THE CHERNOBYL ACCIDENT AND ITS CONSEQUENCES

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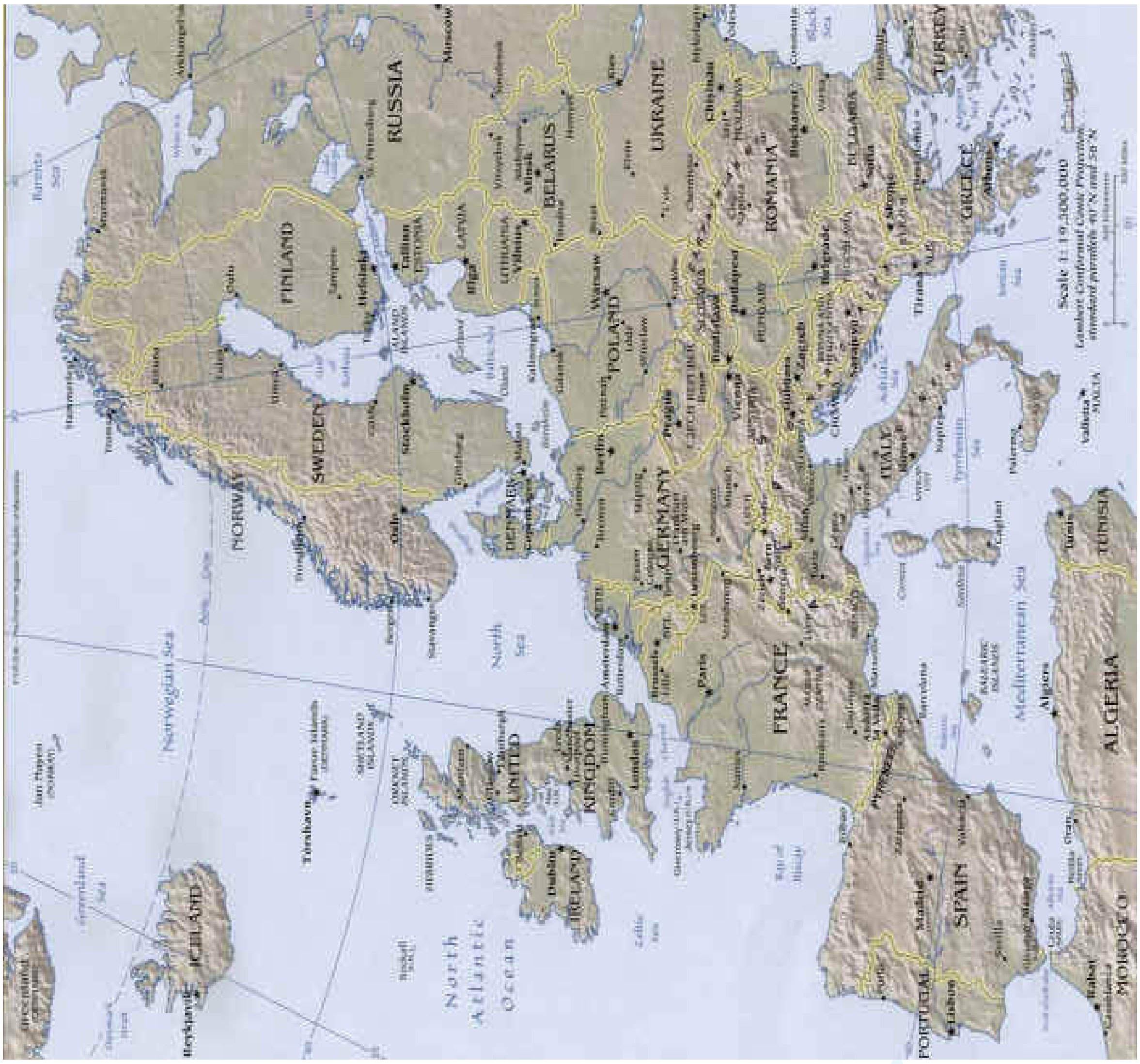


ICELAND
Norwegian Sea
North Atlantic Ocean
IRELAND
UNITED KINGDOM
North Sea
NORWAY
SWEDEN
FINLAND
RUSSIA
BELARUS
UKRAINE
POLAND
GERMANY
FRANCE
SPAIN
PORTUGAL
ITALY
ROMANIA
BULGARIA
GREECE
TURKEY
Mediterranean Sea
MOROCCO
ALGERIA
TUNISIA

Industrial site of the Chernobyl NPP after accident

Release of radionuclides

- **Hundreds of different radionuclides build up in the active core of nuclear reactor. They differ in their physical and chemical properties and especially in their half-lives as well as in the art and energy of emitted radiation.**
- **Destroying of the Chernobyl reactor caused release of these radionuclides. Many of them have a very short half-lives. Such radionuclides decayed by release or soon after release. They were important only for irradiation of people that lived up to some tens of kilometers from the Chernobyl reactor.**
- **The total activity of realized radionuclides with half-lives some hours and higher are shown in next slides.**

Inert gases and volatile radionuclides released in the Chernobyl accident

Radionuclide	Half-life	Activity released (PBq) *
Inert gases		
^{85}Kr	10.27 a	33
^{133}Xe	5.25 d	6,500
Volatile elements		
^{129m}Te	33.6 d	240
^{132}Te	3.26 d	1,150
^{131}I	8.04 d	1,760
^{133}I	20.8 h	910
^{134}Cs	2.06 a	47
^{136}Cs	13.1 d	36
^{137}Cs	30.0 a	85

Notice: 1 PBq =10^{15} Bq

Data of the 2008 UNSCEAR, vol.II, United Nations, 2011, New York

Elements with intermediate volatility released in the Chernobyl accident

Radionuclide	Half-life	Activity released (PBq)*
^{89}Sr	50.5 d	115
^{90}Sr	29.12 a	10
^{103}Ru	39.3 d	168
^{106}Ru	368 d	73
^{140}Ba	12.7 d	240

Notice: *1 PBq =10^{15} Bq

Data of the 2008 UNSCEAR, vol.II, United Nations, 2011, New York

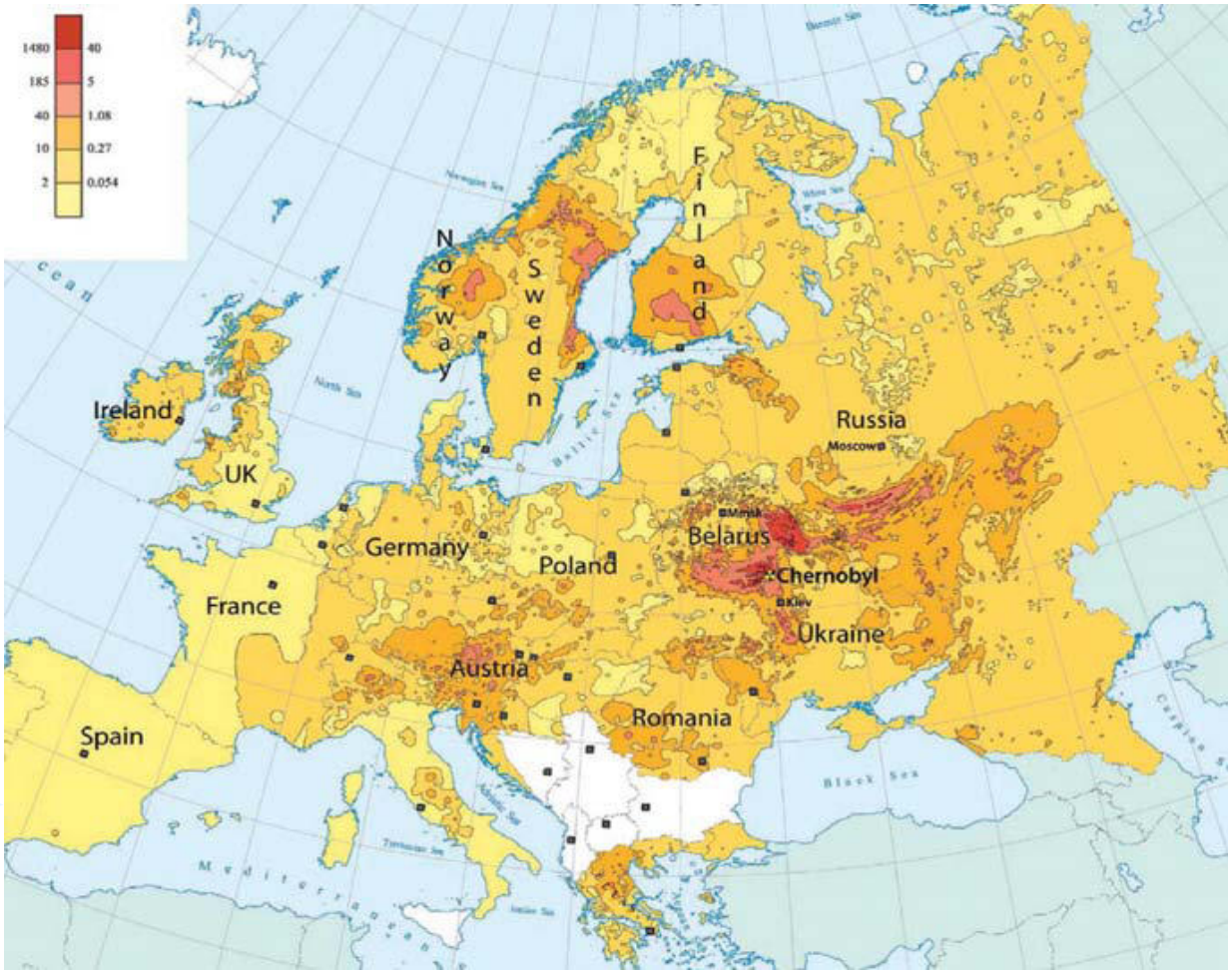
Refractory elements (including fuel particles) released in the Chernobyl accident

