Stary Vishkov, 2001

Evaluation of external exposure from the Chernobyl fallout and terrestrial radionuclides in the Bryansk region, Russia

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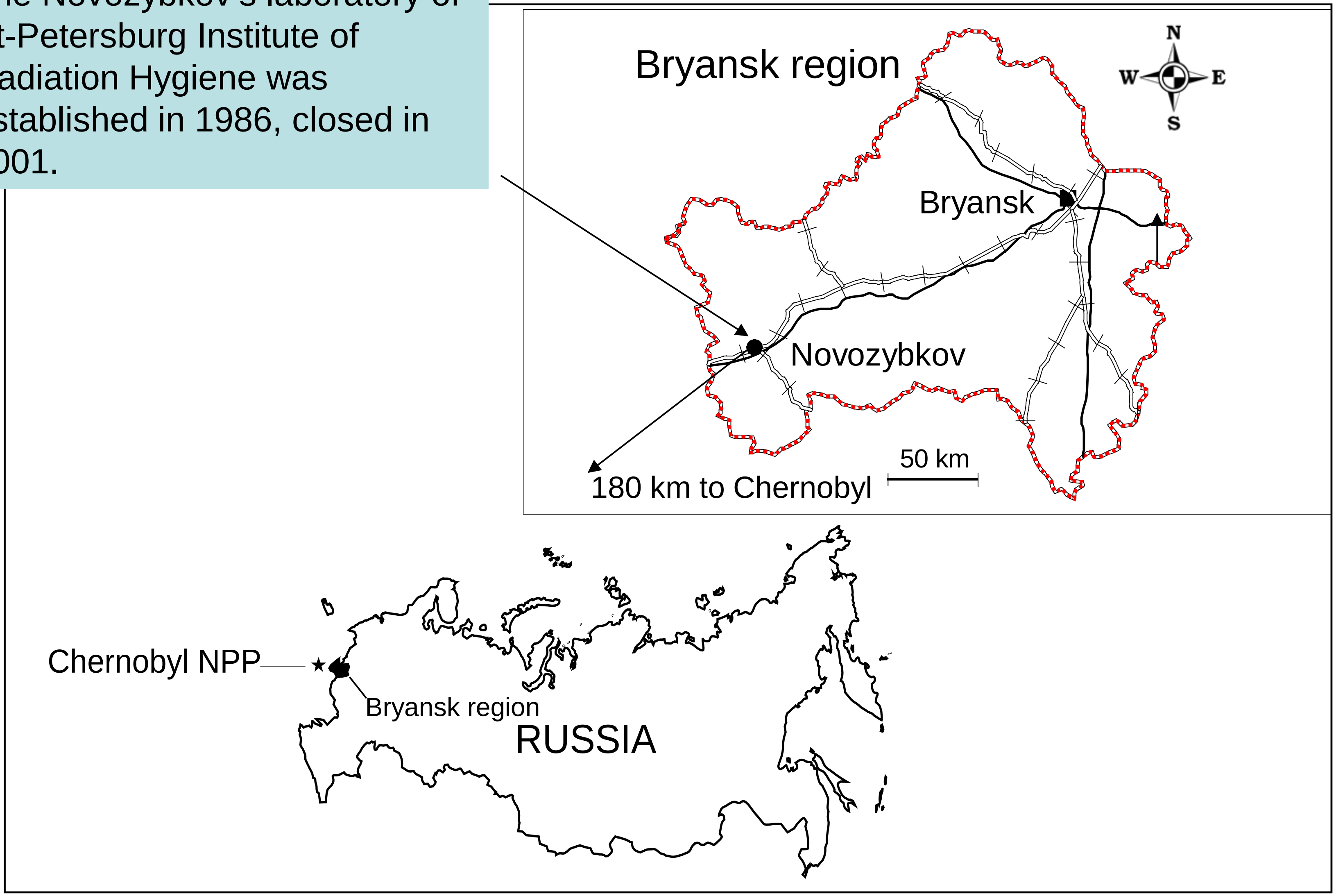
Position of the Koriyama city and the Bryansk region

Location of the Bryansk region in Russia

The Novozybkov's laboratory of St-Petersburg Institute of Radiation Hygiene was established in 1986, closed in 2001.



Some characteristics of the Bryansk region

- Area – 34857 km^2
- Population – 1.47 million (the census 1989)
- Number of settlements – 3015 (the census 1989)
- Climate – moderate, continental
- Precipitation – 585 mm/year (in Novozybkov)
- Annual temperature – +6.5 °C (in Novozybkov)
- Snowfall period – November-March

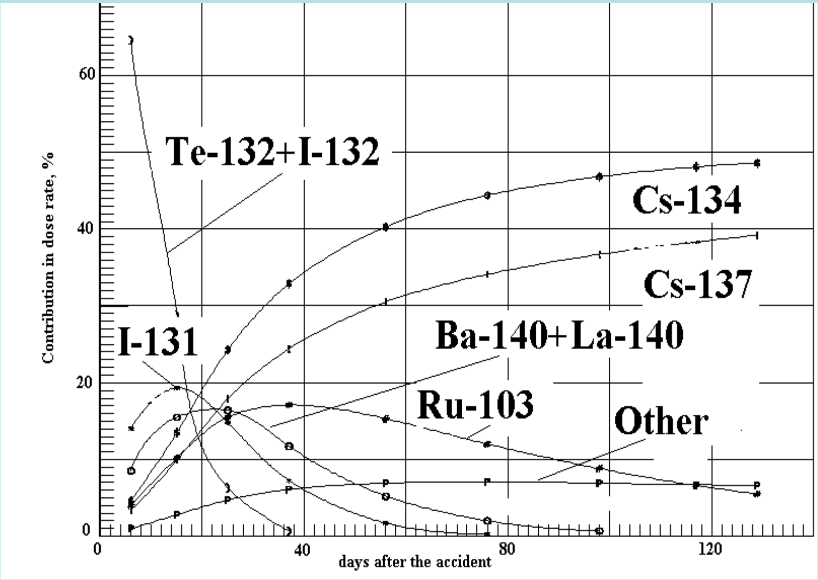
Source: Novozybkov, 2001.

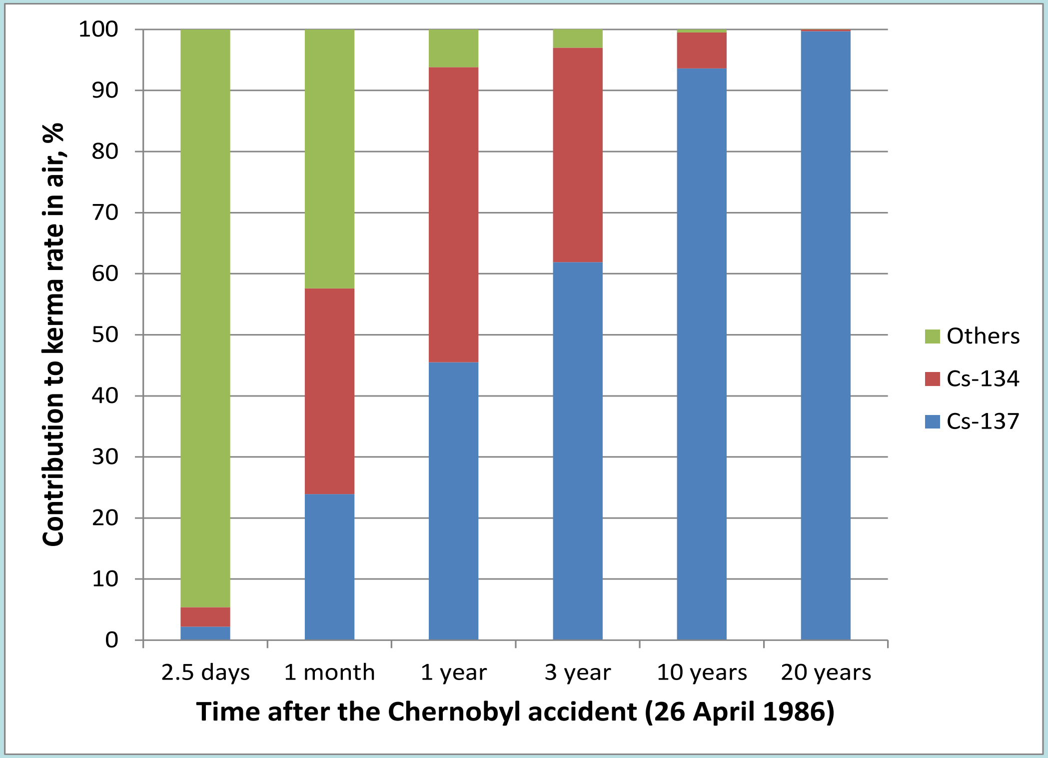
List of radionuclides detected in Chernobyl fallout in the Bryansk region

Nuclide	A_i/A_{137Cs} (at time t = 3.5 d)*	d_i (nGy h^{-1} per kBq/m^2)	Half-life (day)
^{95}Zr	0.079	3.23	65 (64)
^{95}Nb	0.081	3.35	35
^{103}Ru	1.61	2.21	39
$^{106}Ru+^{106}Rh$	0.47	0.94	368
^{125}Sb	0.06	2.15	1,011
^{131}I	7.64	1.74	8.0
$^{132}Te+^{132}I$	7.15	11.5	3.2
^{133}I	1.02	2.72	0.9
^{134}Cs	**0.54**	**6.85**	**752**
^{136}Cs	0.19	9.08	13
$^{137}Cs+^{137m}Ba$	**1.0**	**2.55**	**11,023**
^{140}Ba	0.41	0.93	13
^{140}La	0.45	9.27	1.7
$^{144}Ce+^{144}Pr$	0.079	0.24	284
^{90}Sr	0.01-0.02	-	10403
$^{239}Pu+^{240}Pu$	<0.001	-	$>2.4\times10^9$

*-29 April 1986; Source: Atlas…., 2009; Bailiff et al., 2004; Jacob and Likhtarev,1996.

