IAEA Vienna (CN 224)
20 February 2014

Overview of public exposures from major radiological events

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OUTLINE

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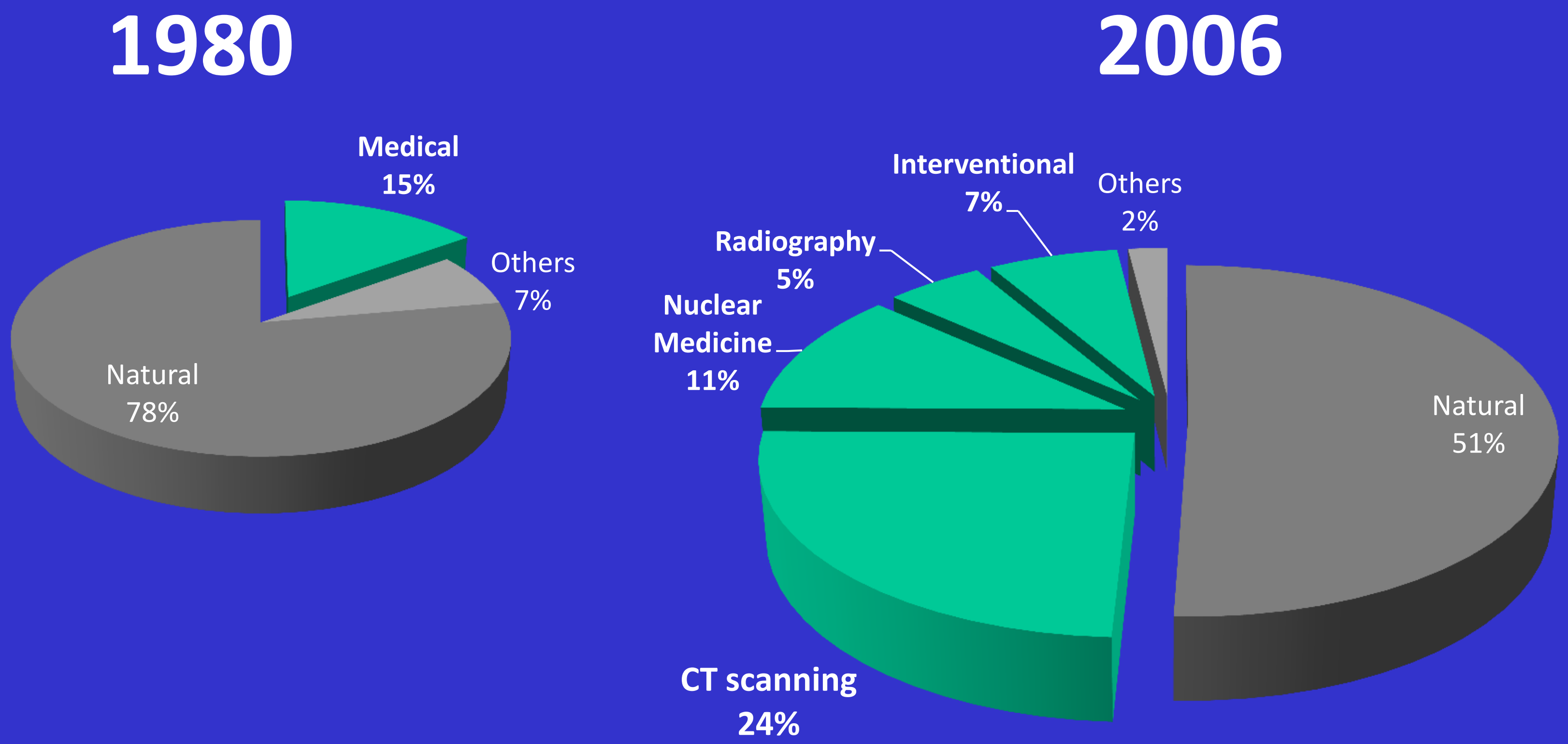
Distribution of annual per caput effective doses in the U.S. in 2006

Source	%	Main component
Background	50	Rn and Tn (37%)
Medical	48	CT scans (24%)
Consumer	2	Cigarette smoking (35%)
Occupational	<0.1	Navy nuclear power (51%)
Industrial	<0.1	Irradiation from nuclear medicine patients (72%)

Total: 6.2 mSv y^{-1} (NCRP 160; 2008)

Distribution of annual effective doses in the U.S.*



AVERAGE: 3.6 mSv in 1980

AVERAGE: 6.2 mSv in 2006

*NCRP Report 160

SCOPE OF THE PRESENTATION

COVERAGE

- Exposures resulting from large environmental releases of radioactive materials
- Focus on reactor accidents and nuclear weapons tests
- Dose estimates for local populations

History of nuclear power

- **1942-1962: Era of military uses**
  - **Use of nuclear weapons in Japan**
  - **Multiple atmospheric nuclear weapons tests**
  - **Large environmental releases: Hanford, Mayak**
  - **Accidents: Windscale, Kyshtym**
- **1963-1979: Era of electricity generation**
  - **Development of nuclear power for civilian purposes**
  - **Accident: Three Mile Island**
- **1980-to date: Era of critical review**
  - **Nuclear reactor accidents: Chernobyl, Fukushima**
  - **End (?) of atmospheric weapons testing**

Categories of nuclear “events”

- Accidents:

  - Reactor: Windscale (1957), TMI (1979), Chernobyl (1986), Fukushima (2011)

  - Other : Kyshtym (1957), Goiania (1987)

- Nuclear weapons:

  - Use: Japan (1945)

  - Testing: Trinity (1945), Nevada and Kazakhstan (1950s), Marshall Islands (1950s)

  - Pu production: Hanford (1940s), Mayak (1940s)

ENVIRONMENTAL RELEASES

Accidental releases to the atmosphere (PBq)

	^{131}I	^{137}Cs	^{90}Sr	Other
REACTORS:				
Windscale (1957)	**0.6**	**0.05**	**<0.001**	**^{210}Po**
TMI (1979)	**0.001**			**^{133}Xe**
Chernobyl (1986)	**1800**	**85**	**10**	**^{134}Cs, etc.**
Fukushima (2011)	**160**	**15**	**0.14**	**^{134}Cs, etc.**
OTHER:				
Kyshtym (1957)		**0.26**	**4.0**	**^{144}Ce-Pr, etc.**
Goiania (1987)		**0.05**		

Releases from the nuclear weapons industry (PBq)