Radionuclide	Half-life	Activity, PBq *
^{95}Zr	64.0 d	84
^{99}Mb	2.75 d	> 72
^{141}Ce	32.5 d	84
^{144}Ce	284 d	50
^{239}Np	2.35 d	400
^{238}Pu	87.74 a	0.015
^{239}Pu	24,065 a	0.013
^{240}Pu	6,537 a	0.018
^{241}Pu	14.4 d	2.6
^{242}Pu	376,000 a	0.00004
^{242}Cm	18.1 a	0.4

Notice: *1 PBq =10^{15} Bq

Data of the 2008 UNSCEAR, vol.II, United Nations, 2011, New York

Contamination of European countries with the isotope cesium-137 as a result of the Chernobyl accident



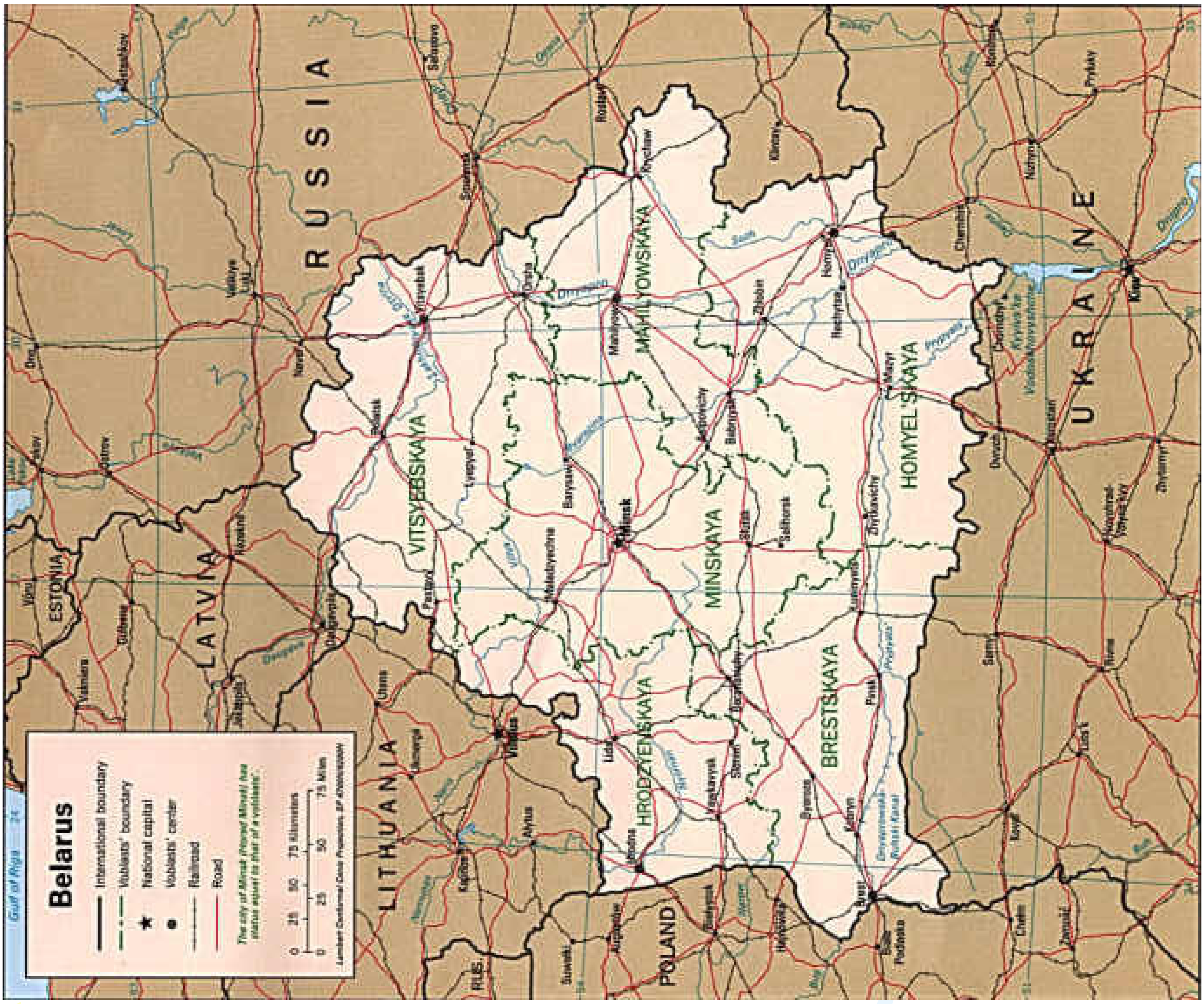
De Cort et al. Atlas of Caesium Deposition on Europe after the Chernobyl Accident (1998). Contamination levels are given in kBq/m^2 and Ci/km^2.


Smolensk
Minsk
Mahilyow
Krychaw
Cherykaw
Bykhiv
Babruysk
Rahachow
Chachersk
Bryansk
Russia
Belarus
Luninyets
Prypyats'
Kalinkavichy
Mazyr
Khoyniki
Yel'sk
Narowlya
Chornobyl'
Plant
Vystupovychi
Pershotravneve
Ovruch
Lypnyky
Narodychi
Korosten'
Kyivs'ke
Vodoskhovyshche
(reservoir)
Ukraine
Zhytomyr
Kiev
Dnipro
Desna
Sozh
Vyetka
Homyel'
Novozybkov
Klimovo
Kuz'minichy
Chernihiv
Confiscated/Closed Zone
Greater than 40 curies per square kilometer (Ci/km2) of Cesium-137
Permanent Control Zone
15 to 40 Ci/km2 of Cesium-137
Periodic Control Zone
5 to 15 Ci/km2 of Cesium-137
Unnamed zone
1 to 15 Ci/km2 of Cesium-137
0
50
100 Kilometers
0
50
100 Miles

Deposition of cesium-137 and iodine-131 released into the environment as a result of the Chernobyl accident

Country	Cesium-137	Iodine-131
Belarus	16.3 PBq (440,000 Ci)*	325.6 PBq (8.8 Millions Ci)*
	15.2 PBq (410,000 Ci)**	
Russia	19.2 PBq (520,000 Ci)**	
Ukraine	11.1 PBq (300,000Ci)**	180 PBq (4.9 Millions Ci)***
Other European countries	22.2 PBq (600,000 Ci)**	
Total the World	85 PBq (2.3 Millions Ci)**	1,760 PBq (47.6 Millions Ci)**

Notice: * Assessment of M.Malko (1998):
** Official data of Belarus, Russia, Ukraine published in the UNSCEAR Report 2008 (2011);
*** Assessment of I. Likhtarev (Ukraine)



Belarus
International boundary
Voblasts' boundary
National capital
Voblasts' center
Railroad
Road
RUSSIA
UKRAINE
LITHUANIA
LATVIA
ESTONIA
POLAND
VITSYEBSKAYA
MAHILYOWSKAYA
MINSKAYA
HOMYEL'SKAYA
BRESTSKAYA
HRODZYENSKAYA
Minsk

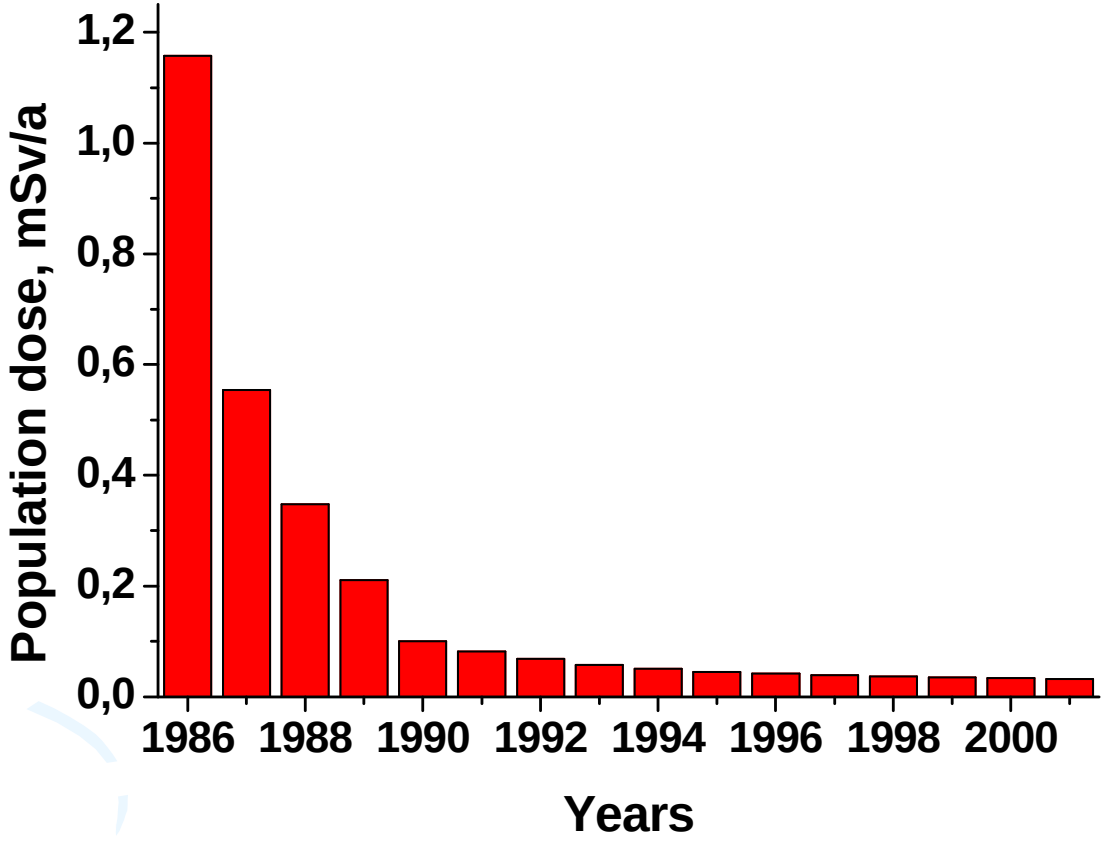
Zoning of the territory of the Republic of Belarus according to the level of radioactive contamination and dose loads on the population