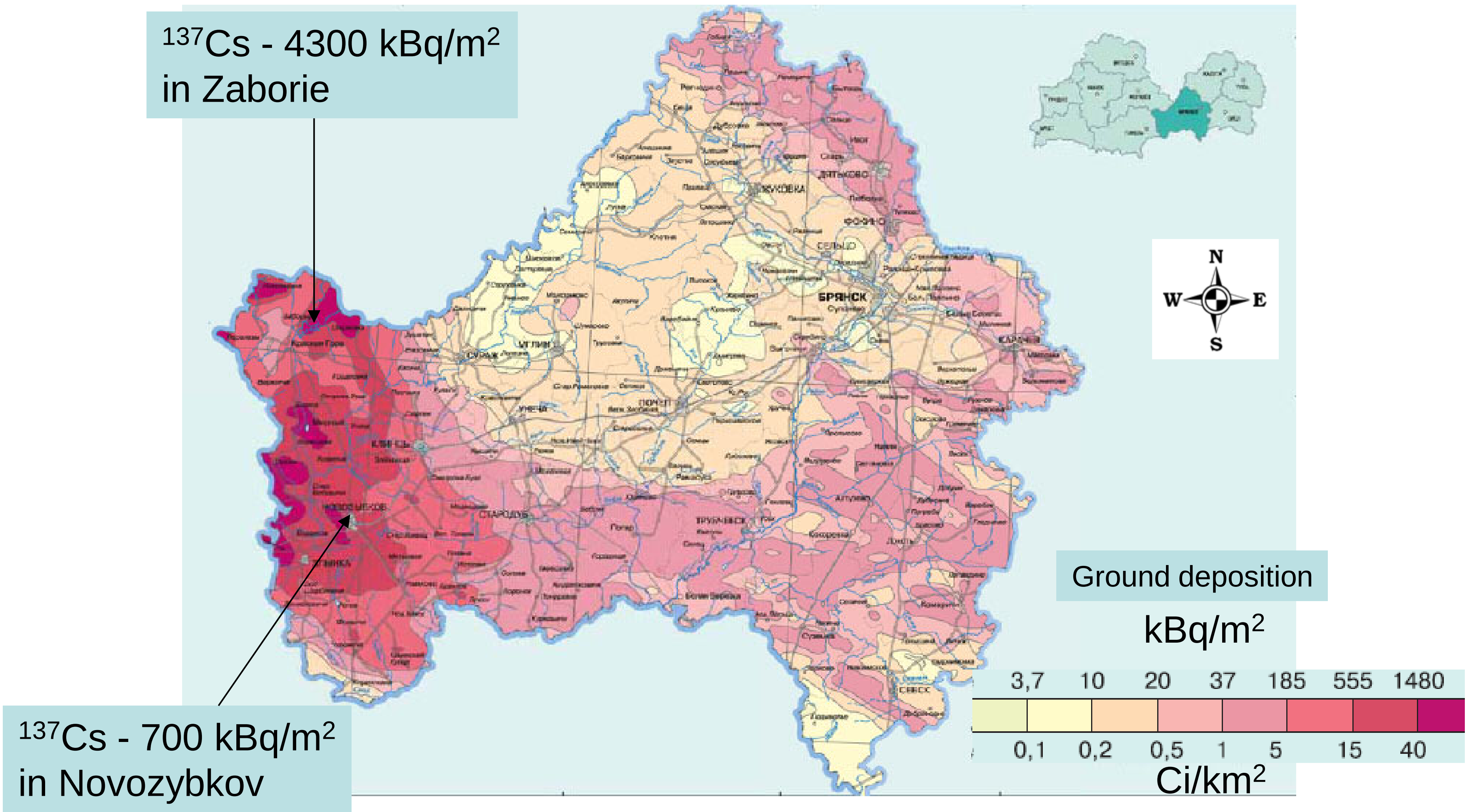
Contribution to kerma rate in air from γ-ray emitting technogenic radionuclides after the Chernobyl accident





Source: Golikov et al., 1993

Map of the ground contamination by ^{137}Cs, the Bryansk region, 1986.



Source: **The Atlas of recent and predictable aspects of consequences of Chernobyl accident on polluted territories of Russia and Belarus, 2009.**

Levels of soil contamination with ^{137}Cs and number of settlements and population in the radioactively contaminated area of the Bryansk region (on 01 January 2006)

^{137}Cs inventory in soil as for 1991		Number of settlements	Number of population
kBq/m^2	Ci/km^2		
37-185	1-5	539	172000
185-555	5-15	236	133000
>555	>15	194	78600
Total contaminated*		**969**	**383600**

* + four settlements (the restriction zone), from which the citizens were evacuated in 1986.

Since 1991, the annual effective dose limit is set at 1 mSv per year.

Source: Law of the Russian Federation of 15 May 1991 No 1244-1; Onischenko, 2009; the 1989 Population and Housing Census for the Bryansk region.

Modern approach for estimation of current effective dose

- Periodical estimation (once per 3-5 y) of current accidental doses to the population in each of these settlements is a part of the Federal and local programs of mitigation of consequences of the major nuclear accidents in the country (EMERCOM, 1995, 1996).
- The task is not trivial, taking into account large number of contaminated villages and towns as well as pronounced differences in population structures between the settlements.
- To solve this problem, a few model approaches were developed (Jacob and Likhtarev, 1996; Golikov et al., 2002) and officially introduced to practice (Balonov,1993).
- In accordance with these approaches, the current direct measurements and well verified dose estimations are performed at a limited number of settlements (e.g., 10-12) and then, the values obtained are extrapolating for dose assessments on other settlements using models numeric parameters valid for current time period.
- Both external and internal doses are the objects of model calculations.
- This presentation deals with the doses from external gamma radiation, which in rural areas may contribute up to 50% and more of the total accidental dose.

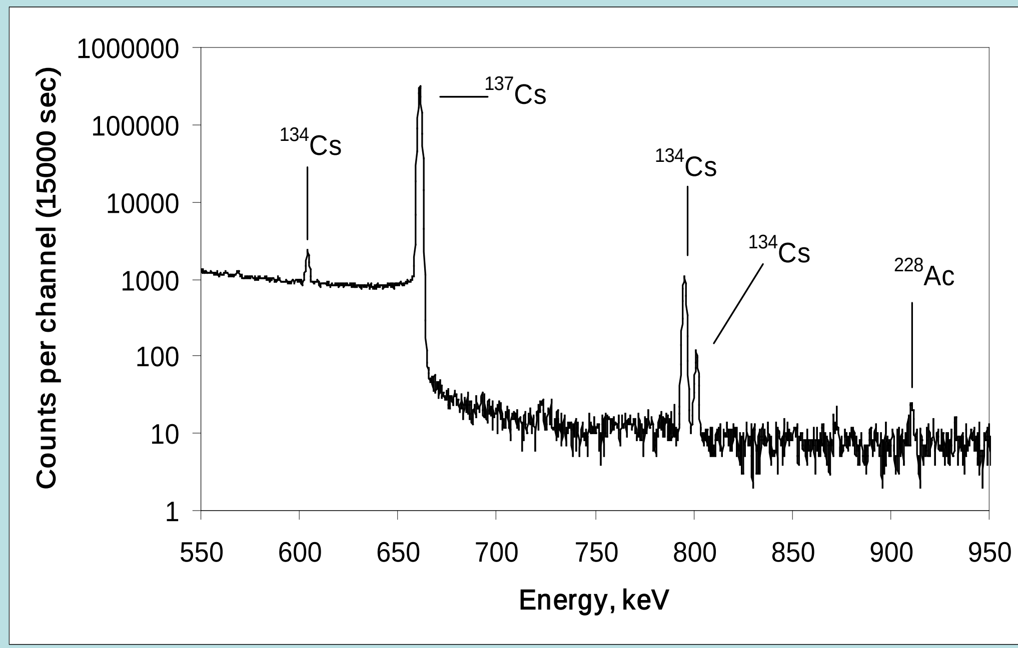
Parameters of the model for evaluation of the current effective external dose (E_{ext}, mSv/y) from Chernobyl fallout

- Ground deposition density of ^{137}Cs in a settlement's area (inside and outside settlement) (***A***, kBq/m^2).
- Normalized (per unit of ^{137}Cs ground deposition) values of dose rate in air from ^{137}Cs at typical locations *j* inside and outside a settlement ($D_{air\ CsJ}$, nGy/h per kBq/m^2).
- Durations of time spent by representatives of the population group *i* at these locations (occupancy factors) (P_{ij}, h or proportion).
- Multiplicative factor, to convert absorbed dose rate in air to the effective dose rate(***R***, Sv/Gy).