	^{131}I	^{137}Cs	^{90}Sr	Other
WEAPONS:				
Japan (1945)	**160**	**0.22**	**0.14**	**All F.P.**
Nevada (1950s)	**5600**	**8**	**5**	**All F.P.**
Global (1950-60s)	**675000**	**950**	**620**	**^{14}C, etc.**
Pu PRODUCTION:				
Hanford (air)	**27**		**0.002**	**^{103}Ru, etc.**
Mayak (air)	**40**			
Mayak (water)		**12**	**20**	**^{103}Ru, etc.**

Environmental releases (PBq)

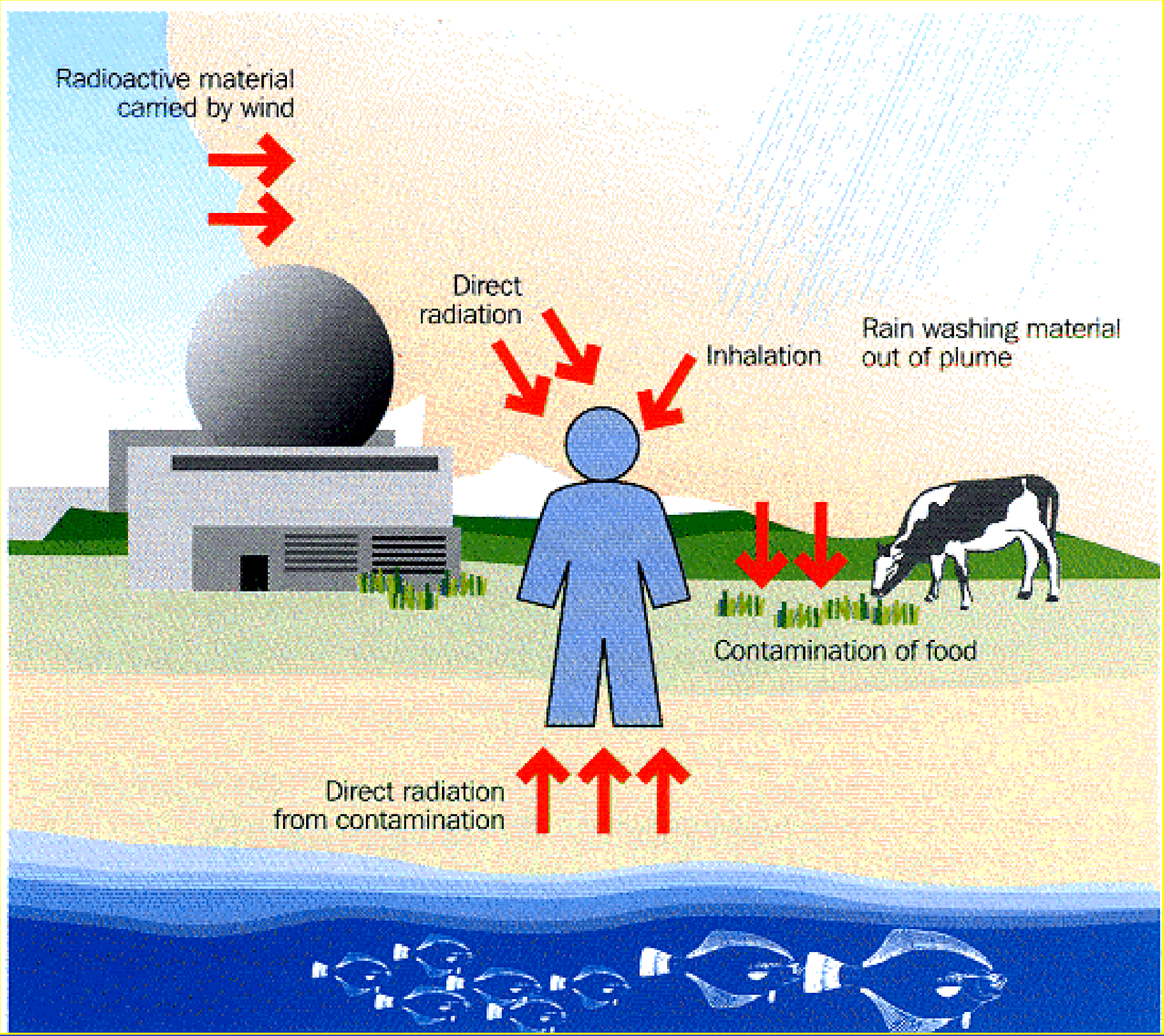
	^{131}I	^{137}Cs	^{90}Sr
ACCIDENTS:			
- Reactor	**2000**	**100**	**10**
- Other		**0.3**	**4**
NUCLEAR WEAPONS:			
- Use	**160**	**0.2**	**0.1**
- Testing	**700000**	**1000**	**600**
- Pu production (air)	**70**		
(water)		**10**	**20**

Comparison of activities produced and released (PBq)

Radio-nuclide	Half-life	Fission (1 Mt)	Chernobyl (inv.)	Chernobyl (rel.)	Inv./ 1 Mt	Rel./ 1 Mt
^{137}Cs	30 y	5.9	260	85	44	14
^{90}Sr	29 y	3.9	220	10	57	2.6
^{144}Ce	285 d	191	3,920	50	21	0.27
^{95}Zr	64 d	921	5,300	84	5.8	0.09
^{141}Ce	32 d	1,640	5,550	84	3.4	0.05
^{131}I	8 d	4,210	4,800	1,760	1.1	0.4

PATHWAYS OF EXPOSURE

Exposure Pathways



PATHWAYS OF EXPOSURE

EXTERNAL IRRADIATION

- Direct radiation from the source
- Radioactive cloud
- Activities deposited on the ground