Description of zones	Annual equivalent dose	Contamination levels with Chernobyl isotopes		
		^{137}Cs	^{90}Sr	^{238}Pu, ^{239}Pu, ^{240}Pu
	mSv/year	kBq/m^2 (*Ci/km^2*)	kBq/m^2 (*Ci/km^2*)	kBq/m^2 (*Ci/km^2*)
Residence zone with periodic radiation control	<1	37 – 185 (*1 – 5*)	5.55 –18.5	0,37 – 0.74
Zone with the right to ressetling	>1, but <5	185 – 555 (5 – 15)	18.5 - 74	0.74 – 1.85
Zone of subsequent resettling	>5	555 – 1,480 (*15 – 40*)	74 - 111	1.85 – 3.7
Zone of priority resettling	>5	>1,480 (>40)	>111	>3.7
Evacuation (exclusion) zone	Territory in 30-km zone around the Chernobyl NPP, from which the population was evacuated in May – September 1986			

Irradiation doses of inhabitants of rural settlements situated in contaminated areas of Belarus in mSv (Assessment of M.Malko)

Year	Contamination level, kBq/m² (*Ci/km²*)					
	3.7 (*0.1*)	37 (*1*)	37-185 (*1-5*)	185-555 (*5-15*)	555-1,480 (*15-40*)	1,480 (40)
1986	0.0972	0.9719	2.896	8.339	23.62	38.87
1987	0.0468	0.4681	1.395	4.016	11.37	18.72
1988	0.0296	0.2957	0.8812	2.537	7.186	11.83
1989	0.0181	0.1806	0.5382	1.549	4.388	7.224
1990	0.0104	0.1042	0.3104	0.8938	2.531	4.167
1991	0.0089	0.0885	0.2639	0.7597	2.152	3.542
1992	0.0079	0.0772	0.2302	0.6628	1.877	3.090
1993	0.0069	0.0686	0.2043	0.5883	1.666	2.743
1994	0.0062	0.0621	0.1849	0.5324	1.508	2.482
1995	0.0057	0.0570	0.1698	0.4890	1.385	2.280
1996	0.0053	0.0531	0.1583	0.4556	1.290	2.124
1997	0.0049	0.0495	0.1475	0.4247	1.203	1.980
1998	0.0047	0.0469	0.1397	0.4021	1.139	1.875
1999	0.0044	0.0443	0.1319	0.3799	1.076	1.771
2000	0.0043	0.0425	0.1267	0.3647	1.033	1.700
2001	0.0041	0.0405	0.1206	0.3472	0.9833	1.619
1986-2001	0.2651	2.651	7.899	22.74	64.41	106.0

Temporal patterns of the normalized dose of the whole body irradiation of affected populations of Belarus



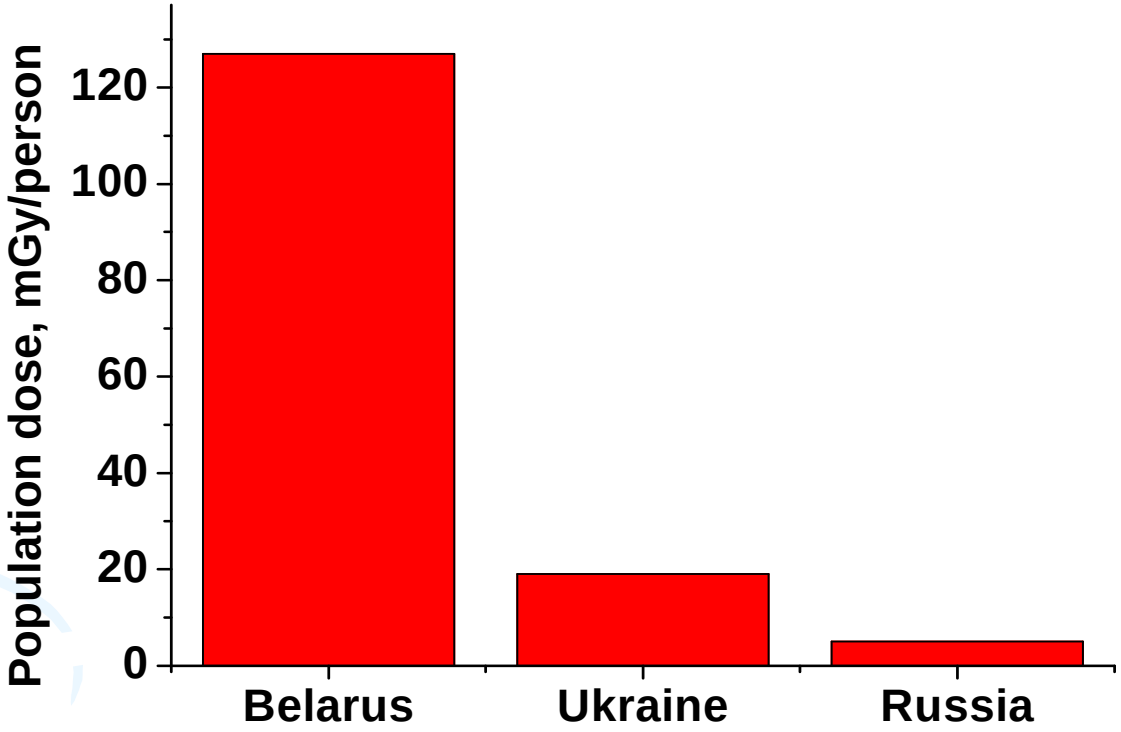
Assessment (M.Malko)of irradiation doses of inhabitants of rural settlement Vysoki Borak (Krasnapolye district, Mogilev region) and Chudziany (Cherikau district, Mogilev region)

Year	Irradiation doses, mSv	
	Vysoki Borak	Chudziany
	Contamination level, kBq/m^2 (Ci/km^2)	
	2,479 (*67*)	5,420 (146.5)
1986	65.1	142.4
1987	31.4	68.6
1988	19.8	43.3
1989	12.1	26.5
1990	7.0	15.3
1986-1990	135.4	296.1

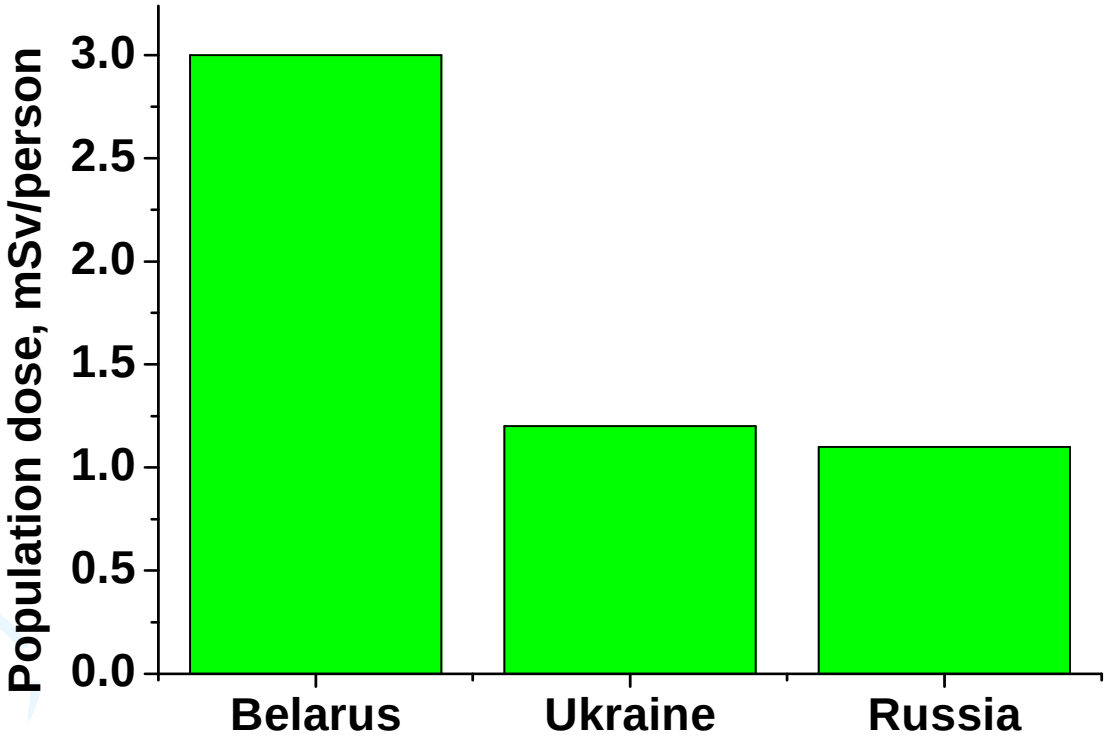
Doses of the whole body irradiation of emergency workers involved in 1986-1990 in mitigation of direct Chernobyl consequences (V.K.Ivanov, Moscow, 2010)

Country	Number of workers	Mean dose, mGy
Belarus	91,000	51
Russia	188,174	107
Ukraine	229,219	151
Estland	4,832	99
Latvia	6,065	117
Lithuania	6,960	109
Combined	526,250	117

Mean population doses of the thyroid gland irradiation as a result of the Chernobyl accident



Mean population doses of the whole body irradiation as a result of the Chernobyl accident



Numbers of affected persons in Belarus and their collective and population doses accumulated in 1986-2010

Group of people	Number of persons	Average irradiation dose, mSv	Collective irradiation dose, person·Sv
Evacuated inhabitants of 30-km zone	24,725		519
Liquidator	116,567	~ 35.7	4,161
Ressetled persons	110,275	~ 60	6,617
Evacuees, liquidator and resettled persons combined together	251567	~45	11,300
Republic Belarus as a whole	10,000,000	~ 3	30,000

Registers of congenital disorders in Belarus

Published data of the Belarusian National Genetic Monitoring System created by Prof. Lazuk G.I were used for assessment of data shown in the previous slide.

