organs depending on geomorphologic position
I/ flat warteshed slope; II/upper part of slope III/ terrace IV/terrace basement,
V/central part of depression

Organs and components: (1) wood, (2) inner bark (bast),
(3) needles and twigs of current year, (4) cones

and also caesium-137 in different pine organs depending on geomorphologic position for flat watershed slope, upper part and different terraces, you can see it here and for different organs.

. The effect of the tree age on ^{137}Cs content in various tree organs and components (kBq/kg, dry weight, ^{137}Cs deposition is 370 kBq/m^2).

Age (years)	Organs and components						
	Wood	Bark		Branches		Leaves (needles)	Cones
		Inner	External	Large	Small		
				Pine			
45	0.04	0.20	0.39	0.03	0.09	0.29/0.06*	0.16
12	0.10	0.57	0.45	0.14	0.31	0.84/0.23	No data
				Birch			
45	0.12	0.30	0.22	0.56	0.43	2.75	No data
12	0.59	1.70	0.32	1.45	2.62	2.89	No data

* Numerator - young needles of current year, denominator - old needles (2-3 years old)

For example, effect of tree age on caesium-137 content in various tree organs and components which is also very essential.
These are only a few examples but you will get much more information in this particular book

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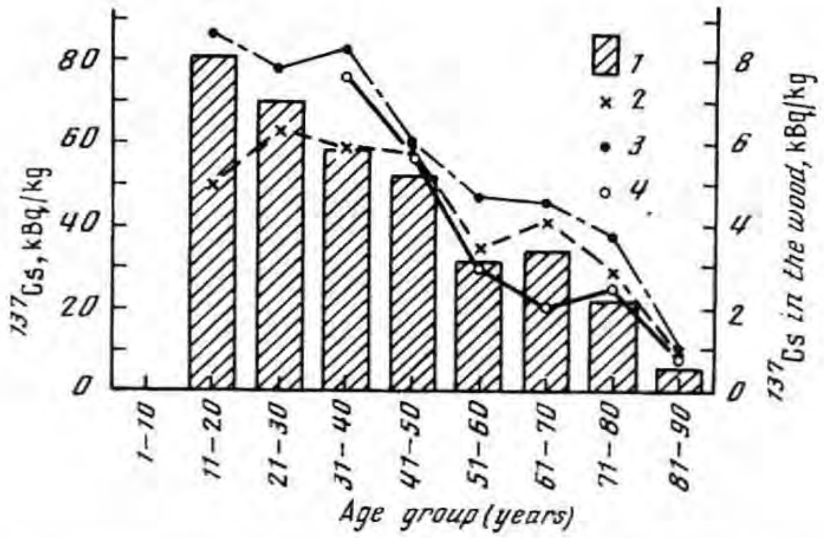

5. ^{137}Cs content in the pine components and organs depending on the stand age: (1) wood, (2) inner bark, (3) needles and twigs of current year, (4) cones

and it is one example which is also caesium content in pine components and organs depending on the stand age. You can see that all the trees less in caesium.


Thank you very much
for your attention