Soil sampling using the steel dismountable sampler and laboratory analysis of the samples obtained

A soil core

Tasks:
- detection of radionuclides;
- determination of activity concentrations;
- determination of vertical distributions;
- determination of inventory;
- evaluation of dose rate in air.



^{137}Cs and ^{134}Cs identification by semiconductor γ-spectrometry for a soil sample from Muravinka, 2001

Instruments for measurements of gamma dose rate in air and *in situ* γ-ray spectrometry

Portable scintillation spectrometers SKIF-3 with NaI(Tl) detectors

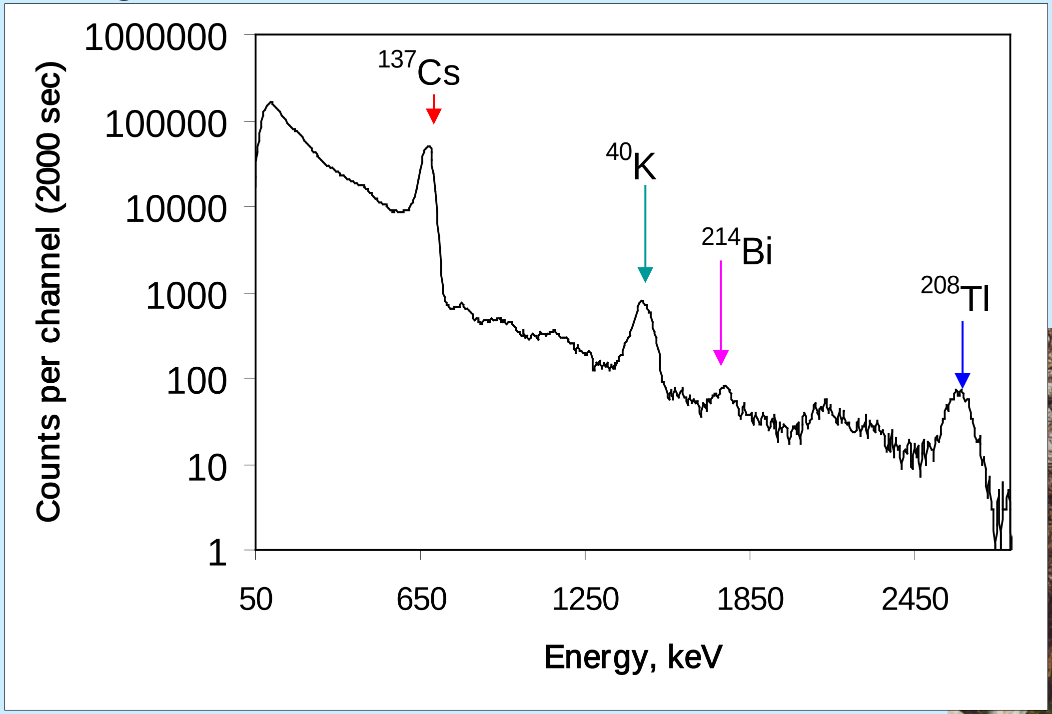
Gamma-monitor EL-1101

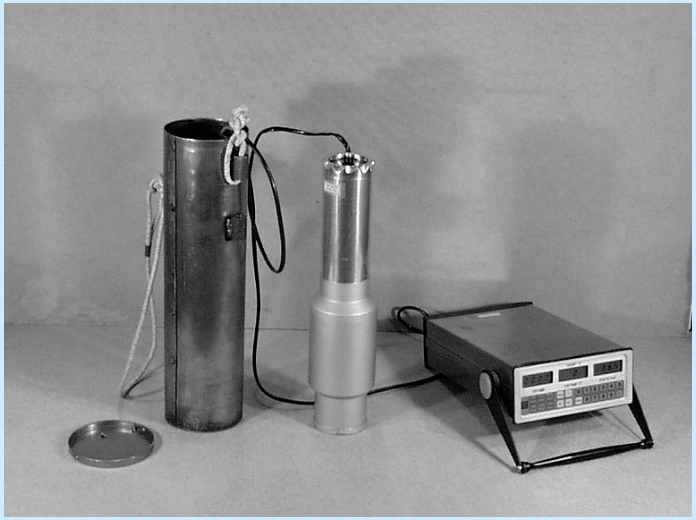
Nomad™Plus portable spectroscopy system (EG&G ORTEC) with Ge detector

Muravinka sand-pit, May 1998

Gamma-ray spectrum recorded with a scintillation (NaI (Tl)) portable spectrometer at a kitchen-garden in Novozybkov district in spring 2002

Task:
- evaluation of contribution from artificial and terrestrial radionuclides into total gamma dose rate.





^{137}Cs – artificial radionuclide (RN)
^{40}K – terrestrial (natural) RN
^{214}Bi - terrestrial (natural) RN of ^{238}U family
^{208}Tl - terrestrial (natural) RN of ^{232}Th family

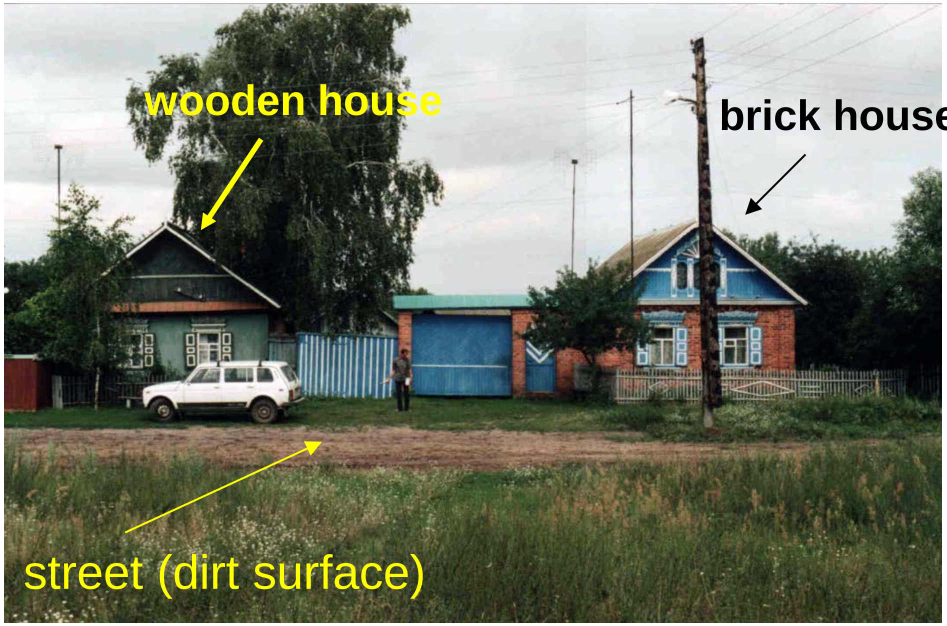
The rural settlement of Novie Bobovichi. A satellite view.
The locations used in the dose assessments are indicated.

135 m a.s.l. 52.625° N 31.734° E, 12.08.2011

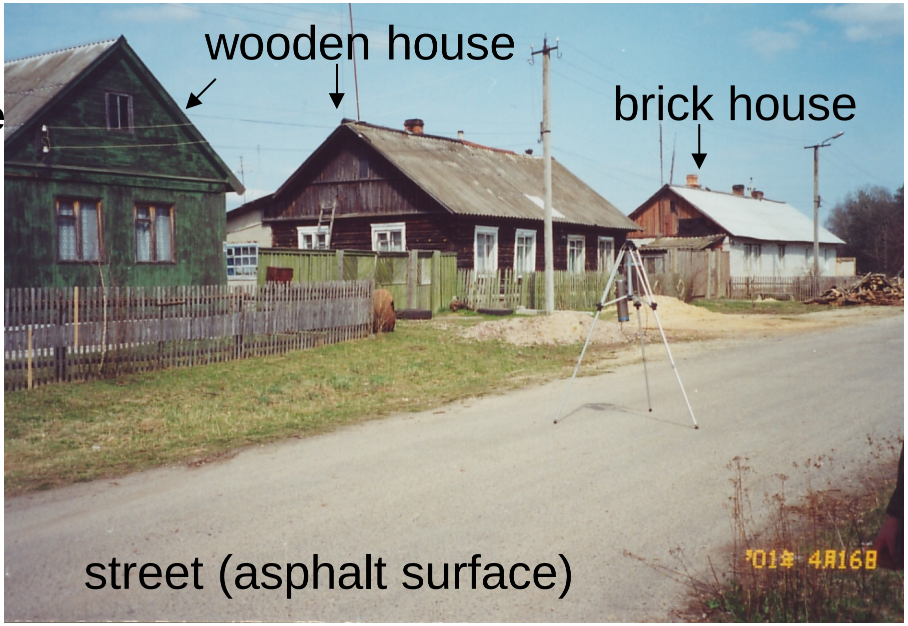
The urban settlement of Novozybkov. A satellite view.