Various aspect of teratology, mutagenesis and human genetics were studied in Belarus already before the accident at the Chernobyl NPP. At the time of accident the Belarusian National Genetic Monitoring System (since 1979), Abnormal Embryo and Early Fetal Morphogenesis Monitoring System (since 1980), and Multiple Congenital Malformation Syndrome Monitoring (since 1983) were in operation. Abnormal developments in spontaneous abortuses were monitored from 1968 to 1987. No such registers existed in Ukraine and Russia before the accident at the Chernobyl NPP

Specific of the National Genetic Monitoring System in Belarus

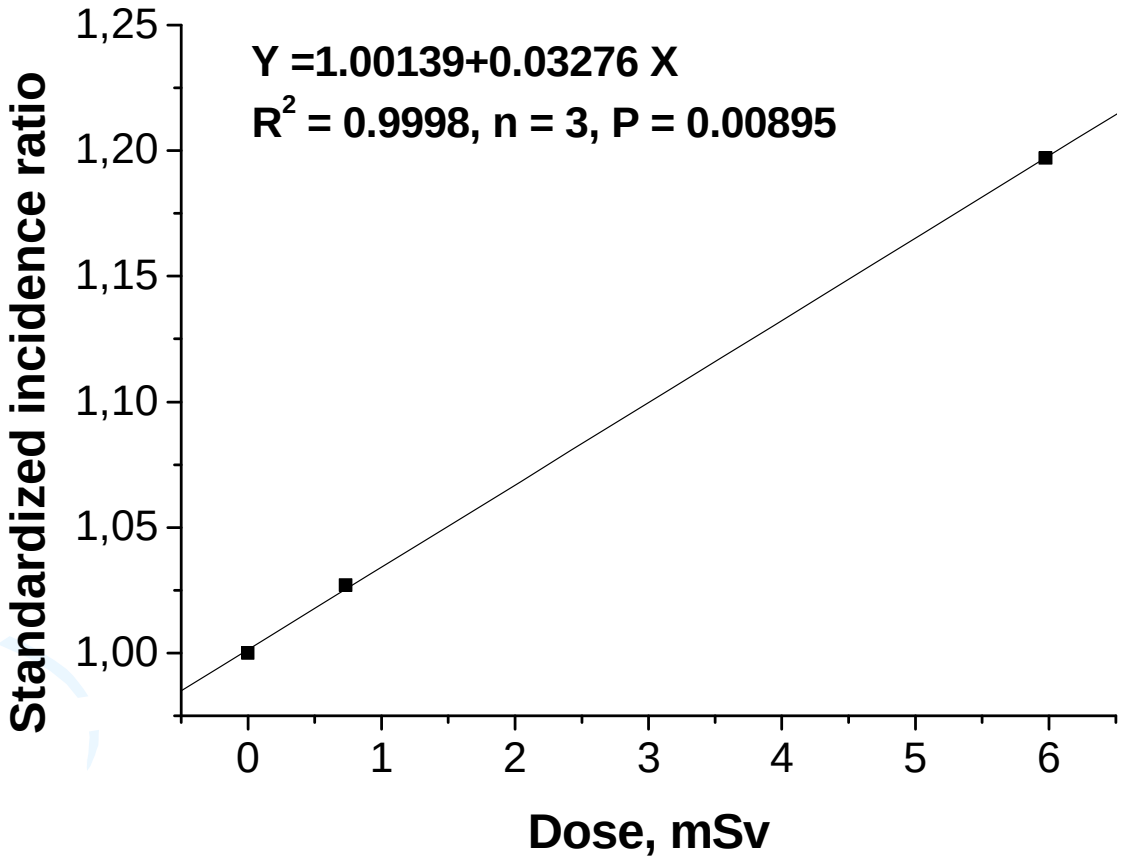
The Belarusian System of the National Genetic Monitoring registers congenital malformations that can be unambiguously diagnosed irrespectively of the level of physician's qualification and the levels of maternity hospitals. The list of such malformations includes anencephaly, spina bifida, cleft lip and/or palate, polydactyly, limb reduction defects, oesophageal atresia, anorectal atresia, Down's syndrome not associated with other anomalies and some multiple congenital malformations. The registration of these malformations is obligatory in Belarus. They determine approximately 40-50% from the total number of malformations registered in medical institutions of Belarus.

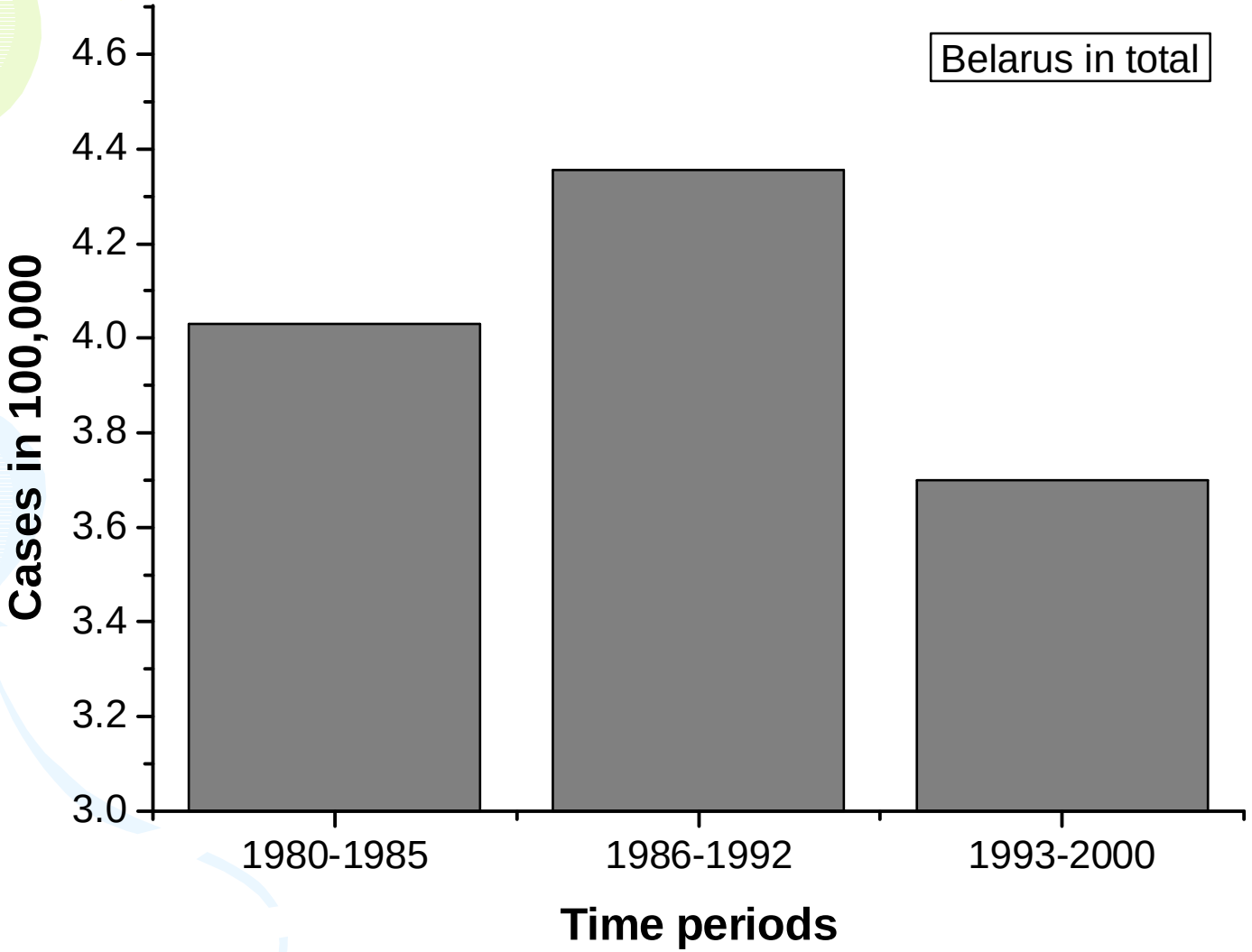
Data shown in previous slide were assessed for such obligatory congenital disorders.

Standardized incidence ratio of the incidence in obligatory congenital malformations in neonates of Belarus