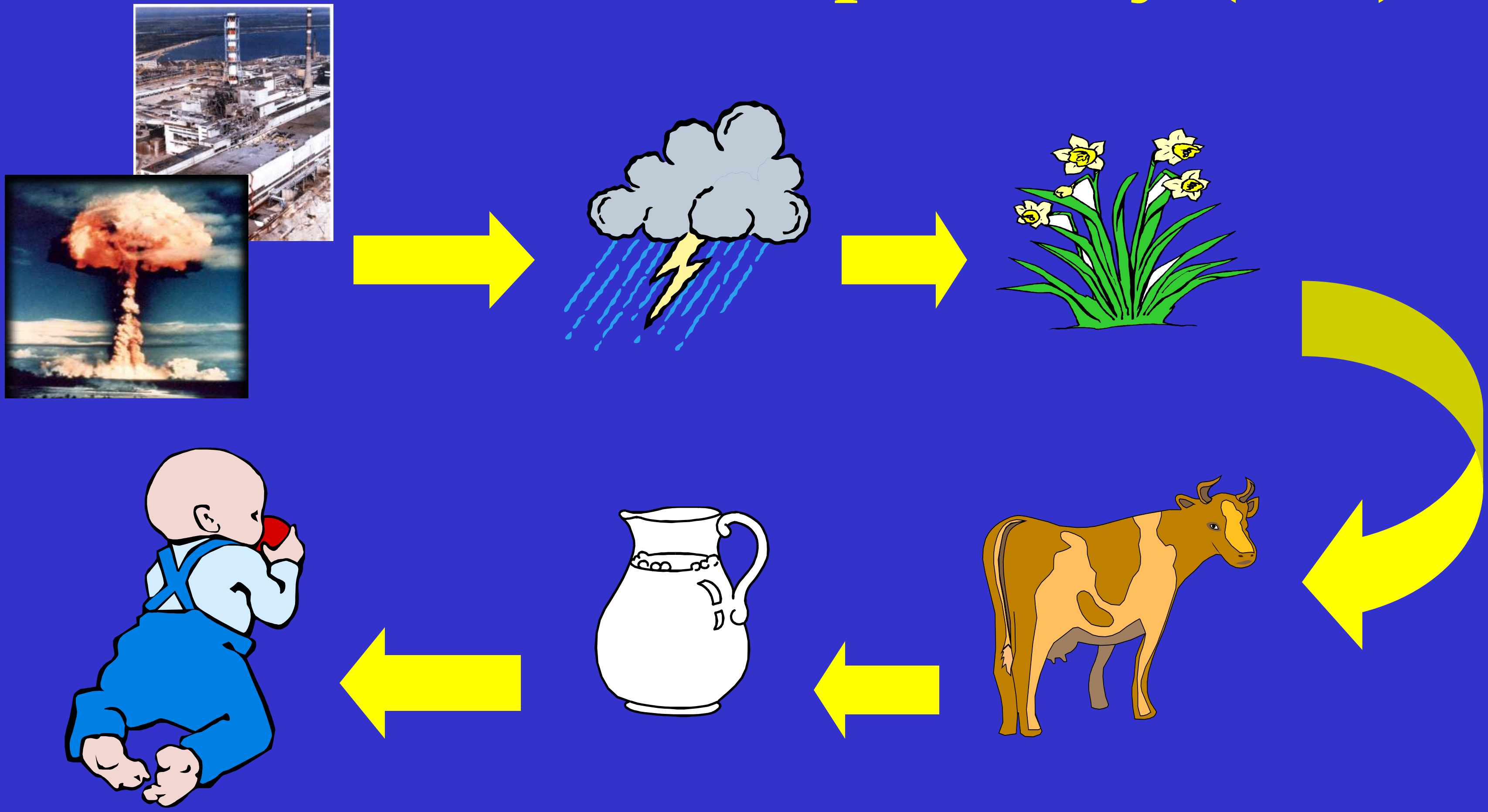
INTERNAL IRRADIATION

- Inhalation
- Ingestion

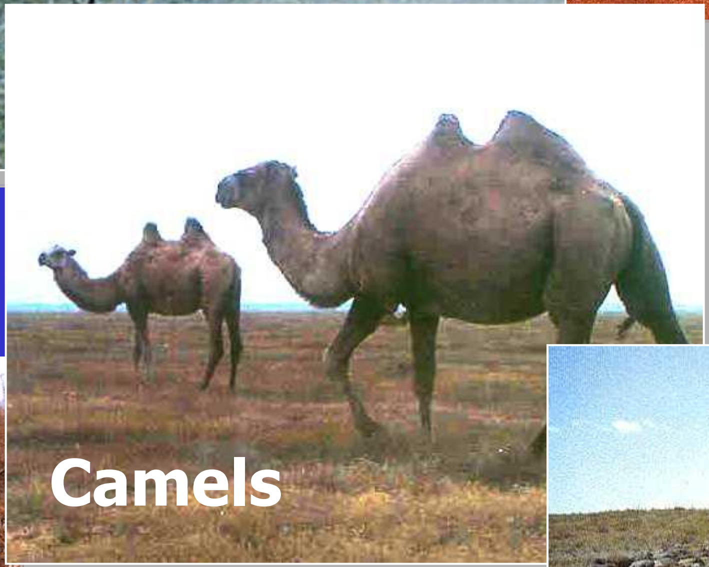
Exposure pathways

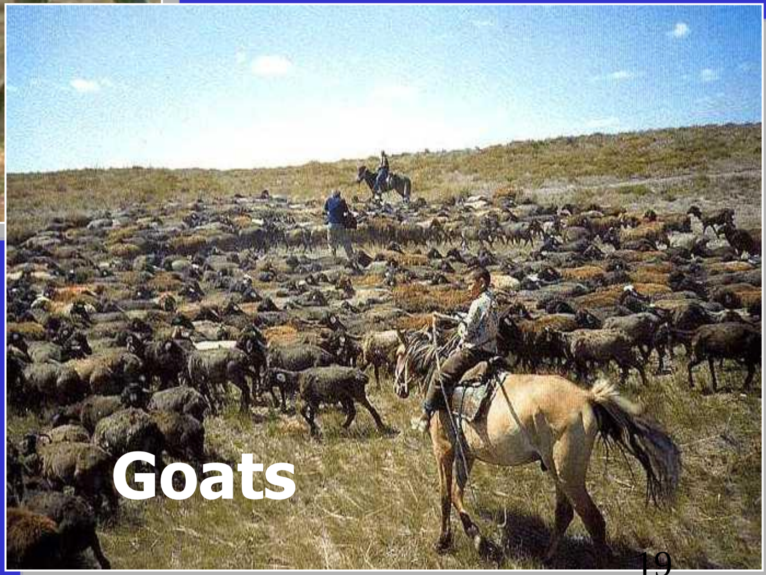
Event	Main pathways	Main radionuclides
Hanford, Mayak (air), Trinity, NTS, Kazakhstan, Windscale, Chernobyl	Ingestion (milk)	^{131}I
Japan	Direct radiation	^{235}U, ^{239}Pu
Kyshtym	External, ingestion	^{90}Sr
Goiania	External, ingestion	^{137}Cs
TMI	External	^{133}Xe
Marshall Islands	Ingestion	^{133}I, ^{131}I, ^{132}Te-I
Mayak (water)	External, ingestion	^{137}Cs, ^{90}Sr
Fukushima	External, inhalation, ingestion	^{131}I, ^{137}Cs, ^{134}Cs

Pasture-cow-milk pathway (^{131}I)



Sources of animal milk in Kazakhstan





Estimated contributions to the thyroid dose (%) [Chernobyl; BY]