180 m a.s.l. 52.518° N 31.958° E, 06.04.2014

Overall view of living areas in the village of Kozhany and the town of Novozybkov (1-storey houses)



Kozhany, 2003

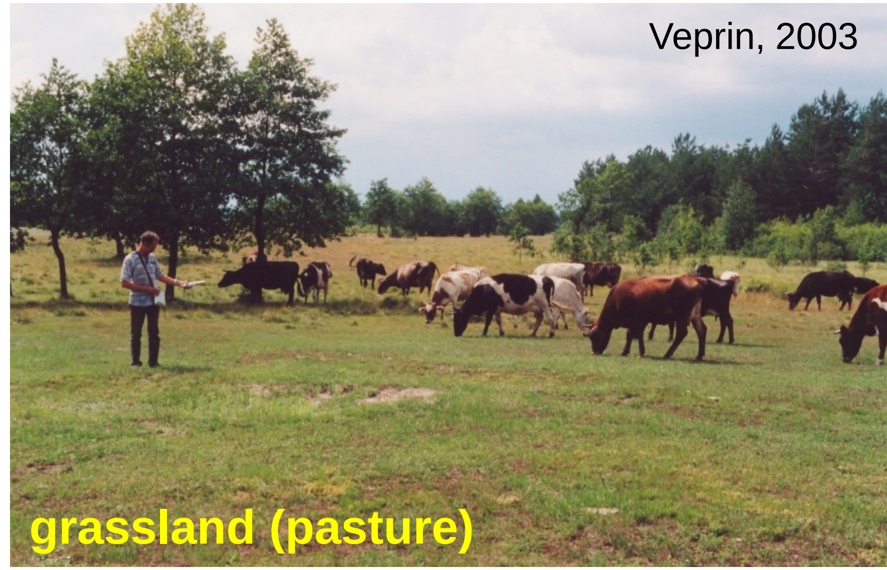


Novozybkov, 2001

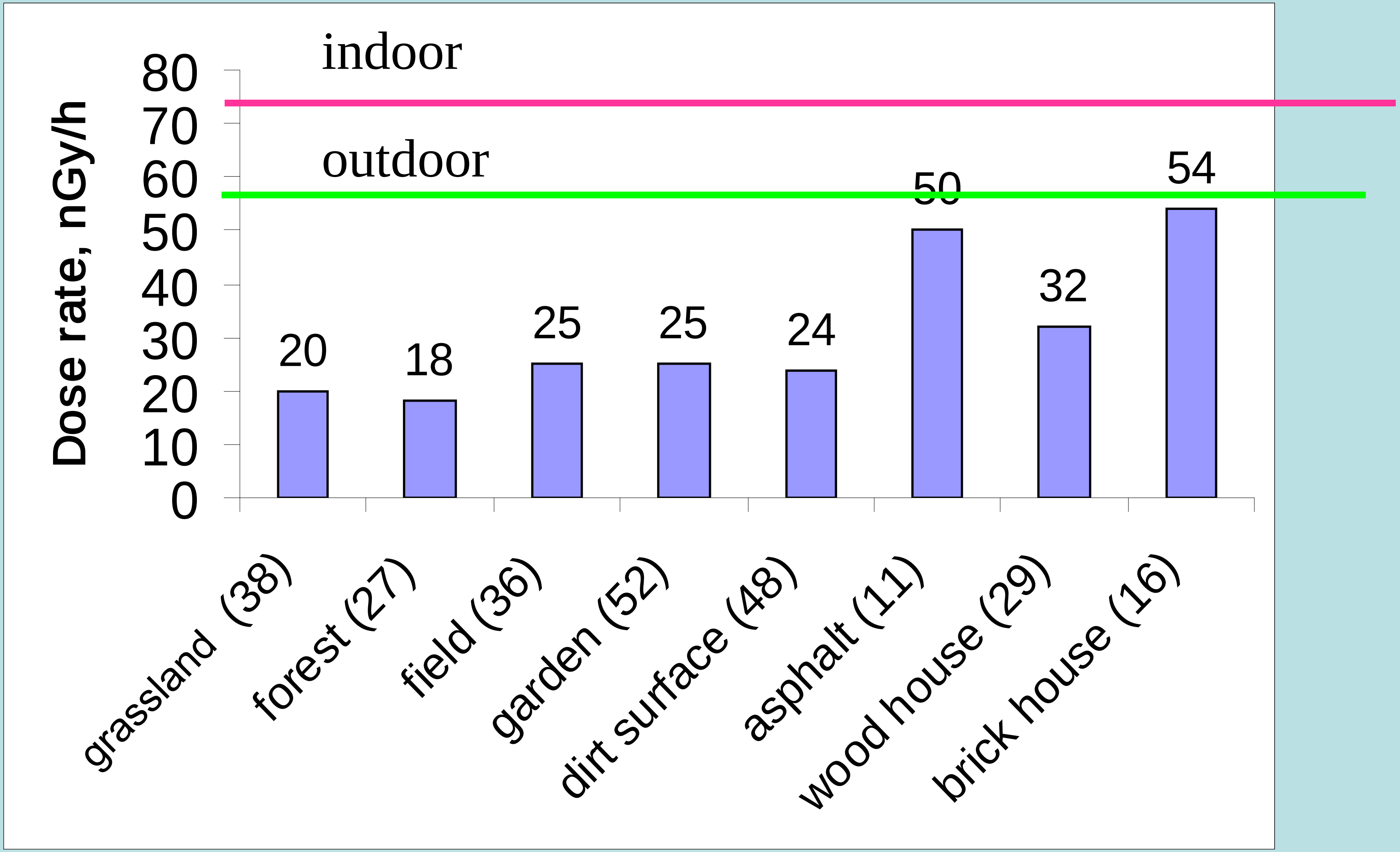
Locations inside settlements (living area)

Indoor locations

Locations outside settlements



Absorbed dose rates in air from natural radionuclides in typical locations (30 settlements, the 1996-2001 survey, number of sites is given in brackets), nGy h^{-1}



The color lines correspond to world-wide median values (UNSCEAR, 2000).

Source: Ramzaev et al., 2006

^{137}Cs-dependent absorbed dose rates in air normalized to 1 kBq/m^2 ^{137}Cs inventory in soil in 1996-2001 (30 settlements, summer period).

Location	n	Mean, nGy/h	CV, %
Forest	57	1.15	17
Grassland outside settlement	38	1.04	21
Grassland inside settlement	78	0.48	25
Kitchen-garden	281	0.41	17
Ploughed field	47	0.37	19
Dirt surfaces	229	0.26	50
Asphalt surfaces	197	0.15	47
Wood house (1 storey)	164	0.10	50
Brick house (1 storey)	52	0.05	80
Multi-storey house	50	0.02	>100

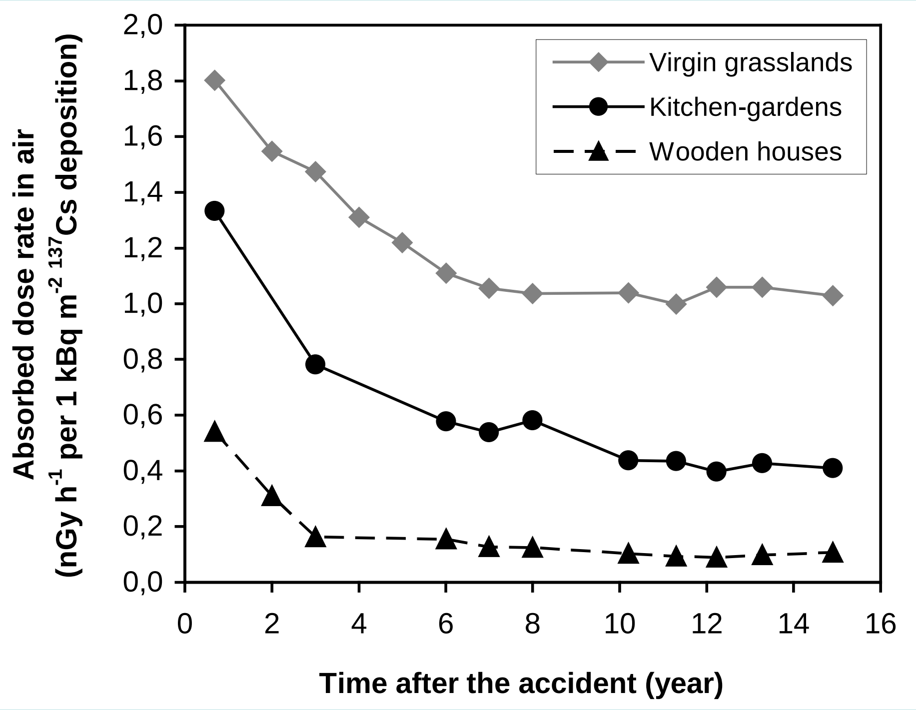
Soil samples were collected at 467 sites.