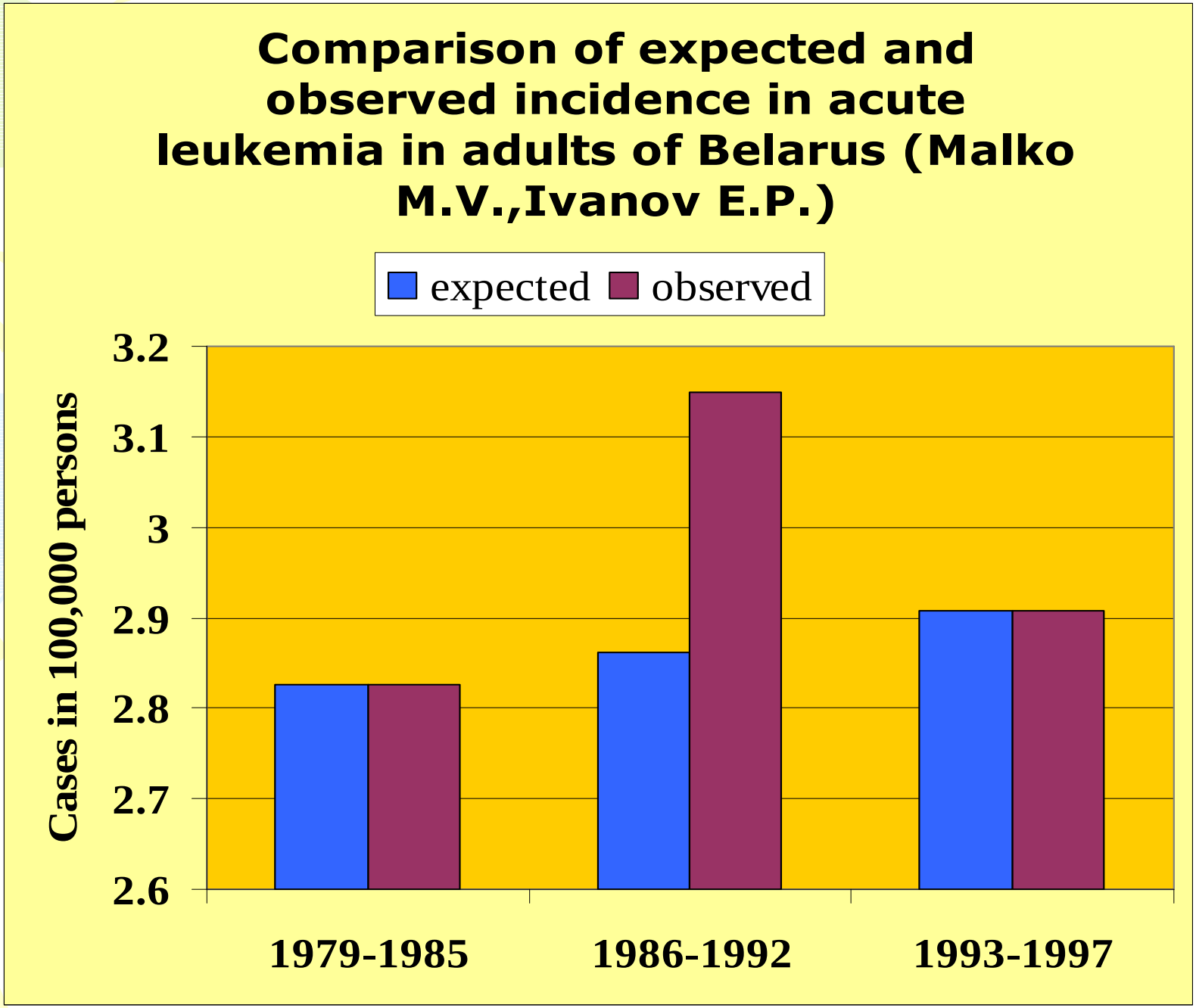
Parameters	Area		
	Control	Low-contaminated	High-contaminated
Number of born	202,577	156,856	42,611
Observed	1,179	938	297
Expected	1,179	912.9	248
O - E	0	25.1	49
SIR	1	1.027	1.198
95%CI of SIR	-	0.943÷1.119	1.055÷1.360
h, mSv	0	0.733	5.976
ERR, %/mSv	-	3.7	3.3
95% of ERR, %/mSv	-	-.7.8÷16.2	0.9÷6.0
AR,%	0	2.7	16.5
95% of AR in %	0	-6.0÷10.6	5.2÷26.5

Standardized incidence ratio of the incidence in obligatory congenital malformations in neonates of Belarus





Time-averaged incidences in the acute childhood leukemia in the entire Belarus (Ivanov E.P., Malko M.V)


Comparison of expected and observed incidence in acute leukemia in adults of Belarus (Malko M.V.,Ivanov E.P.)
expected
observed
Cases in 100,000 persons
3.2
3.1
3
2.9
2.8
2.7
2.6
1979-1985
1986-1992
1993-1997

Additional (radiation-induced) leukemias in Belarus caused by the Chernobyl accident (assessment of M.Malko, E.P.Ivanov et al)

Category	Period	Additional cases	95% of additi-onal cases	Relative risk	95% of relative risk
Acute leukemia in children					
(0-1) year	1987-1992	23	3-53	1.639	1.083-2.482
(0-14) year	1987-1995	197	110-293	1.26	1.145-1.385
Acute leukemia in adults					
Adults	1986-1992	158	44-280	1.101	1.028-1.179

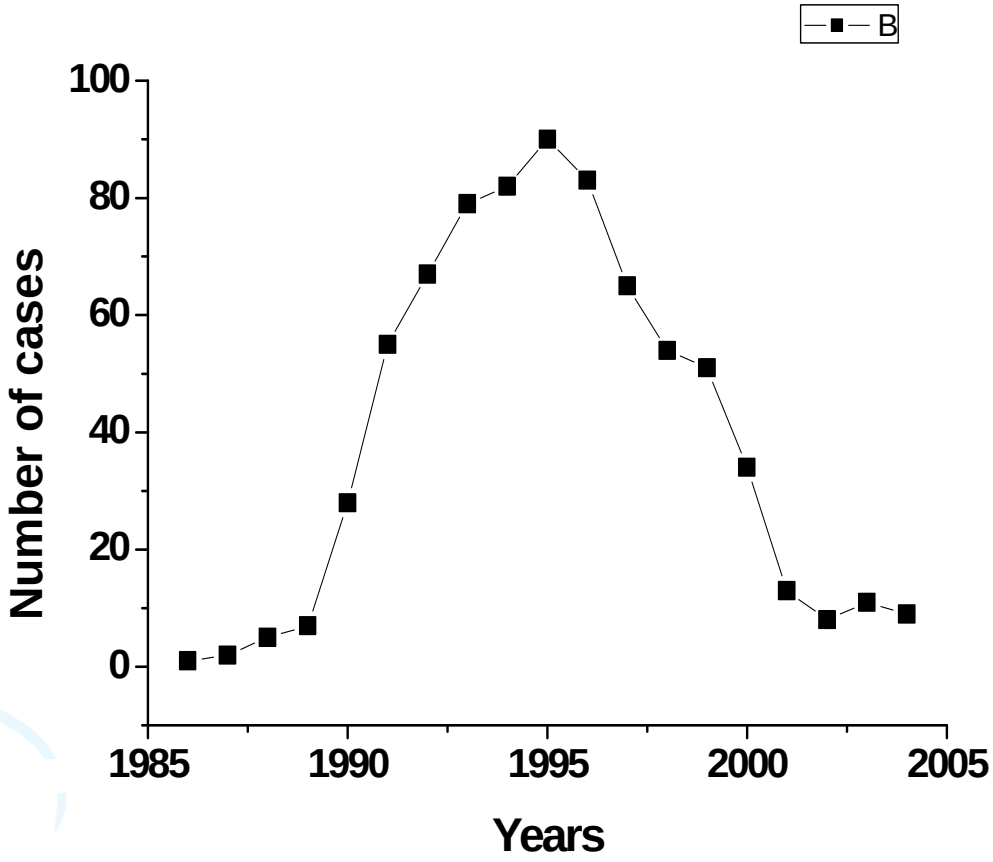
Radiation risk coefficients of congenital disorders and leukemia caused in Belarus by the Chernobyl accident (assessment of M.Malko, Ivanov E.P.)

Category	Period	EAR	95% CI of EAR	ERR/Sv	95% CI of ERR
Obligatory congenital disorders					
Newborns	1987-1992	-	-	33	9 – 60
Acute leukemia in children					
(0-1) year	1987-1992	560	73-1300	1650	210 –3800
(0-14) year	1987-1995	50.3	28.1-74.7	154	8.6 –228
Acute leukemia in adults					
Adults	1986-1992	13.9	3.7-24.7	4.9	1.4 – 8.7

Time-averaged crude and standardized (World standard) rates of the incidence of thyroid cancers in

Country	Time Period	Crude rate, 10^6 a^{-1}	Standardized rate, 10^6 a^{-1}	Sources
UK, England and Wales	1981-1990	0.6	0.5	[15]
UK, England and Scottish Cancer Register	1981-1990	0.6	0.5	[15]
Poland	1980-1989	0.5	0.5	[15]
Slovakia	1980-1989	0.7	0.6	[15]
Hungary	1985-1990	0.3	0.3	[15]
Ukraine	Before Chernobyl accident	0.5	-	[16]
Belarus	1966-1985	0.44	-	M.M.

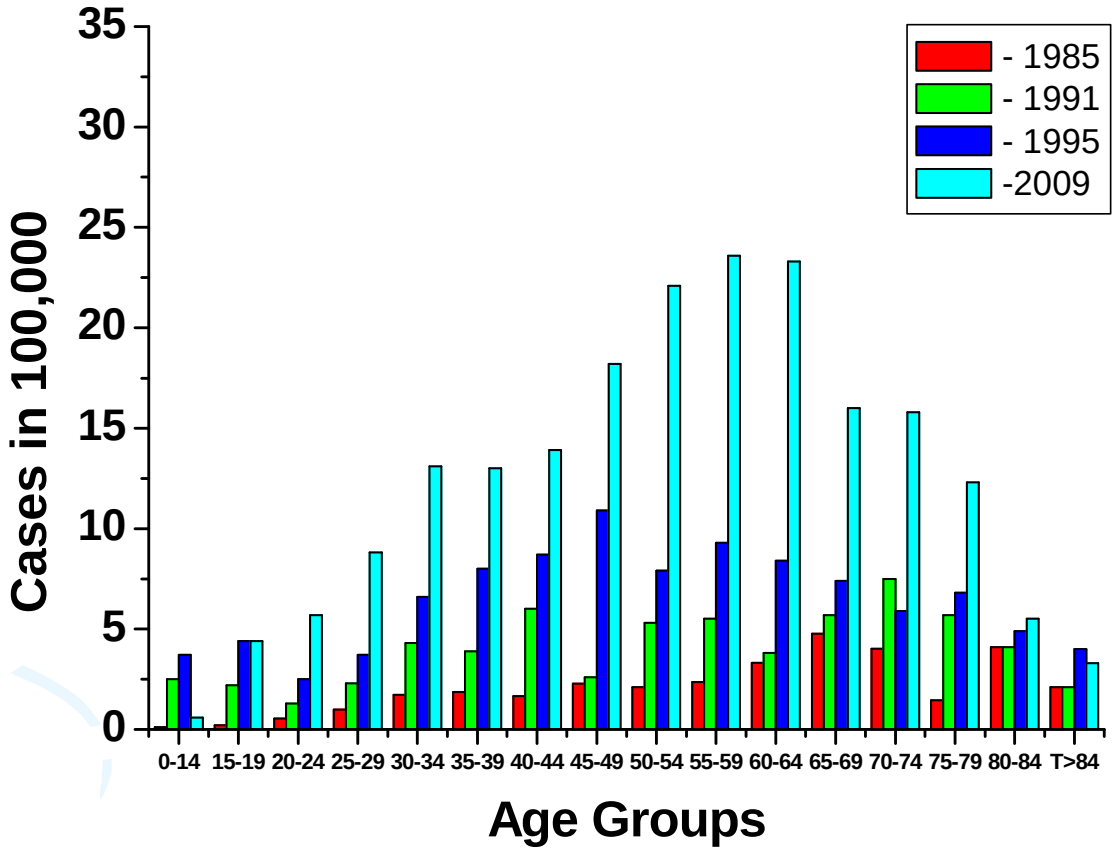
Temporal patterns of the incidence in thyroid cancer in children of Belarus (less than 15 years at the diagnose, data of Prof. Demidchik E.P.)