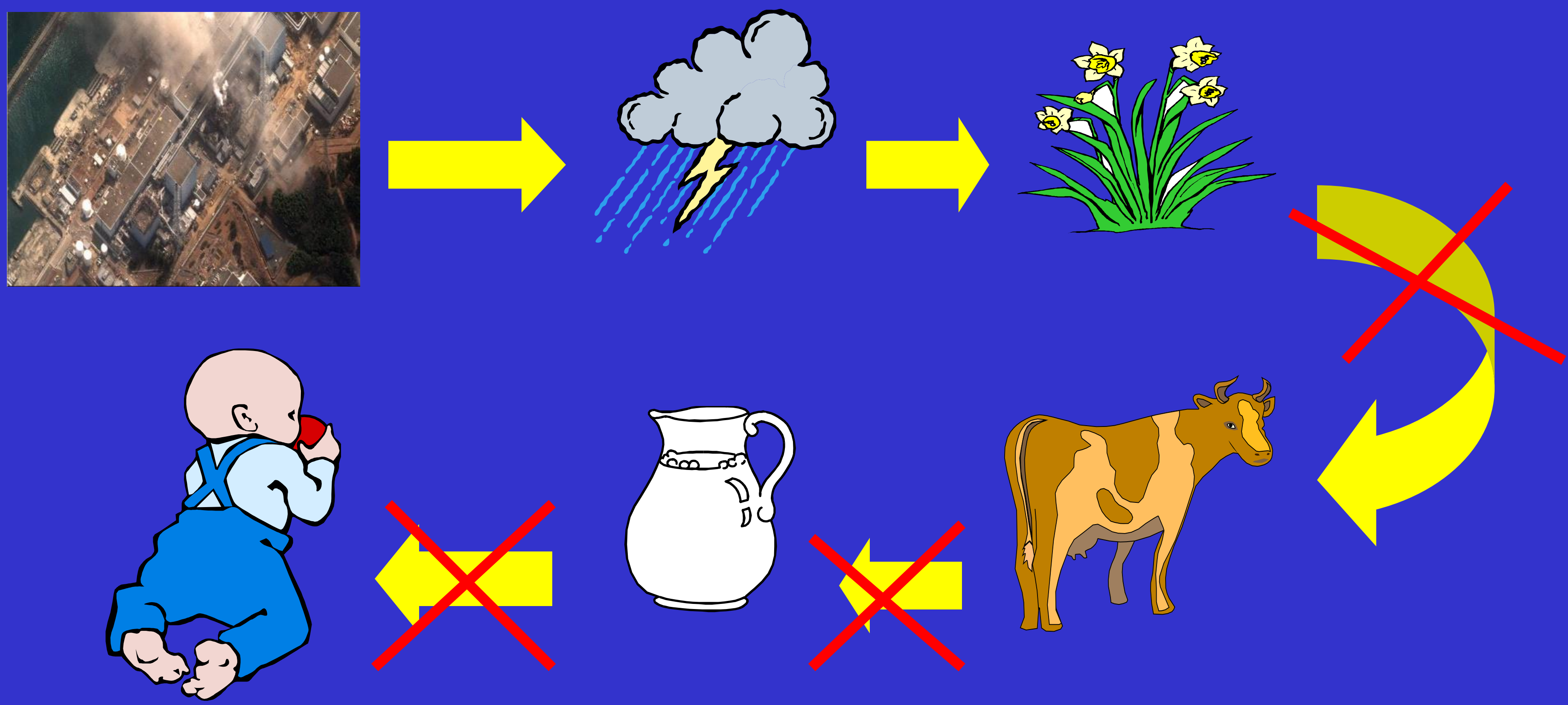
Pathway	Average contribution (%)	Range (%)
^{131}I ingestion	96	86 – 99
^{133}I, ^{132}Te ingestion	2	0.3 – 9
^{134}Cs, ^{137}Cs ingestion	1	0.02 – 5
External irradiation	1	0.8 – 9

Fallout study: estimates* of internal and external doses in St. George, UT from event Harry (19 May 1953)

Organ/tissue	Infant dose (mGy)	Adult dose
	Internal irradiation	
Thyroid	840	51
Lower large intestine	25	5.0
Upper large intestine	8.8	2.0
Bone surfaces	7.6	1.3
Total body	1.1	0.5
	External irradiation	
Total body	~10	~10

*provided by Lynn Anspaugh

Fukushima: reduction of doses from ^{131}I



COUNTERMEASURES

COUNTERMEASURES

EXTERNAL IRRADIATION

- **Direct radiation from the source: none**
- **Radioactive cloud: shielding, evacuation**
- **Activities deposited on the ground: shielding, decontamination**

INTERNAL IRRADIATION

- **Inhalation: shielding, KI**
- **Ingestion: control of foodstuffs production and consumption**

Practical means to reduce the dose

- The dose from external irradiation is much lower for people staying indoors in basements than for those staying outdoors.
- The dose from inhalation of radioiodines is reduced by intake of KI pills before the passage of the radioactive cloud and by staying indoors.
- The dose from ingestion of radioiodines is also reduced by intake of KI pills, but a more efficient way is to abstain from eating contaminated foodstuffs.
- Evacuation from contaminated territories reduces the dose for all pathways.

Effectiveness of Chernobyl countermeasures

Countermeasures	US$ per man-Sv	Area, time
	External dose	
Sheltering	0.02-1	Pripyat, 26-27 April 1986
Evacuation	1,000 – 15,000	30-km zone, April - May 1986
Relocation	130,000-500,000	Contaminated areas, 1990
	Internal dose	
Iodine prophylaxis	0.02-1	April-May 1986
Restriction s on local foods	13,800-120,000	Bryansk Oblast, Russia, 1989

Evacuation/Relocation

Event	Year	Timing	Population size
Mayak (Techa)	1950-1951	Late 1951	7,500
Kazakhstan	1953	5 d – 2 h before test	3,300
Marshall Islands	1954	Within 3 d	227
Kyshtym	1957	Within 2 y	12,000
TMI	1979	Within a week	144,000
Chernobyl	1986	Within 10 d Within 1-4 mo	99,000 17,000
Fukushima	2011	Within a week	110,000

Importance of the timing of the intake of KI

Time between intake of I-131 and KI (h)	Thyroid dose with KI (mGy)	Dose ratio to control group
0	0.6	0.026
8	1.5	0.07
16	3	0.13
24	3.1	0.14
36	15.6	0.68
48	15.4	0.67
Control group (w/o KI)	23	1

Mean I-131 thyroid doses (mGy)
[Pripyat evacuees: inhalation doses]