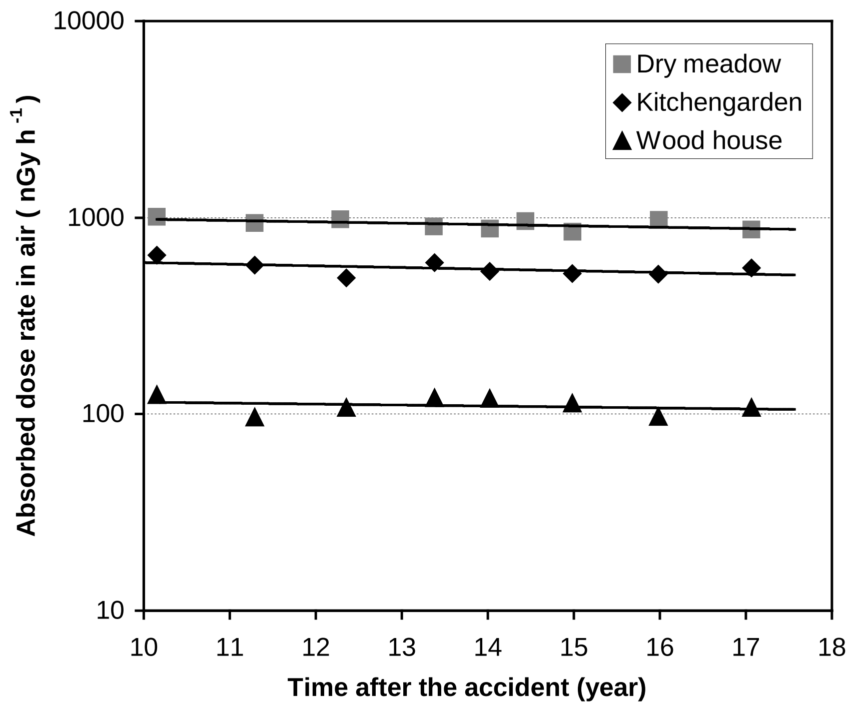
^{137}Cs inventory range: 10-3950 KBq/m^2; median: 530 kBq/m^2

CV – coefficient of variation.

Source: Barkovsky et al., 1996; Ramzaev et al., 2006.

Long-term trends of dose rate in air due to Chernobyl radiocesium





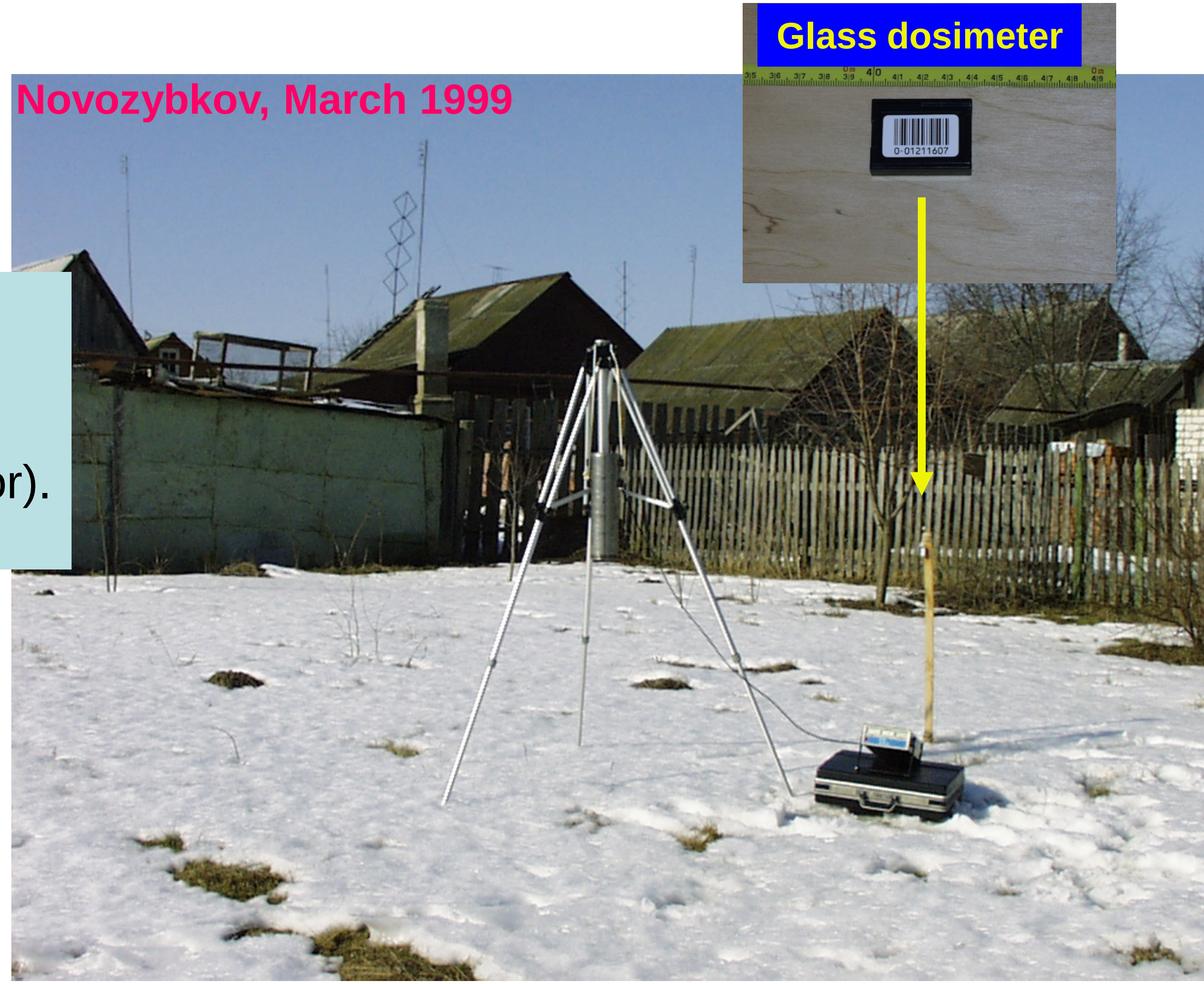
Dynamics of normalized absorbed dose rates in air from ^{137}Cs (per unit of the radionuclide current ground deposition) at three typical locations in the Bryansk Region, 1986-2001. The data show mean values for each location.

Experimental values of absorbed dose rates in air from radiocesium corrected for decay and exponential fits to the data. The long-term measurements were performed during spring-autumn periods in the settlement of Stary Vishkov (kitchen garden and wooden house) and at a meadow located near the village of Veprin. Presently, the dose rates decline by ~ 4% per year.

Source: Ramzaev et al., 2006

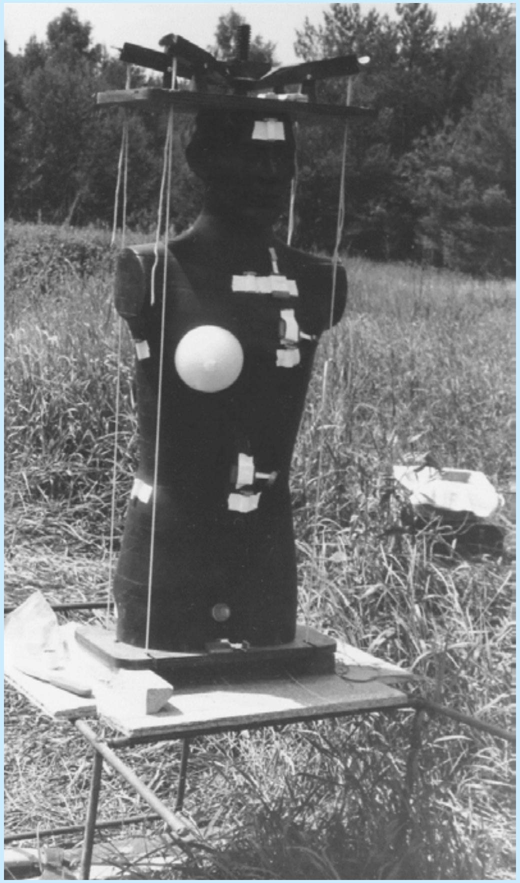
Determination of the winter/summer dose reduction factor ***W*** in a kitchen garden using *in situ* gamma spectrometry and individual dosimeters fastened on the stick.
The ground surface is covered with snow.

In 1998-1999,
factor ***W*** was estimated
as **0.72±10**
(30 sites outdoor and indoor).
Source: Ramzaev et al., 2006