Incidence in thyroid cancer in children of Belarus (diagnosis at age < 15 years, observed data established by Prof. E.P.Demidchic)

Regions	Observed	Expected	O-E	RR
Brest	165	3	162	55
Vitebsk	11	2	9	5.5
Gomel	378	3	375	126
Grodno	43	2	41	21.5
city Minsk	62	3	59	20.7
Minsk region	42	3	39	14
Mogilev	43	2	41	21.5
Combined	744	18	726	41.3

Age specific incidences in thyroid cancer in Belarus in 1985, 1991, 1995, 2009



Incidence in solid cancers in Belarus after the Chernobyl accident (Assessment of M.Malko)

Cancer	Observed	Expected	O - E	95% of (O - E)		Period
Colon	26,254	24,263	1,991	1,537	2,453	1998-2011
Stomach	69,662	66,196	3,466	2,729	4,211	1991-2009
Lung	82,488	79.048	3.440	2,640	4.248	1991-2009
Breast	53,815	52,736	1,079	436	1,729	1992-2009
Kidney	11,901	11,016	885	581	1,197	2005-2011
Urinary bladder	20,938	20,064	874	472	1,283	1990-2010
Thyroid	17,789	7,994	9,795	9.332	10,271	1990-2010
*Skin cancer	89,348	79,348	10,000	9,150	10,860	1996-2012

Notice: * skin cancer including basalioma and excluding melanoma

Relative and attributable risk of radiation-induced solid cancers in Belarus (Assessment of M.Malko)

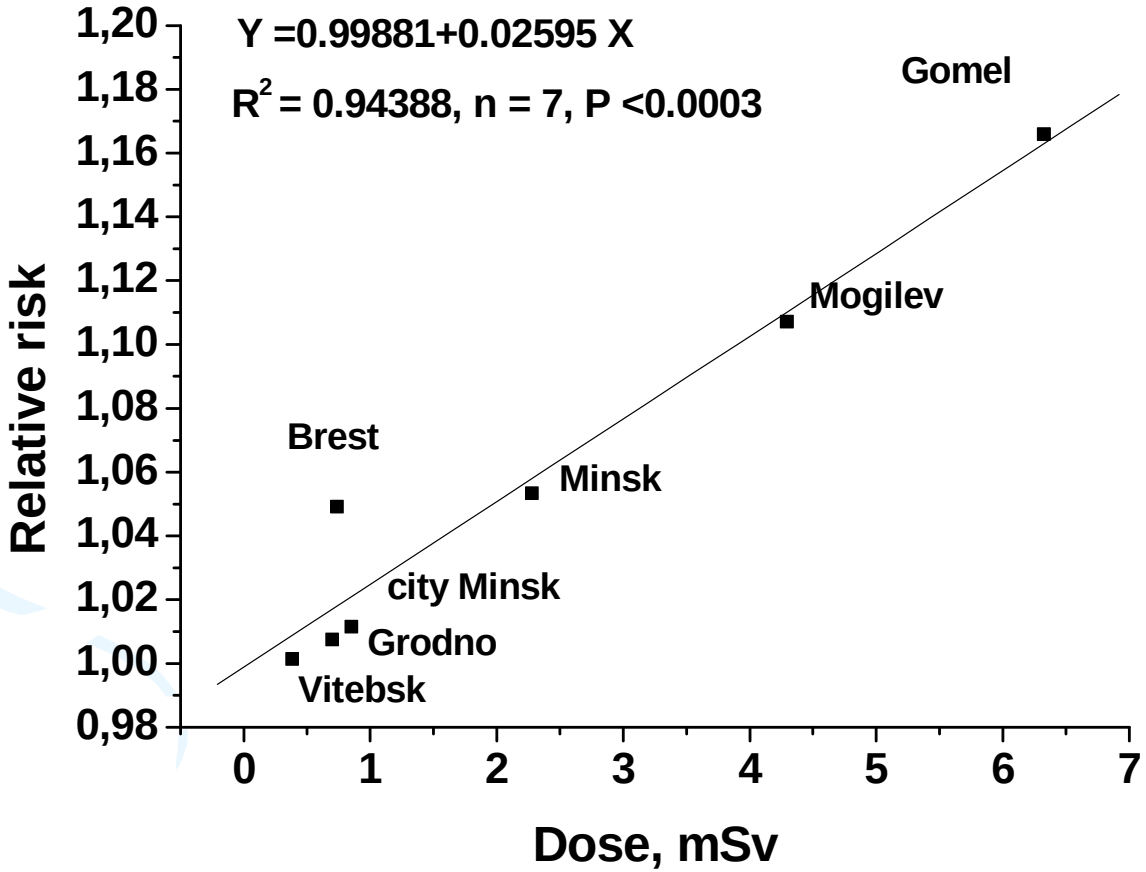
Cancer	h, mGy	RR	95 % CI of RR		AR%	95% CI of AR	
Colon	3	1.082	1.063	1.101	7.6	5.9	9.3
Stomach	3	1.052	1.038	1.094	5	3.6	8.6
Lung	3	1.044	1.033	1.054	4.2	3.2	5.2
Breast	3	1.02	1.009	1.033	2	0.8	3.3
Kidney	3	1.080	1.053	1.109	7.4	4.9	10.1
Urinary bladder	3	1.141	1.116	1.165	12.3	10.2	14.5
Thyroid	127	2.220	2.161	2.282	55.0	53.7	56.2
*Skin cancer	17	1.126	1.115	1.137	11.2	10.3	12.0

Notice: * skin cancer including basalioma and excluding melanoma

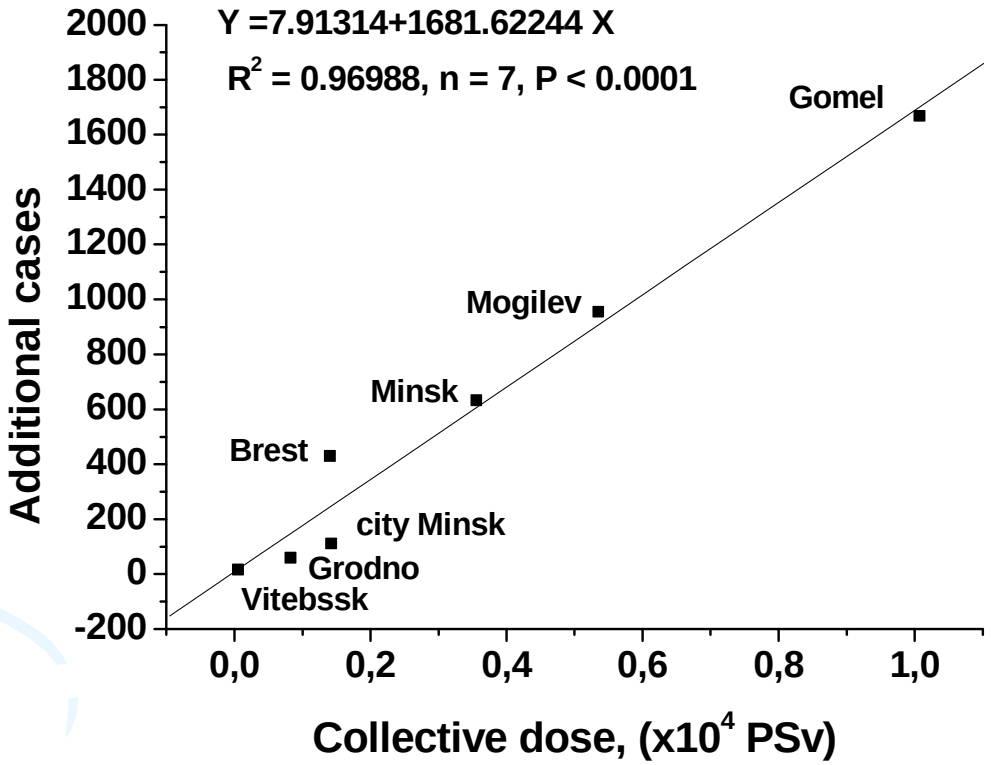
Additional (radiation-induced) solid cancers in Gomel region as a result of the Chernobyl accident (assessment of M.Malko)

Cancer	Period	Additio-nal cases	95% of addition al cases	Relative risk	95% of relative risk
Solid cancers in mixed population					
Stomach	1991-2009	1,526	1,142-1,920	1.155	1.116-1.195
Lung	1991-2009	1,232	411-1,666	1.108	1.072-1.146
Breast	1992-2009	490	240-748	1.064	1.031-1.098
Bladder	1990-2010	383	241-575	1.134	1.080-1.192
Combined	1990-2010	3,631	2,034-4,909	-	-
nm-Skin	1996-2010	6,300	-	1.56	-