KI pills	Mainly indoors	Often outdoors
Yes	45 (40)	115 (9)
No	96 (7)	301 (15)

DOSE ESTIMATES

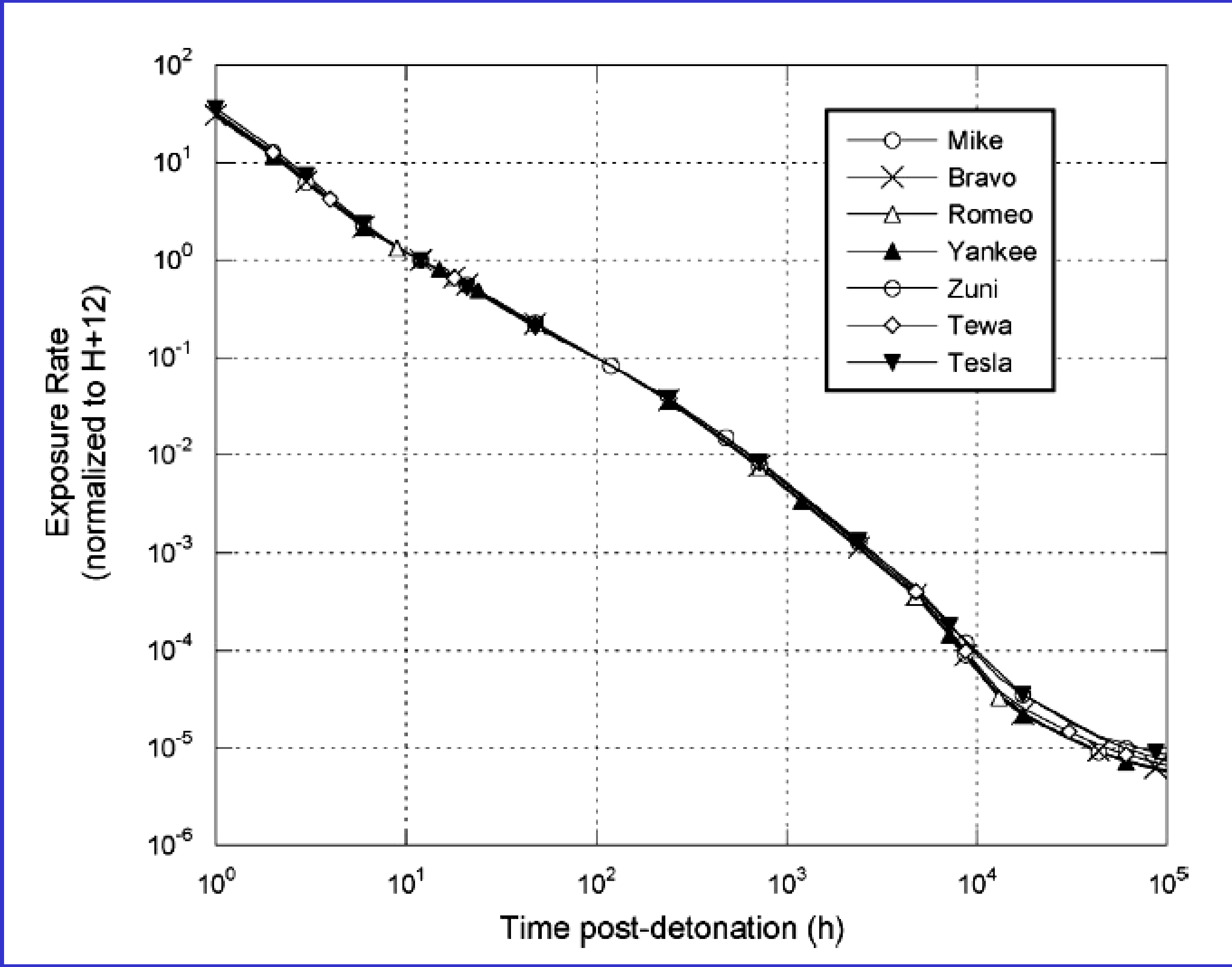
How can dose estimates be compared?

- Collective effective dose commitment
- Truncated collective effective dose commitment
- Annual per caput effective dose
- Effective or organ dose to representative individuals
- Organ dose estimates from epidemiologic or dose reconstruction studies