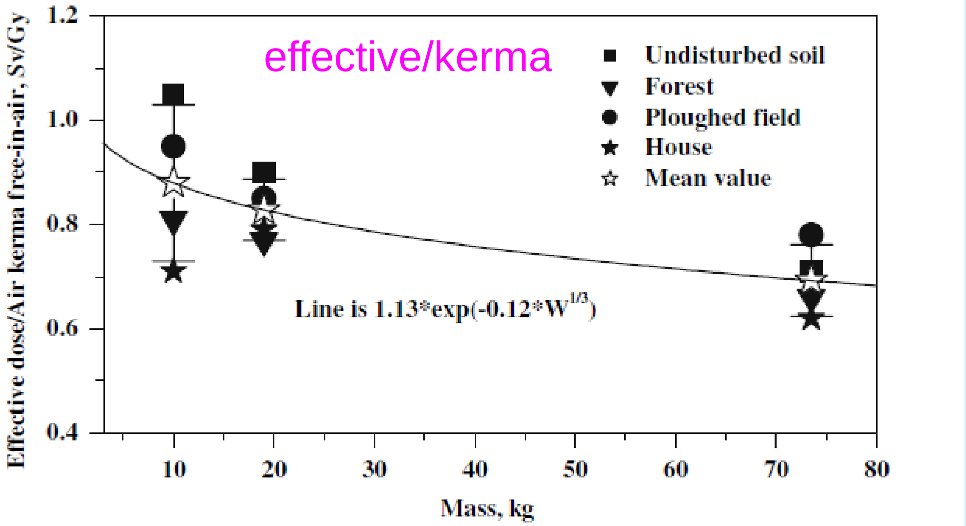


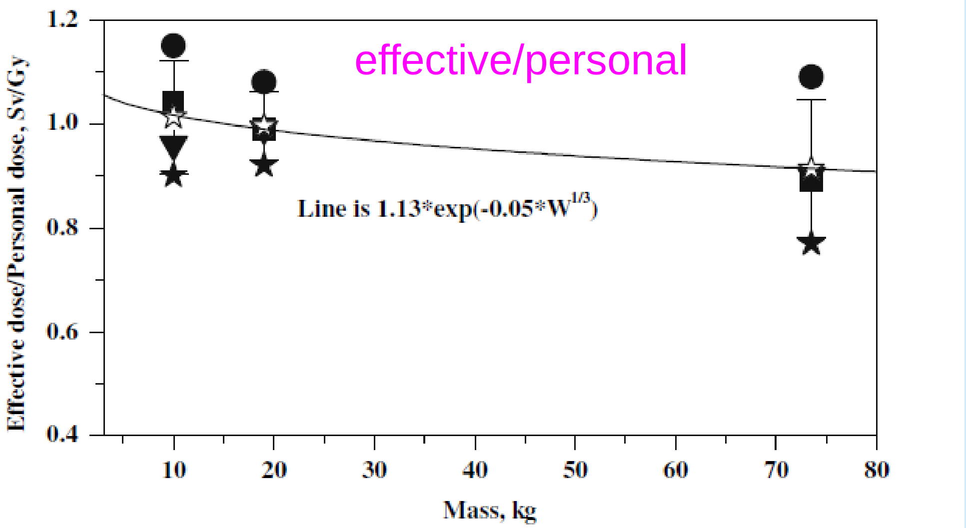
SKIF-3 scintillation gamma spectrometer (SINKO, Russia)
Glass dosimeters (TOSHIBA Glass Corporation, Japan)

Conversion factors *R* (Sv/Gy) from kerma rate in air or personal dose to effective dose as determined from phantom experiments after the Chernobyl accident



Individual TL-dosimeters are placed on and inserted into the Rando phantom; the village of Starye Bobovichi, undisturbed grassland, July 1991.





the 1991-1993 experiments

Source: Golikov et al., 2007

The questionnaire was used to determine the behavior of a human in radiation field by means of occupancy factors p_i

Государственное санитарно-эпидемиологическое нормирование Российской Федерации

2.6.1. Ионизирующее излучение, радиационная безопасность

ПРОВЕДЕНИЕ КОМПЛЕКСНОГО ЭКСПЕДИЦИОННОГО РАДИАЦИОННО-ГИГИЕНИЧЕСКОГО ОБСЛЕДОВАНИЯ НАСЕЛЕННОГО ПУНКТА ДЛЯ ОЦЕНКИ ДОЗ ОБЛУЧЕНИЯ НАСЕЛЕНИЯ

Методические рекомендации
МР 2.6.1.0006-10

Москва
2010

Нормативно-методические документы

Структура сельскохозяйственных угодий и распределение их площади по типам доминирующих почв

Группа почв	Площадь, га		
	Пашня	Сенокосы	Пастбища
Торфяно-болотные			
Песчаные и супесчаные (дерново-подзолистые, дерново-глеевые, дерновые, светло-серые и серые лесные)			
Легко- и среднесуглинистые (дерново-подзолистые; дерновые; серые и темно-серые лесные; выщелоченные и оподзоленные черноземы)			
Тяжелосуглинистые и глинистые (темно-серые лесные; черноземы: выщелоченные, оподзоленные, типичные, обыкновенные, южные; каштановые)			

Должность, фамилия и подпись лица, представляющего данные: ___

___

ФИО лица, проводившего опрос, должность, наименование организации

Приложение 3

Опросная карта для населения (внешнее облучение)

Статус опрашиваемого: взрослый / школьник / дошкольник

Вопросы для взрослых членов семьи:
Профессия ___
№ ТЛД-дозиметра ___
Характер работы:
преимущественно в помещении / преимущественно вне помещения

Характеристика места работы:
- материал стен – дерево / камень.
- число этажей ___
- тип покрытия рабочего места вне помещения – асфальт / грунт

Характеристика места проживания:
- материал стен – дерево / камень.
- число этажей ___
- тип покрытия вне помещения – асфальт / грунт

Вопросы для детей:
Посещает ли ребенок школу – да / нет.
Посещает ли ребенок детский сад – да / нет

Средняя продолжительность пребывания (часов в сутки):
условно летом (без снежного покрова), рабочие дни
- внутри НП в жилом помещении ___;
- внутри НП (на работе, в школе, в детсаде) в производственном помещении ___;
- внутри НП вне помещения ___;
- вне НП: пахота ___, целина ___, дорога ___;

условно летом (без снежного покрова), выходные дни
- внутри НП в жилом помещении ___;
- внутри НП вне помещения ___;
- вне НП: пахота ___, целина ___, дорога ___;

условно зимой (со снежным покровом), рабочие дни
- внутри НП в жилом помещении ___;
- внутри НП (на работе, в школе, в детсаде) в производственном помещении ___;
- внутри НП вне помещения ___;
- вне НП: пахота ___, целина ___, дорога ___;

условно зимой (со снежным покровом), выходные дни
- внутри НП в жилом помещении ___;
- внутри НП вне помещения ___;
- вне НП: пахота ___, целина ___, дорога ___.

Примечание: При ответах на вопросы ненужное вычеркивать. Количество часов в сутках равно 24!!! Под «школой» подразумевается любое учебное заведение для населения группы «школьники»

___

ФИО лица, проводившего опрос, должность, наименование организации

Приложение 4

Документация дозиметрического контроля внешнего гамма-излучения

Форма ведения журнала учета индивидуального дозиметрического контроля внешнего гамма-излучения

Поверхностная активность ^{137}Cs в почве НП на год измерения: ___
Наименование организации, выполняющей измерения ___
Ф.И.О. оператора ___
Дата считывания ___
Тип измерительного прибора ___ № ___
Дата поверки ___
Дата калибровки ___

Номер ТЛД-дозиметра	Фамилия, имя, отчество	Профессия	Тип жилого дома	Год рождения	Дата выдачи ТЛД-дозиметра	Дата сбора ТЛД-дозиметра	H, мкЗв	Примечание
1	2	3	4	5	6	7	8	9

107 Том 4 № 3, 2011 Радиационная гигиена

Parameters:

- Age: adults, school-children, pre-school-children.
- Profession: indoor or outdoor worker, pensioner.
- Type of dwelling: wooden, brick; number of floors
- Duration of time spent at a location *i* in summer and winter seasons (hours or proportion).

The main surveys were conducted in 1989 – 808 questionnaires (Golikov et al., 1993) and in 1995 – 225 questionnaires (Ramzaev et al., 1995).

Annual occupancy factors, p_{ij} (proportion)

rural population (villages)

Type of location	Occupancy factor (p_{ij})				
	Indoor workers	Outdoor workers	Pensioners	Schoolchildren	Pre-school children
Living areas					
Indoors	0.49	0.47	0.68	0.58	0.52
Outdoors	0.21	0.16	0.30	0.23	0.14
Work areas					
Buildings	0.23	0.08	0.00	0.00	0.00
Multi-storey house	0.00	0.00	0.00	0.16	0.25
Work yard	0.03	0.08	0.00	0.00	0.09
Ploughed field	0.02	0.17	0.00	0.00	0.00
Virgin land	0.01	0.03	0.00	0.00	0.00
Remaining areas (forest, meadow)	0.01	0.01	0.02	0.03	0.00

urban population (towns)

Type of location	Occupancy factor (p_{ij})				
	Indoor workers	Outdoor workers	Pensioners	Schoolchildren children	Pre-school
Inside living houses	0.51	0.51	0.75	0.58	0.51
Inside working buildings	0.31	0.10	0.00	0.15	0.25
Outside houses					
Asphalt surfaces	0.07	0.08	0.07	0.08	0.04
Dirt surfaces	0.03	0.23	0.07	0.10	0.12
Kitchen-gardens	0.05	0.05	0.08	0.04	0.03
Virgin land (inside city)	0.01	0.01	0.01	0.04	0.04
Forests, meadows	0.02	0.02	0.02	0.01	0.01

Source: Golikov et al., 2002

The equation used to calculate annual external effective dose to the population group *i* from the Chernobyl fallout normalized to ^{137}Cs ground deposition, *Ei* (nSv/y per kBq/m^2) is:

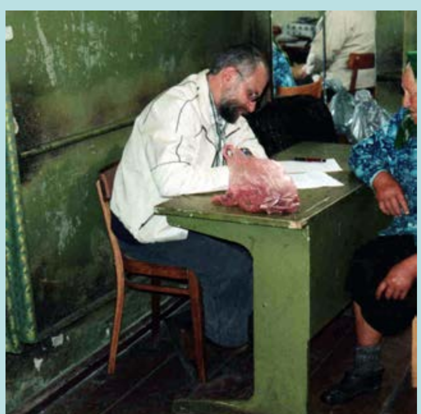
$$E_i = R\,8760\left[0.59\sum_j \dot{D}_{\mathrm{air\ Cs},j} P_{ijs} + 0.41\,W \sum_j \dot{D}_{\mathrm{air\ Cs},j} P_{ijw}\right], \qquad (1)$$

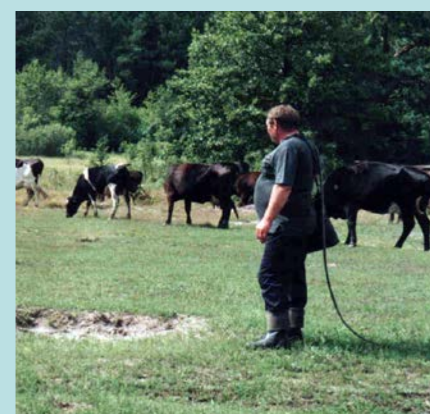
- where,
- ***R*** is the conversion factor of the absorbed dose rate in air to the effective dose rate (Sv/Gy);
- 8760 – number of hours in a year;
- $D_{air\ Cs,j}$ is the normalized absorbed dose rate in air at location of type *j* (nGy/h per kBq/m^2);
- occupancy factors ***Pijs*** and ***Pijw*** are the fractions of time spent by representatives of the *i*-th population group at a location of *j* type in summer (*s*) and winter periods (*w*), respectively;
- ***W*** is dose rate reduction factor in wintertime due to presence of snow cover;
- 0.59 and 0.41 are the relative durations of summer (7 months) and winter (5 months) periods, respectively;
- Additional dose from ^{134}Cs is calculated based on the $^{134}Cs/^{137}Cs$ activity ratio of 0.54 on 26 April 1986.
- Annual effective doses due to terrestrial radionuclides (TRN) can be calculated from equation 1 using location specific average values TRN-dependent dose rates instead of normalized dose rates from radiocesium.