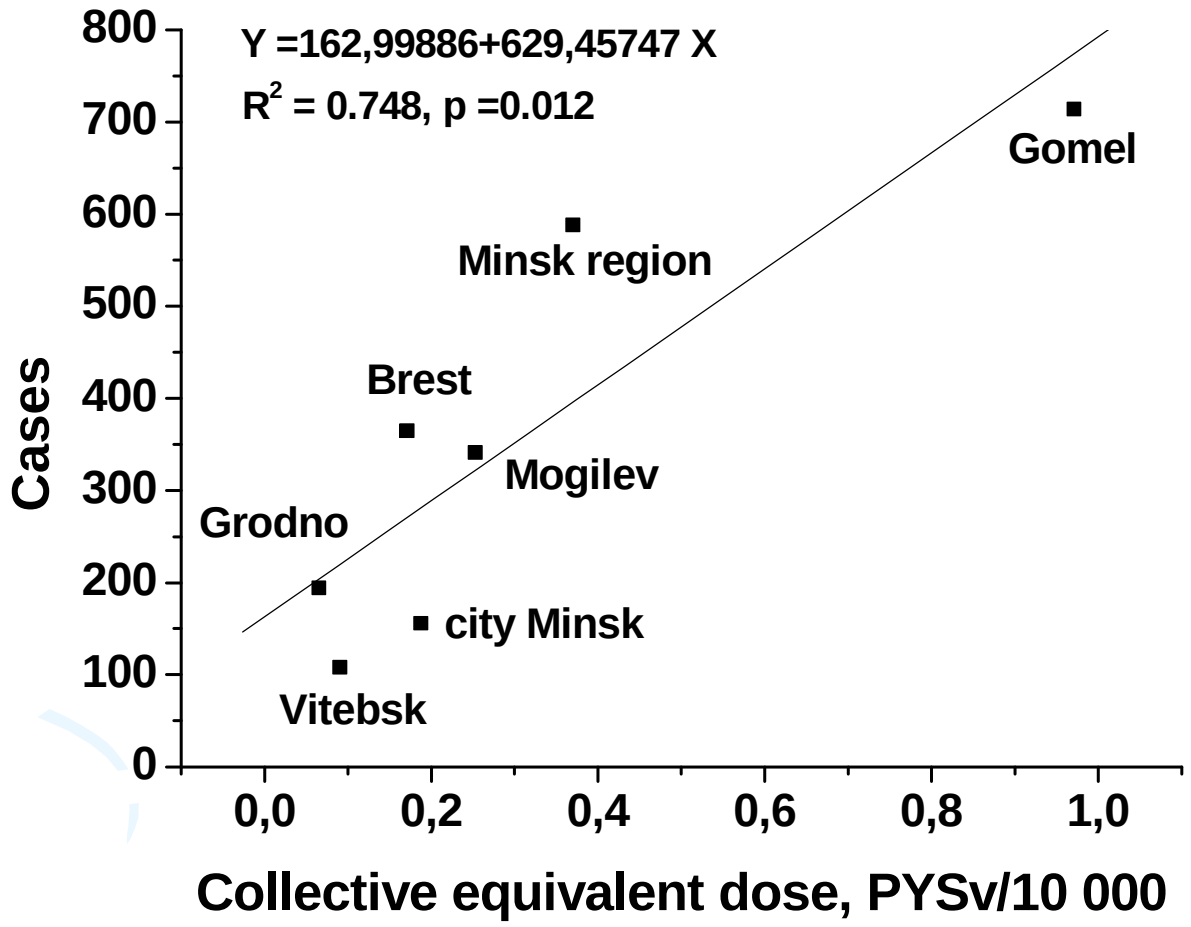
Relative risk of the incidence in stomach cancers in populations of Belarusian regions (Assessment of M.Malko)



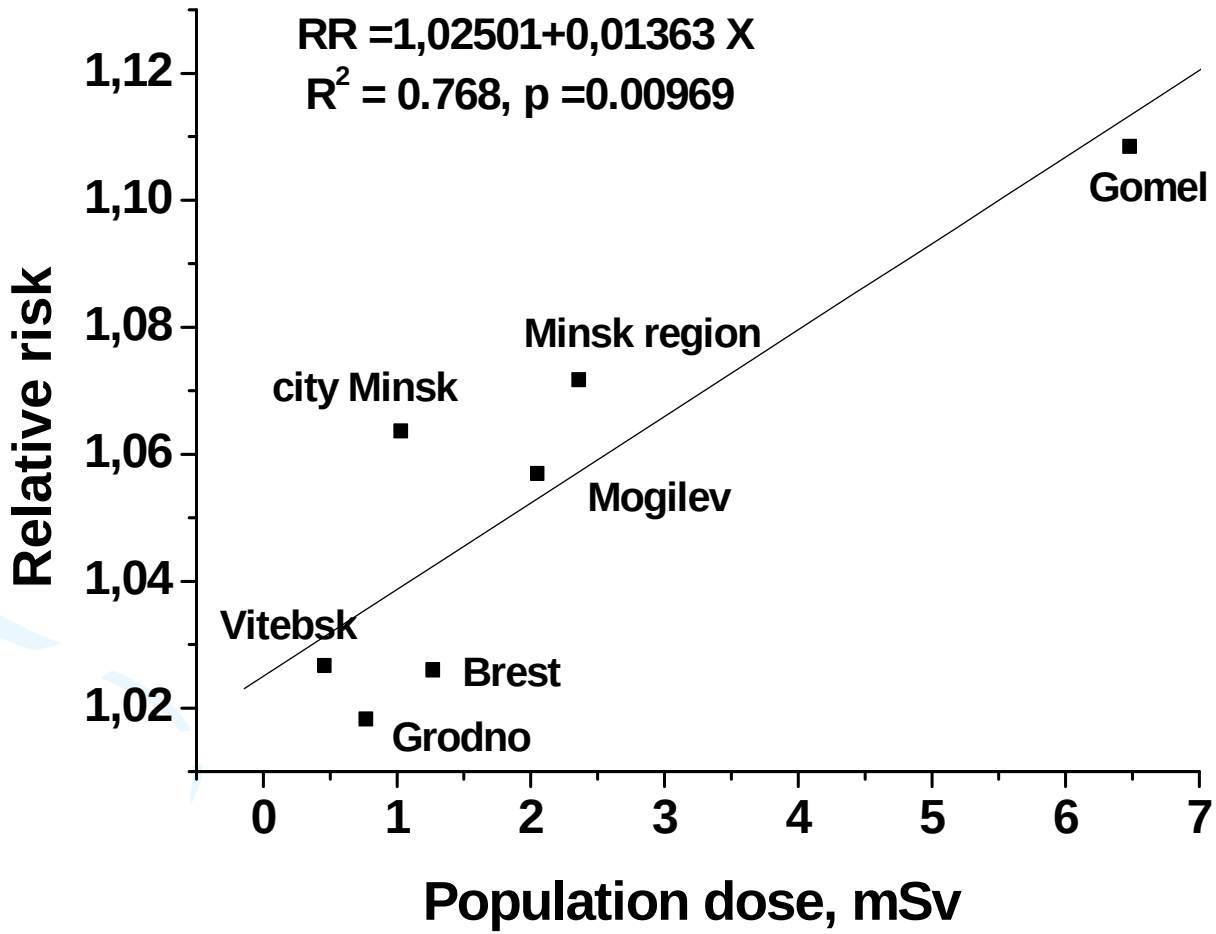
NUMBERS OF ADDITIONAL STOMACH CACERS AS A FUNCTION OF COLLECTIVE DOSE OF IRRADIATION (Assessment of M.Malko)



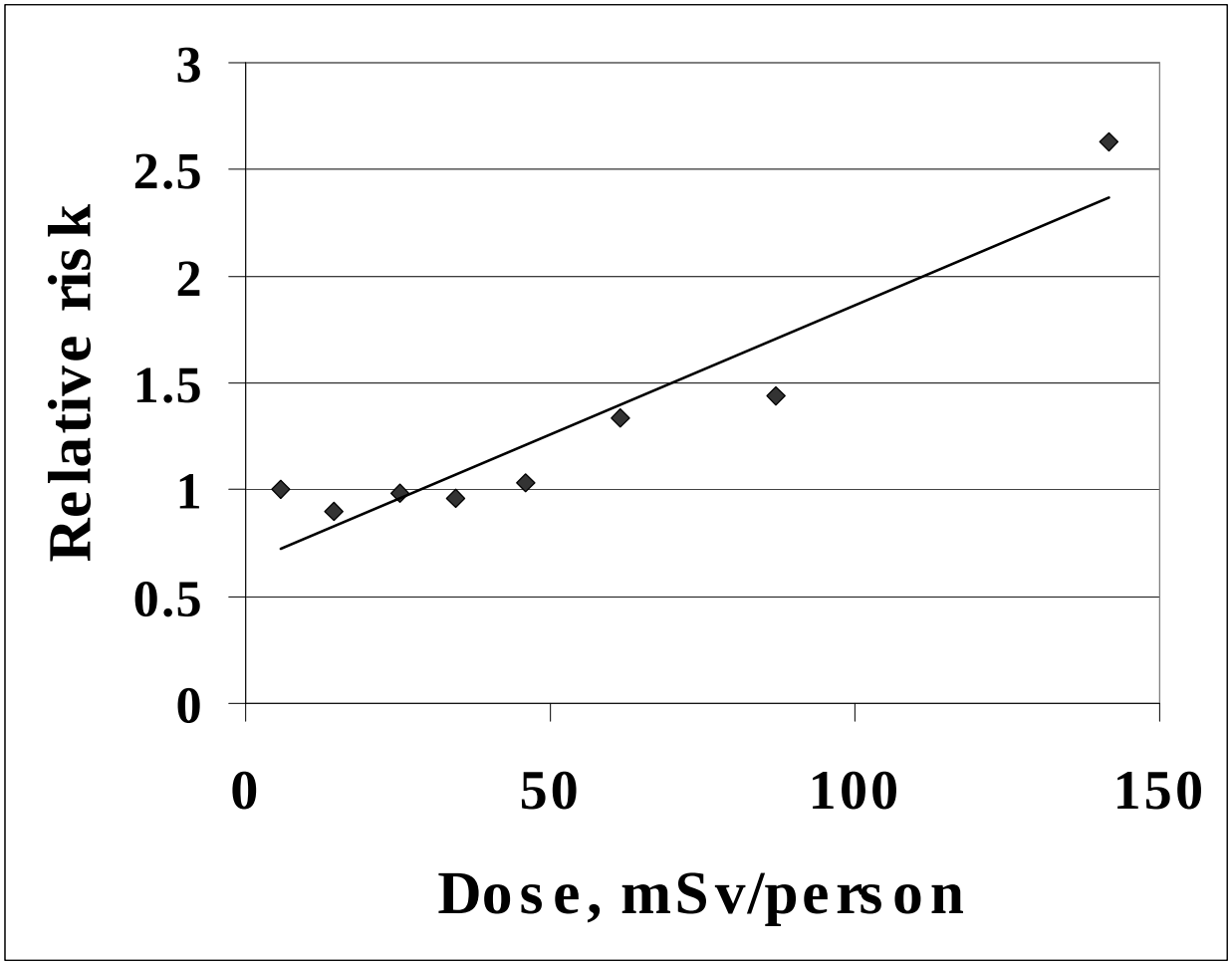
Numbers of additional lung cancers in Belarus in 1991-2001 (M.Malko, 2011)