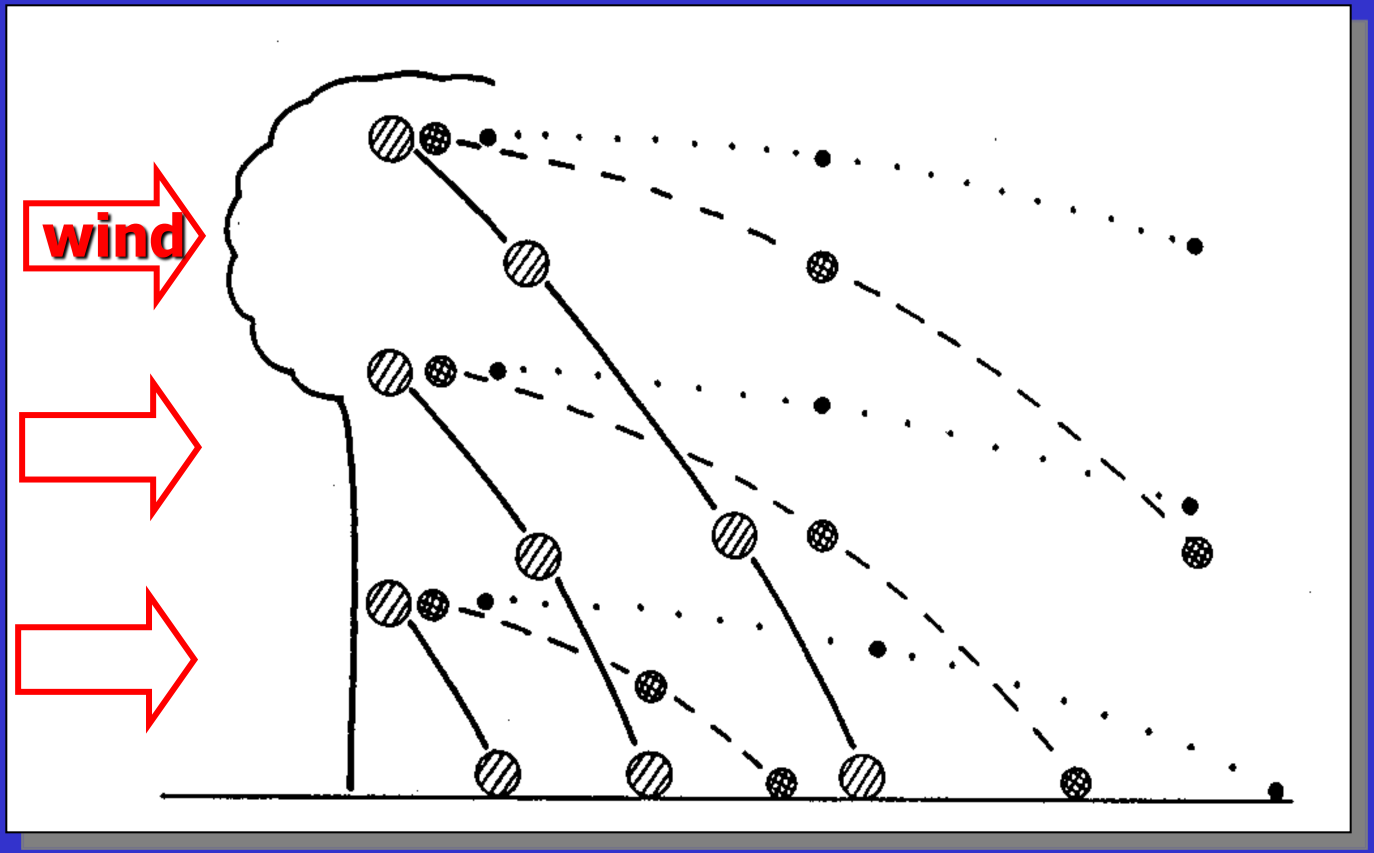
Some influencing parameters

- Radionuclide characteristics (half-life and physico-chemical form)
- Height of release and meteorological conditions
- Time of year (pasture season)
- Location and time after the accident
- Lifestyle and dietary habits of the exposed population; age
- Countermeasures

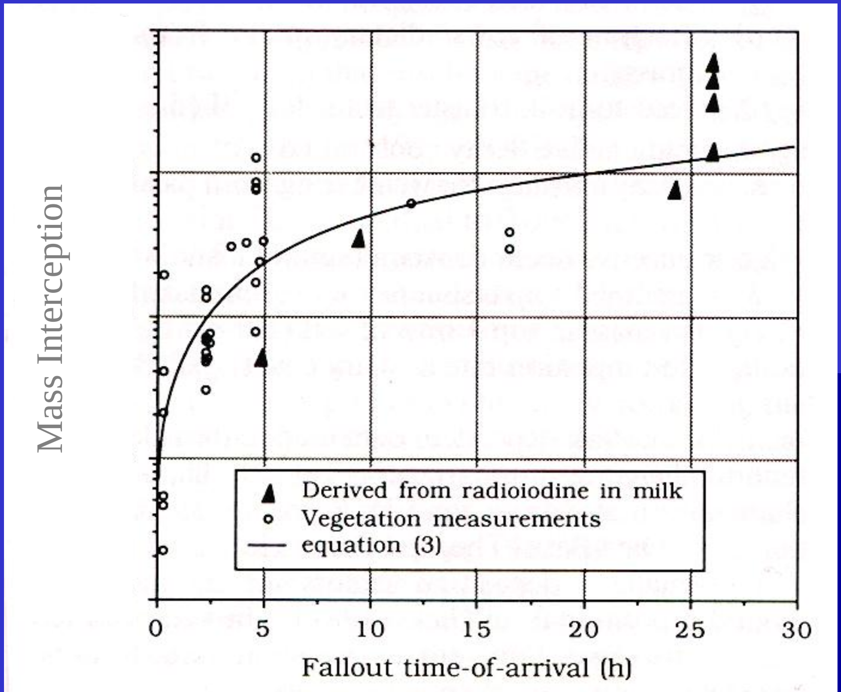
Fallout from nuclear weapons tests: variation of the exposure rate with time



Size of particles deposited decrease with increasing altitude of debris cloud, wind velocity, and distance downwind.

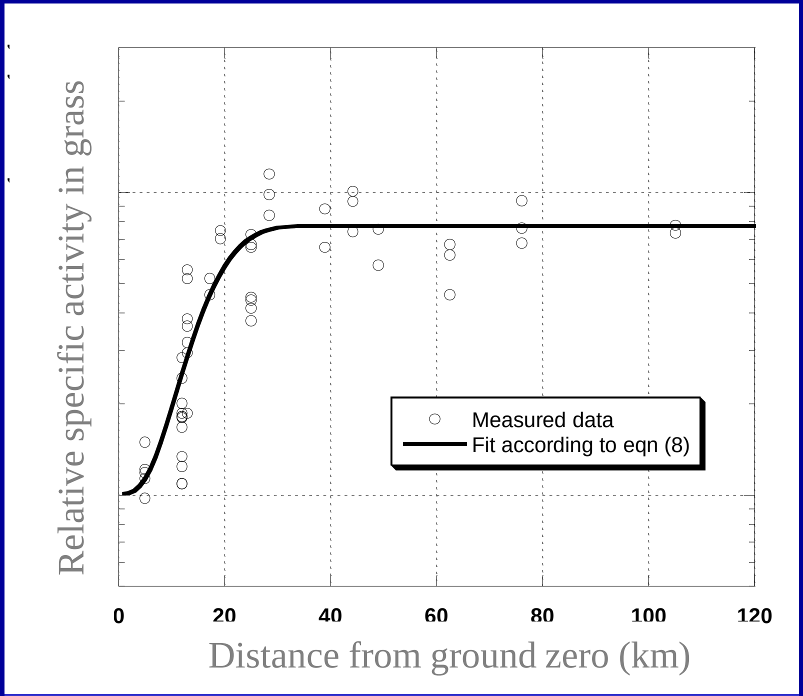


Critical model parameter is <u>fraction of fallout deposition</u> intercepted and retained by vegetation.