Source: Golikov et al., 2002; Ramzaev et al., 2006.

Average annual external effective doses from terrestrial radionuclides (mSv) and normalized annual external effective doses from ^{137}Cs contamination (mSv per MBq/m^2 ^{137}Cs current inventory in soil) to selected groups of population of Bryansk Region in 1996–2001

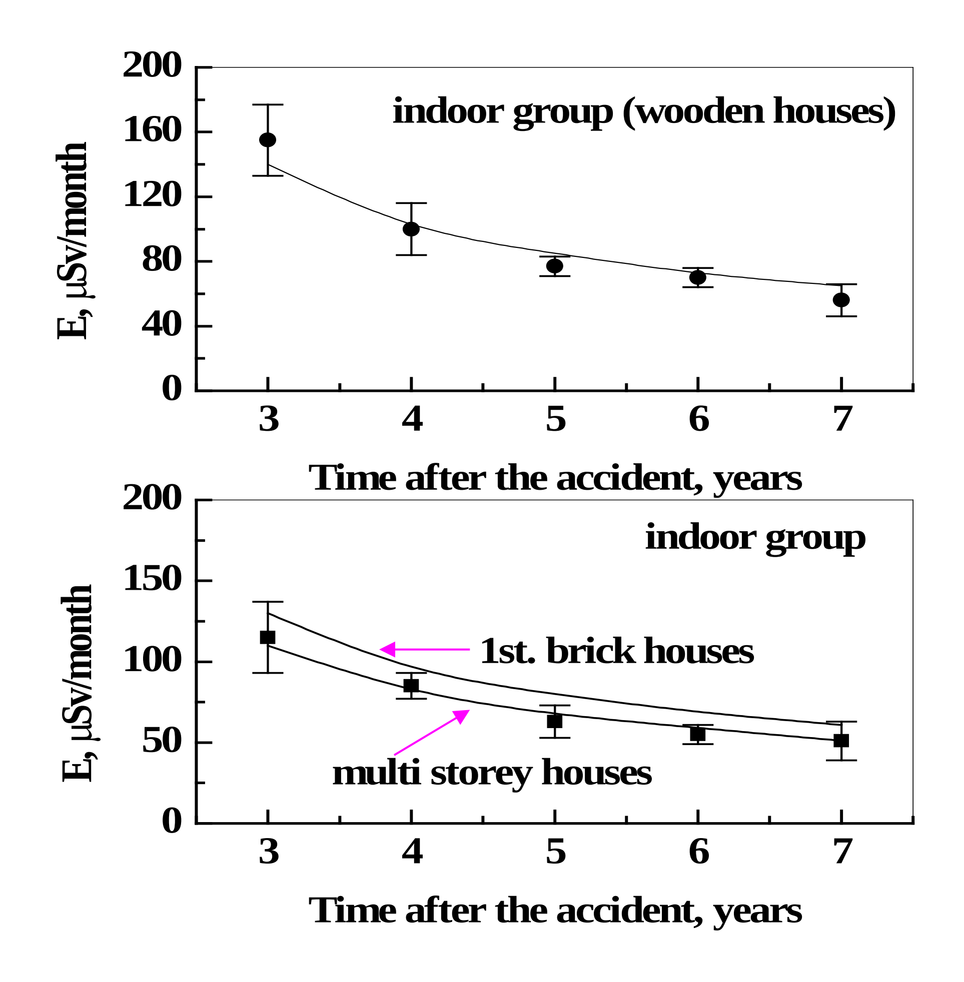
Living area	Annual effective dose from					
	Terrestrial radionuclides (mSv)			^{137}Cs (mSv per MBq m^{-2} ^{137}Cs inventory)		
	Indoor workers	Pensioners	Herdsmen	Indoor workers	Pensioners	Herdsmen
(1) Brick house + asphalt yard + asphalt street	**0.27**	0.27	0.23	**0.66**	0.82	1.93
(2) Wooden house + grassy yard + dirt street	0.18	0.16	**0.15**	1.01	1.28	**2.27**
Ratio of (2) to (1)	0.66	0.60	0.63	1.53	1.55	1.18





Source: Ramzaev et al., 2006

Model validation: comparison of model prediction (lines) with the results of individual dose measurements by help of TL-dosimeters (2342 measurements in 55 rural settlements and 420 measurements in Novozybkov town in 1989-1994)



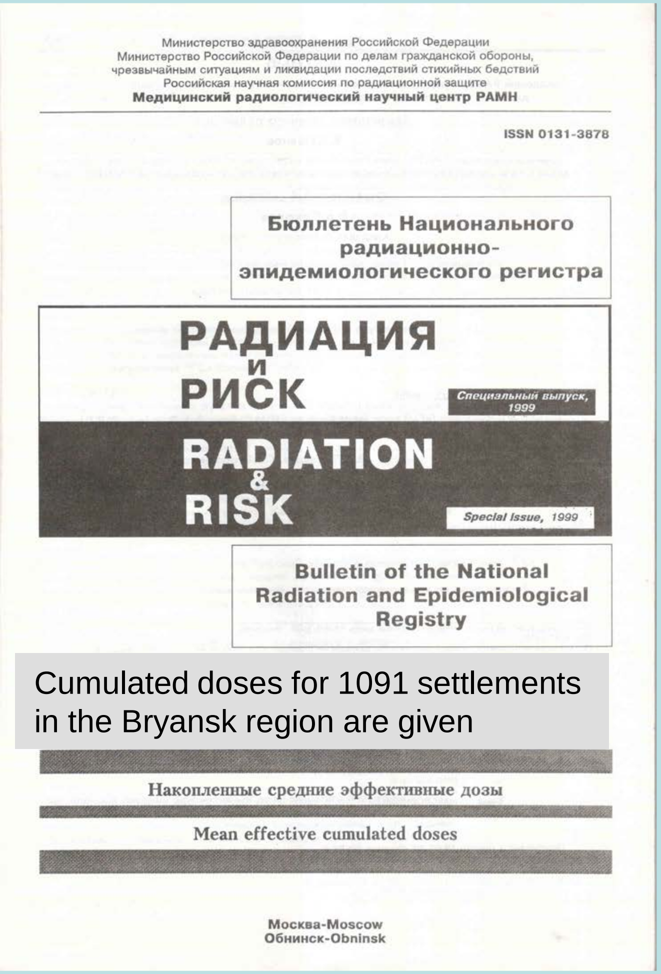
The example: effective monthly dose for indoor workers living in 1-storey wooden and brick houses and in multi-storey houses in Novozybkov (± two standard errors).

Source: Golikov et al., 1999.

Cumulated dose

Effective cumulated external dose for adults, mSv per 1 MBq/m^2 ^{137}Cs initial deposition (for 1986 and 1987-1995)

Type of settlement	**Cumulated dose,** mSv per 1 MBq/m^2	
	1986	1987-1995
Village	**16.7**	**22.6**
Decontaminated village	**16.7**	**17.2**
Town	**10.3**	**11.8**


Министерство здравоохранения Российской Федерации
Министерство Российской Федерации по делам гражданской обороны, чрезвычайным ситуациям и ликвидации последствий стихийных бедствий
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Специальный выпуск, 1999