Time-averaged (1991-2001) relative risk of lung cancer in regions of Belarus (M.Malko, 2011)



RELATIVE RISK OF THE INCIDENCE IN FEMALE BREAST IN WOMEN OF GOMEL OBLAST IN 1997-2003 (Sosnovskaya E. Ya. National Report. Minsk, 2006)



Radiation risk of the incidence in solid cancers estimated for the Belarusian population and for atomic bomb survivors (in cases per 10^4 PYGy)

Cancer	M.Malko			Atomic bomb survivors*			Ratio
	EAR	95% of EAR		EAR	95% of EAR		
Colon	44.7	34.5	55.1	8	4.4	12	5.6
Stomach	61.9	44.5	79.5	9.5	6.1	14	6.5
Lung	60.2	41.7	78.9	7.5	5.1	10	8.0
Breast	44.3	17.9	70.90	9.2	6.8	12	4.8
Kidney	40.5	26.6	54.9	-	-	-	-
Urinary bladder	37.8	31.3	44.4	3.2	1.1	5.4	11.8
Thyroid	4.4	4.2	4.6	1.2	0.5	2.2	3.7

Notices: *Data for atomic bomb survivors that were irradiated at 30 years and reached 70 years (Preston D.L. et al, Radiation Research, vol. 168, 2007, pp.1-64)

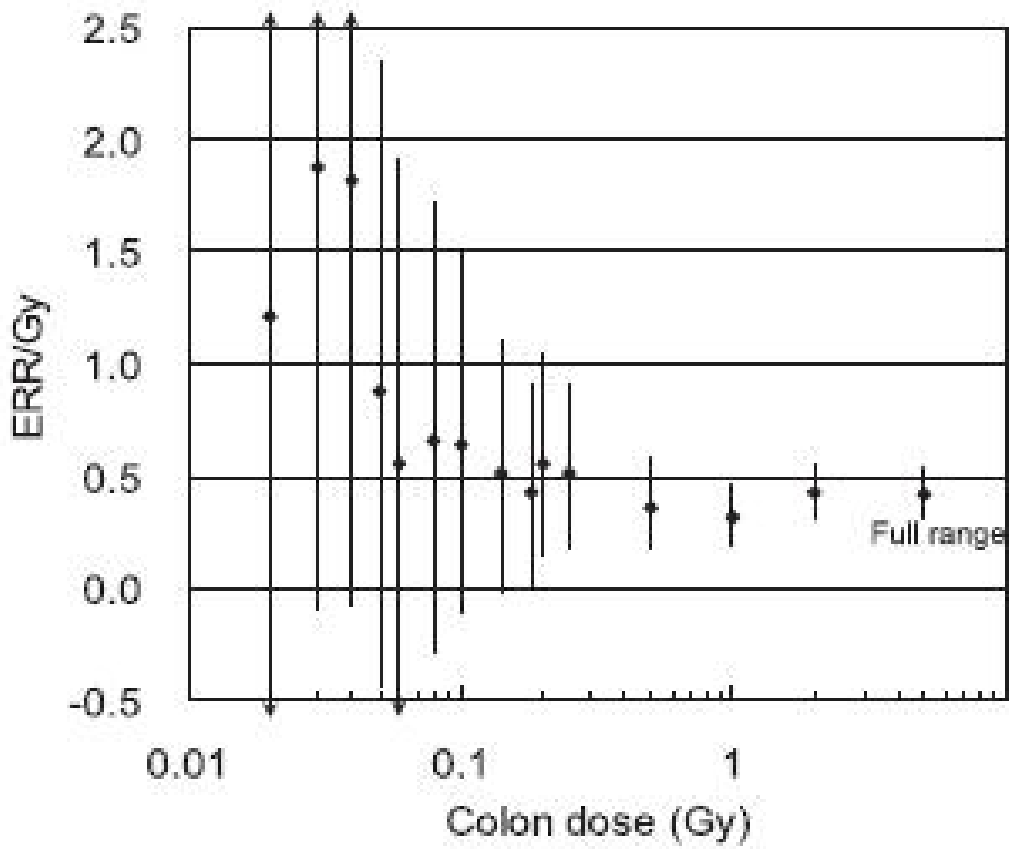
Reasons of difference in values of excessive absolute risk established for the Belarusian population and for atomic bomb survivors

The previous slide demonstrate comparison of values of the excessive absolute risk (EAR) of the incidence in solid cancers in the population of Belarus irradiated in the range of low doses and atomic bomb survivors irradiated in the range of middle and high doses (Preston D.L. et al, Radiation Research, 2007).

The possible reason of higher values of EAR assessed for the Belarusian population is the higher radiation risk of low doses in comparison with radiation risk of middle and high doses.

Reliability of this conclusion is supported by data indicating that excessive relative risk of the incidence in solid cancers in the range of low doses by atomic bomb survivors is by some factors higher that in the range of middle and higher doses (next slide).

Excessive radiation risk of the incidence in solid cancers in atomic bomb sirvivors (Kotara Ozasa et al, Radiation research, vol. 177, 2012, pp.229-243)



Doubling doses of radiation –induced health effects caused in Belarus by the Chernobyl accident (assessment of M.Malko)

Leukemia	Infants (0-1 year)	1 mSv
Leukemia	Children (0-14 years)	5 mSv
Congenital disorders	Newborn children	15 mSv
Solid cancers	Entire population	100 mSv

Incidence in mortality of affected populations from general somatic diseases

- Soon after the accident at the Chernobyl NPP significant increase in the incidence in general somatic diseases was observed in different categories of affected populations of Belarus, Ukraine and Russia
- Especially high increase was observed in case of diseases of the endocrine and cardivasculare system, in diseases of digestive organs and in urogenital diseases
- In case of evacuated and resettled inhabitants of high contaminated territories of Belarus an additional mortality from general somatic diseases mostly from diseases of the cardivascular system occurred

Mortality of adolescents and adults of Belarusi evacuated from the Belarusian part of the 30-kilometer zone (Assessment of M.V.Malko, performed on the basis of data of Antipova S.I. et al. Mediko-biologitcheskie aspekty avarii na Tchernobylskoi AES. Analitiko-informatsionnyi byulleten. Minsk. N4, 1996, p. 3-49)

Year	Observed	Expected	O - E	SIR
1993	220	176	44	1.25
1994	250	143	107	1.75
1995	169	127	42	1.33
Combined	639	446	193	1.43

Mortality of persons resettled from areas of Belarus contaminated to the level 555 kBq/m^2 (15 Ci/km^2) from general somatic diseases (Assessment of M.Malko on the basis of data of Antipova S.I. et al. Analitiko-informatsionnyi byulleten. Minsk. N4, 1996, p. 3-49 (in Russian).)

Year	Observed	Expected	O - E	SIR
1993	1,159	942	217	1.230
1994	1,230	1,052	178	1.169
1995	1,217	1,097	120	1.110
Combined	3,606	3,091	515	1.167

Conclusion

- The accident at the Chernobyl NPP caused in Belarus the statistical significant manifestation of additional heritable anomalies, statistical significant increase in the incidence in leukemia's, malignant neoplasms as well as in general somatic diseases.
- Results of an assessment gives following numbers of additional or radiation-induced health effects occurred in Belarus after the accident at the Chernobyl NPP:

  - approximately 10,000 solid cancers other than thyroid cancer and non-melanoma skin cancers;
  - approximately 10,000 thyroid cancers;
  - approximatelly 10,000 non-melanoma skin cancers

Contributuin of radiation-induced health effects to the general morbidity of the Belarusian population

-Approximately 770,000 new solid cancers (including thyroid cancer and excluding non-melanoma skin cancers) were registered in Belarus in 1987-2012.

- Approximately 20,000 solid cancers (excluding non-melanoma skin cancers)from this number occurred as a result of the Chernobyl accident.

- In accordance with these data the contribution of radiation-induced solid cancers (excluding skin cancers) in the period 1987-2012 was about 2.5%.

- The given data indicate that the radiation factor plays does not belong to the most important factors determining the incidence of malignant neoplasms in Belarus.

- Similar conclusion can be drawn in respect of the role of the radiation factor in case of general somatic diseases

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