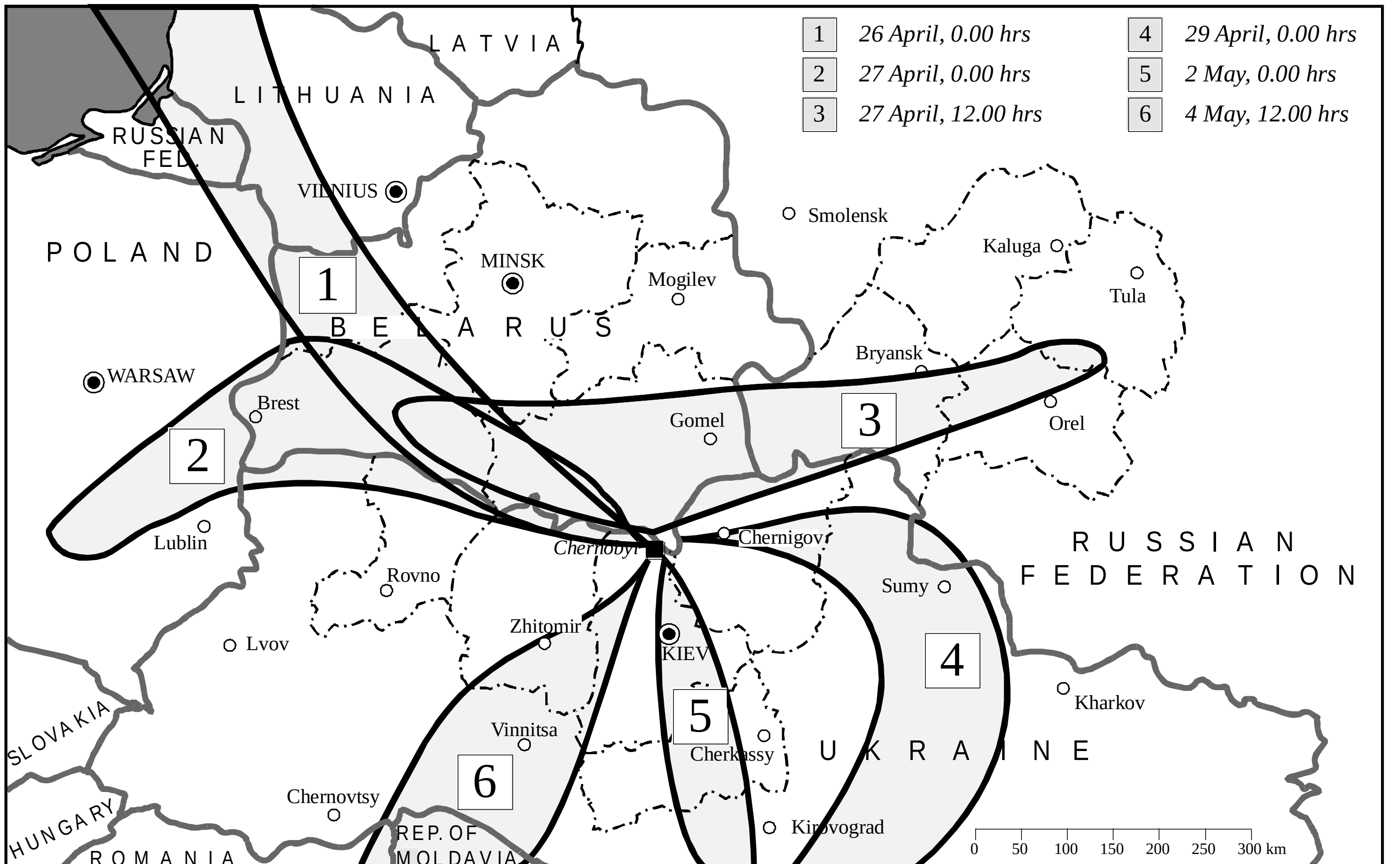


U.S. method ↑

Russian method →

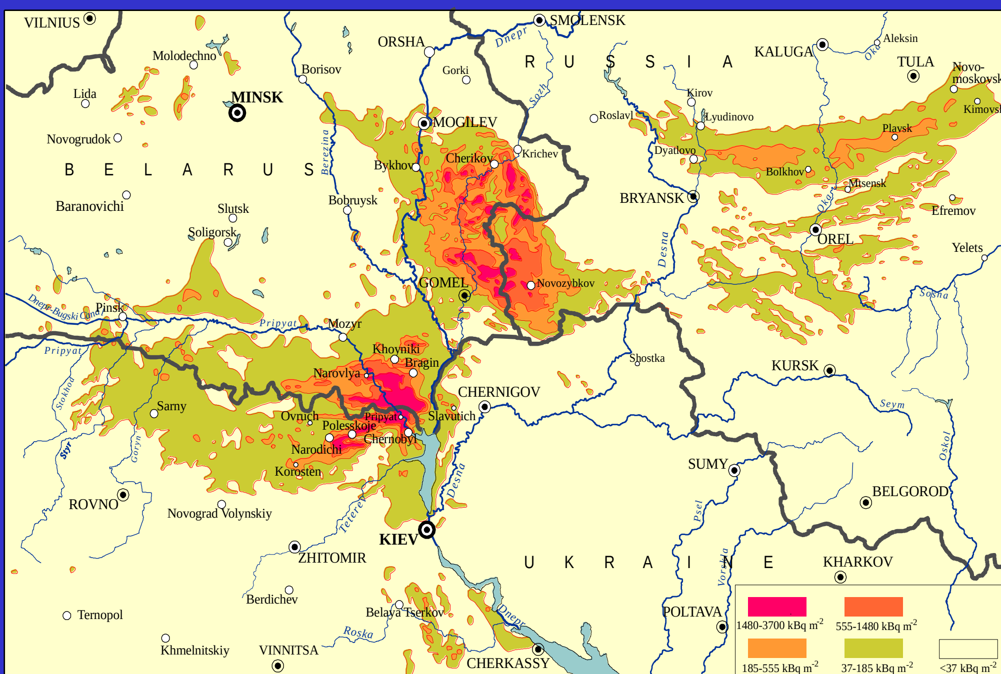


Wind patterns

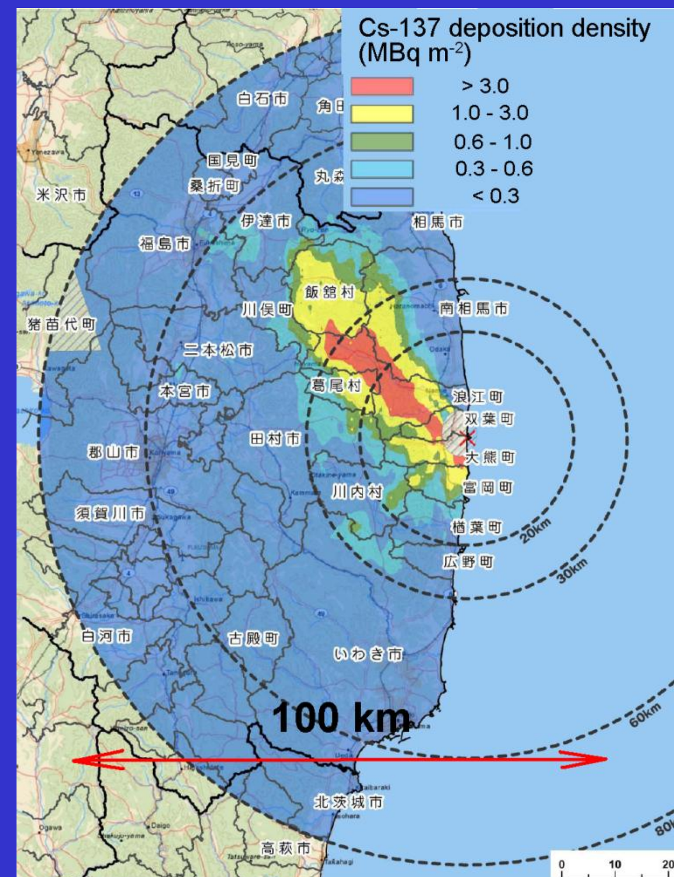


Activities deposited on the ground

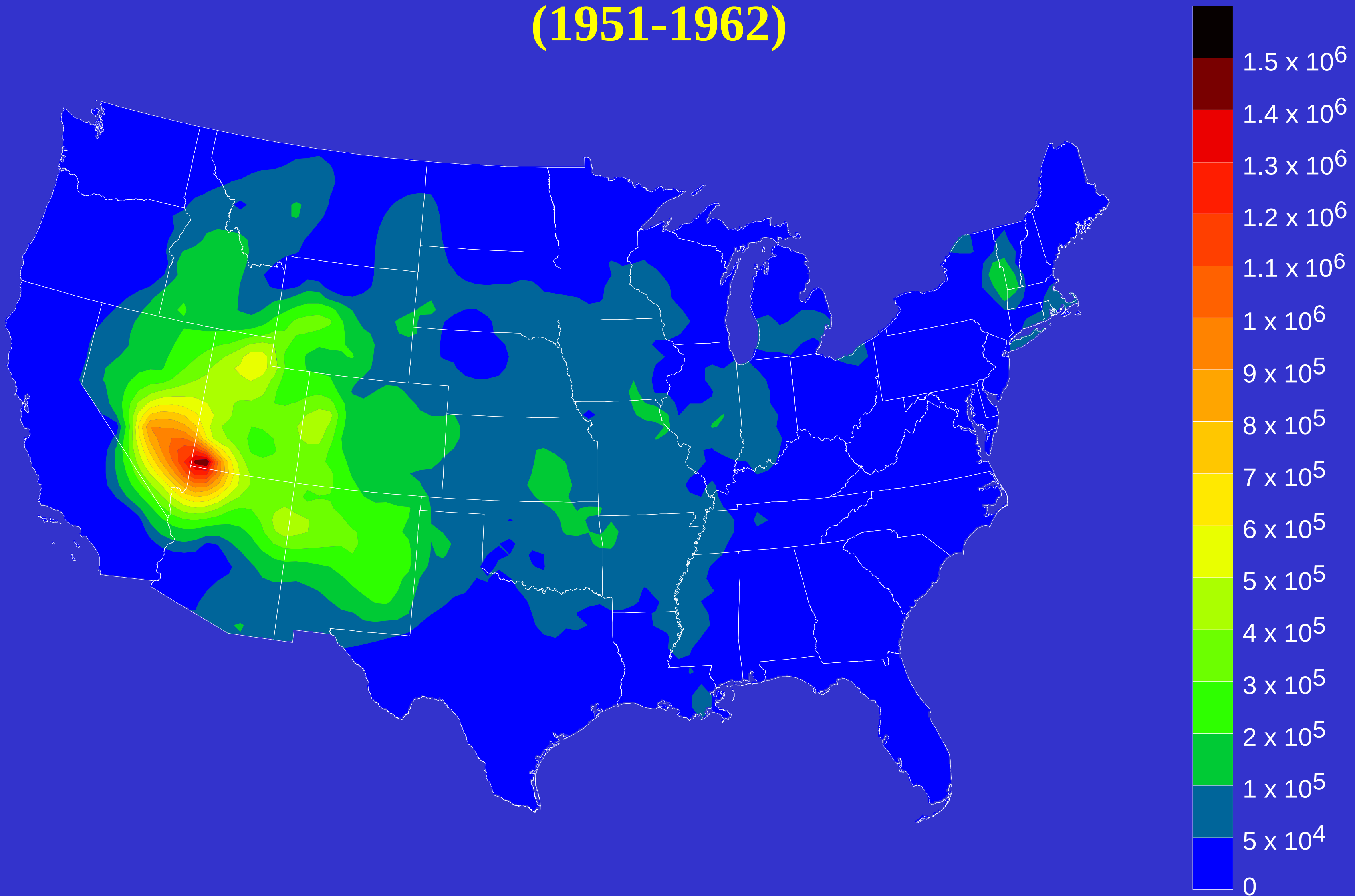
Chernobyl



Fukushima



NCI Estimated I-131 Deposition Density (Bq/m^2) From all NTS Atmospheric Tests (1951-1962)



Dose estimates (mGy) for epidemiologic studies

Event	Epi study	# of subjects	Target organ	Median dose	Mean dose	Max. dose
A bombs	Life span	122,301	Many	1.8	105	>4,000
Hanford	Thy. CA	3,440	Thyroid	97	174	2,800
Mayak (water)	Leukemia	29,730	RBM	210	-	2,000
Nevada	Thy. CA	2,497	Thyroid	55	210	1,400
Kazakhstan	Nodules	2,994	Thyroid	-	349	10,000
RMI	All CA		Thyroid	-	124	9,200
Chernobyl (BY)	Thy. CA	11,732	Thyroid	230	580	33,000
Chernobyl (UA)	Thy. CA	13,204	Thyroid	190	680	42,000

Dose estimates (mGy): other events

Event	Group or individual	Target organ	Mean dose	Max. dose
Mayak (air)	Child born in 1947	Thyroid	2,300	
Kyshtym	1,054 early evacuees	Active marrow	570	
Windscale	Child	Thyroid	6	160
TMI	Critical group	All	2	
Goiania	129 (with internal contamination)	All	240	7,000
Fukushima	Children 0-15 y	Thyroid	2	35

Concluding Remarks (1/2)

- **At the continental and global scales, radiation exposures from medical practices and background account for most of the per caput annual effective dose.**
- **At the local and regional scales, reactor accidents and the development , testing, and use of nuclear weapons have resulted in relatively large doses among population groups.**

Concluding Remarks (2/2)

- Epidemiologic studies related to some of these "events" have been conducted or are in progress to establish or confirm radiation risk estimates.
- It is important to collect and archive all data and reports on these "events" for future reference.

Acknowledgments

Many thanks to

Lynn Anspaugh

Vladimir Drozdovitch

Dunstana Melo

Bruce Napier

Steve Simon

for their help and advice

+ thank you for your attention.