RADIATION & RISK

Special Issue, 1999

Bulletin of the National Radiation and Epidemiological Registry

Cumulated doses for 1091 settlements in the Bryansk region are given

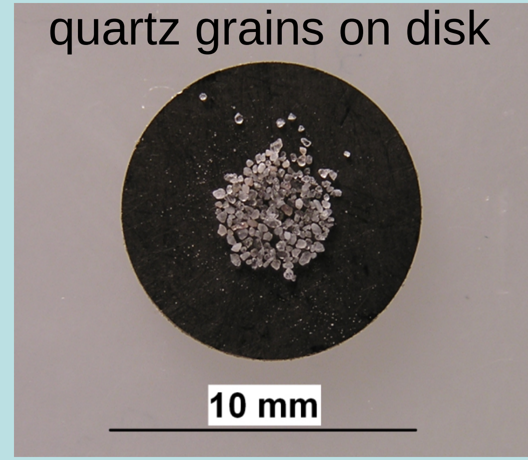
Накопленные средние эффективные дозы

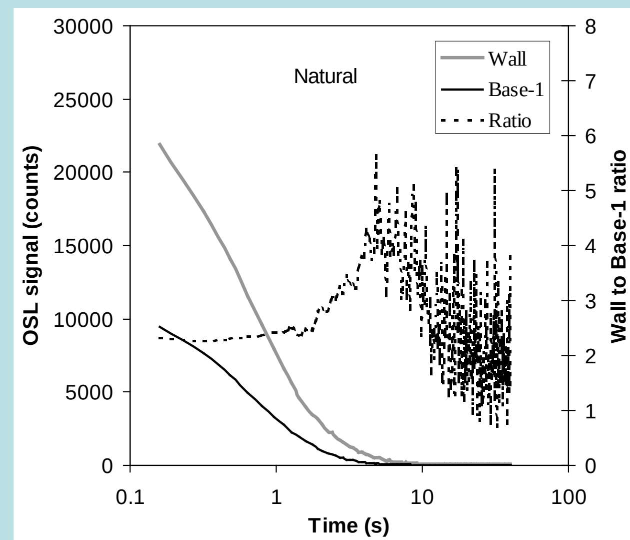
Mean effective cumulated doses

Москва-Moscow
Обнинск-Obninsk

- The mean effective **annual dose** is, first of all, a powerful tool for current management of radioactively contaminated populated areas.
- The mean effective **cumulated dose** - the sum of annual doses for a defined time period (e.g. ten years) - can be also directly applied in epidemiological studies and other applications devoted to health risk assessment.

Cumulated dose validation.
Using quartz inclusions in red bricks as natural dosimeters.

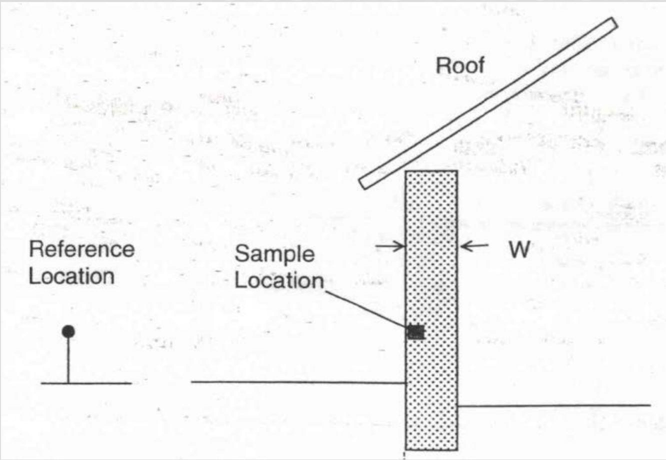


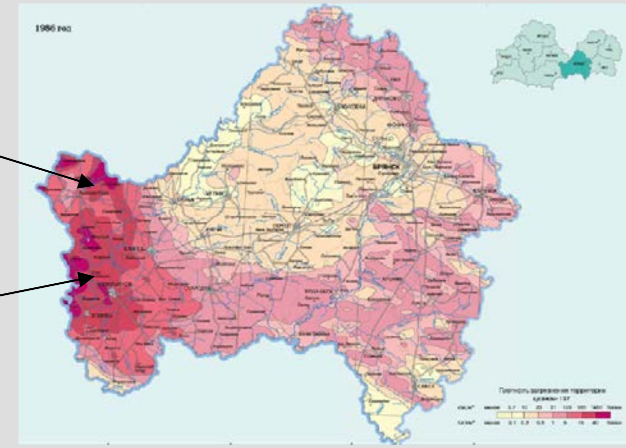


Natural (field) OSL decay curves from quartz samples extracted from the wall of the small brick building (Wall) and the basement of the large house (Baze-1).

Source: Ramzaev et al., 2008

Validation of the model for cumulated dose assessment at reference location (point detector, 1 m above undisturbed soil): comparison of model prediction with the results of cumulated dose measurements in quartz inclusions in red bricks from Zaborie and Novie Bobovichi.





Settlement	Site	^{137}Cs inventory in soil in 1986, MBq/m^2	Sampling year	**Measured dose**, **mGy**	**Modelling dose**, **mGy**
Zaborie	Textile factory	4.46	1997	**515** ± 80	**780** ± 120
Zaborie	Boiler house	4.16	1997	**620** ± 95	**730** ± 120
Zaborie	Pig farm	1.30	1997	**235** ± 45	**230** ± 50
N. Bobovichi	Baza	1.10	2004	**240** ± 50	**240**

Source: Bailiff et al., 2004; Ramzaev et al., 2008.

Conclusions and recommendations:

- A deterministic model has been developed to estimate the external exposure of the rural and urban population of Russia due to environmental contamination by the Chernobyl accident.
- The model consists of five main sub-sections for the following issues:
- 1) kerma rate in air at various types of locations inside and outside settlements;
- 2) occupancy times of different population groups at various types of locations;
- 3) conversion factor from kerma rate in air to effective dose rate;
- 4) ^{137}Cs ground deposition in a settlement area;
- 5) exposure due to terrestrial radionuclides.
- The model was validated by measurements of individual external doses with TL-dosimeters and by retrospective luminescence dosimetry using red bricks as natural dosimeters.
- The model can be adopted for other radiation accidents that are characterised by large-scale contamination of the environment with ^{137}Cs, for example, the Fukushima accident.

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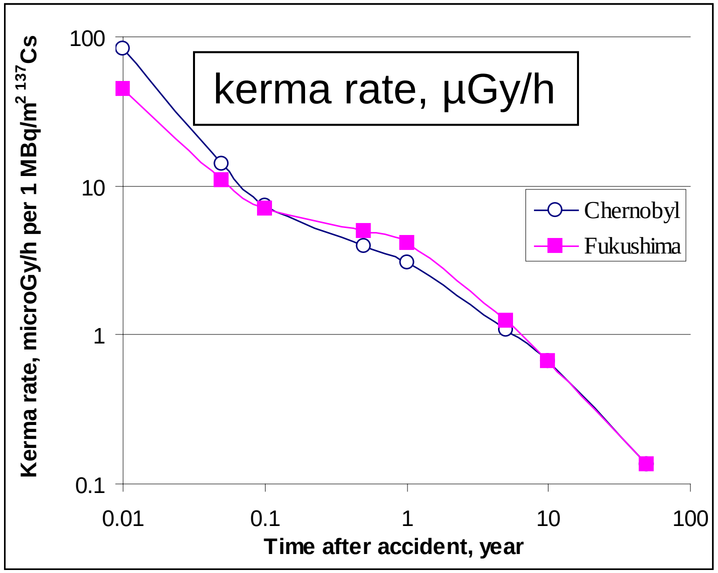
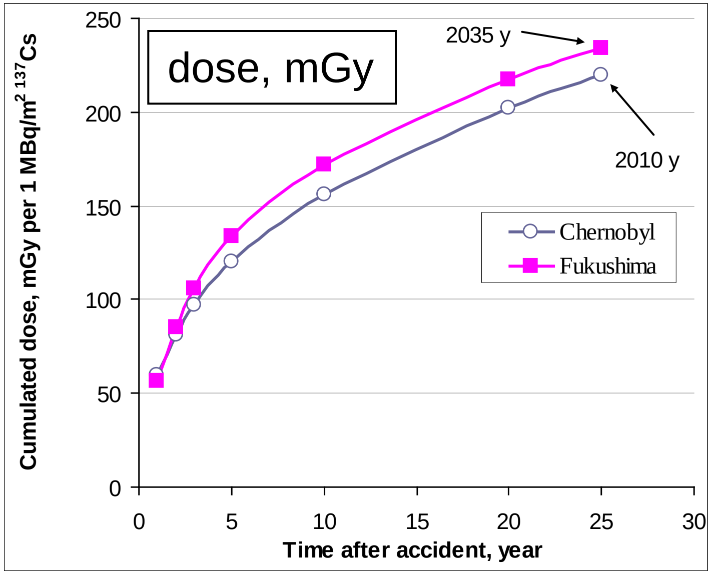
Appendix. Dynamics of kerma rate and cumulated absorbed dose in air at a height of 1 m above undisturbed ground (virgin grassland) from the Chernobyl and Fukushima fallout. The Chernobyl associated doses are calculated based on experimental data collected in the Bryansk region. The expected doses from Fukushima fallout are evaluated assuming ecological similarities between Chernobyl contamination and Fukushima contamination. The doses are normalized on the ^{137}Cs initial ground deposition equal to 1 MBq m^{-2}. The initial depth of a plain source = 0.5 g/cm^2.

Radionuclide	Chernobyl accident, Bryansk Region (on 26.04.1986)	Fukushima Daiichi accident (on 15.03.2011) [1]Japan (except South trace)
^{95}Zr	0.065	-
^{95}Nb	0.064	-
^{103}Ru	1.68	-
^{106}Ru	0.5	-
^{110m}Ag	-	0.0028
^{129m}Te	-	1.1
^{131}I	11	11.5
$^{132}Te+^{132}I$	16.6	8
^{134}Cs	**0.54**	**1.0**
^{136}Cs	0.27	0.17
^{137}Cs	**1.0**	**1.0**
^{140}Ba	0.72	-
^{140}La	0.84	-
^{144}Ce	0.26	-

Ratio to ^{137}Cs activity concentration



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