Dosimetry for Epidemiologic Studies of Environmental Exposure

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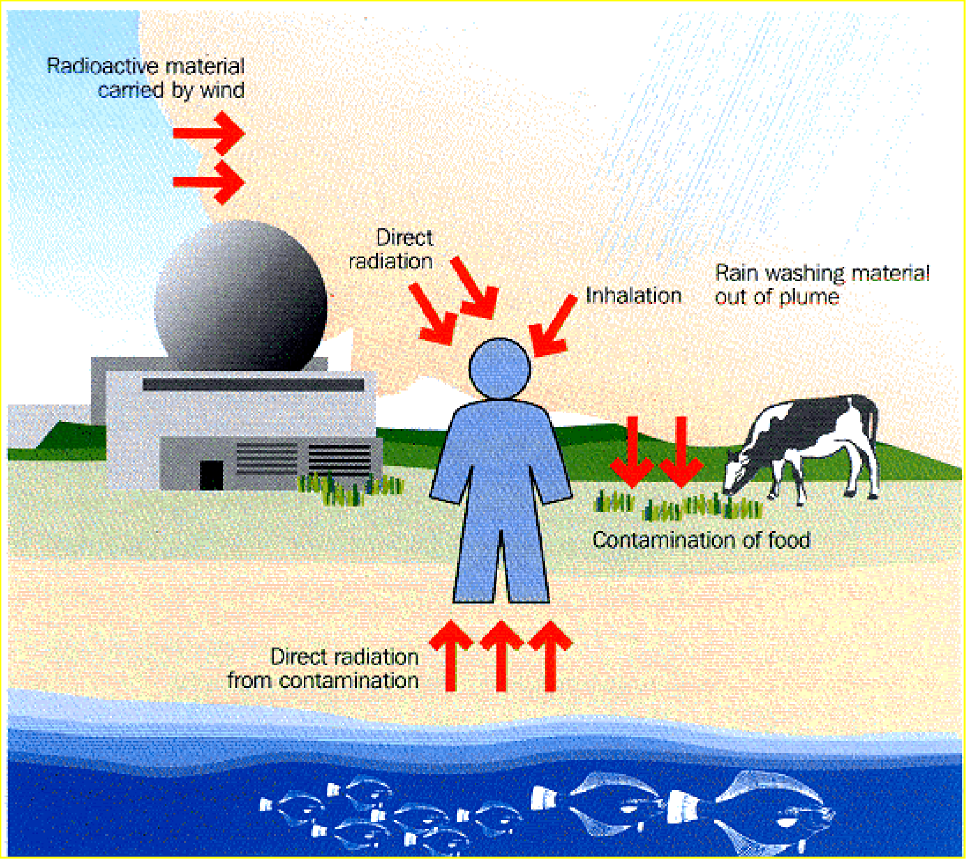
Outline

- Environmental dosimetry
- General scheme of dose calculation and uncertainty assessment
- Sites of environmental exposure
- NCI Chernobyl Studies

Environmental Dosimetry

- Exposures to ionizing radiation resulting from large environmental releases of radioactive materials:
  - Routine releases of radioactivity during early years of operation of plutonium production facilities
  - Atmospheric nuclear weapons tests
  - Reactor accident
- Dose estimates for local populations

Pathways of Environmental Exposure



Pathways of Environmental Exposure (2)

- External irradiation:
  - Direct radiation from the source
  - Radioactive cloud
  - Activities deposited on the ground and other surfaces
- Internal irradiation
  - Inhalation
  - Ingestion with locally produced food

Releases of Radioactivity to the Atmosphere

- Plutonium production facility:
  - Hanford (USA, 1944-1960)
  - Mayak (USSR, 1948-1972)
- Atmospheric nuclear weapons tests:
  - Marshall Islands (USA, 1946-1958)
  - Semipalatinsk (USSR, 1949-1962)
  - Nevada (USA, 1951-1958)
- Reactor accidents:
  - Windscale (UK, 1957)
  - Three-Mile Island (USA, 1979)
  - Chernobyl (USSR, 1986)
  - Fukushima Daiichi (Japan, 2011)

General Scheme of Dose Calculation and Uncertainty Assessment

Assessment of Radiation Doses

- There is no prescribed approach for defining and presenting scenarios of exposure
- Dose depends on a number of factors:
  - Radionuclide composition of the activity released
  - Transport of radionuclides in the environment
  - Time, location, residence data, behavior and dietary pattern of exposed population

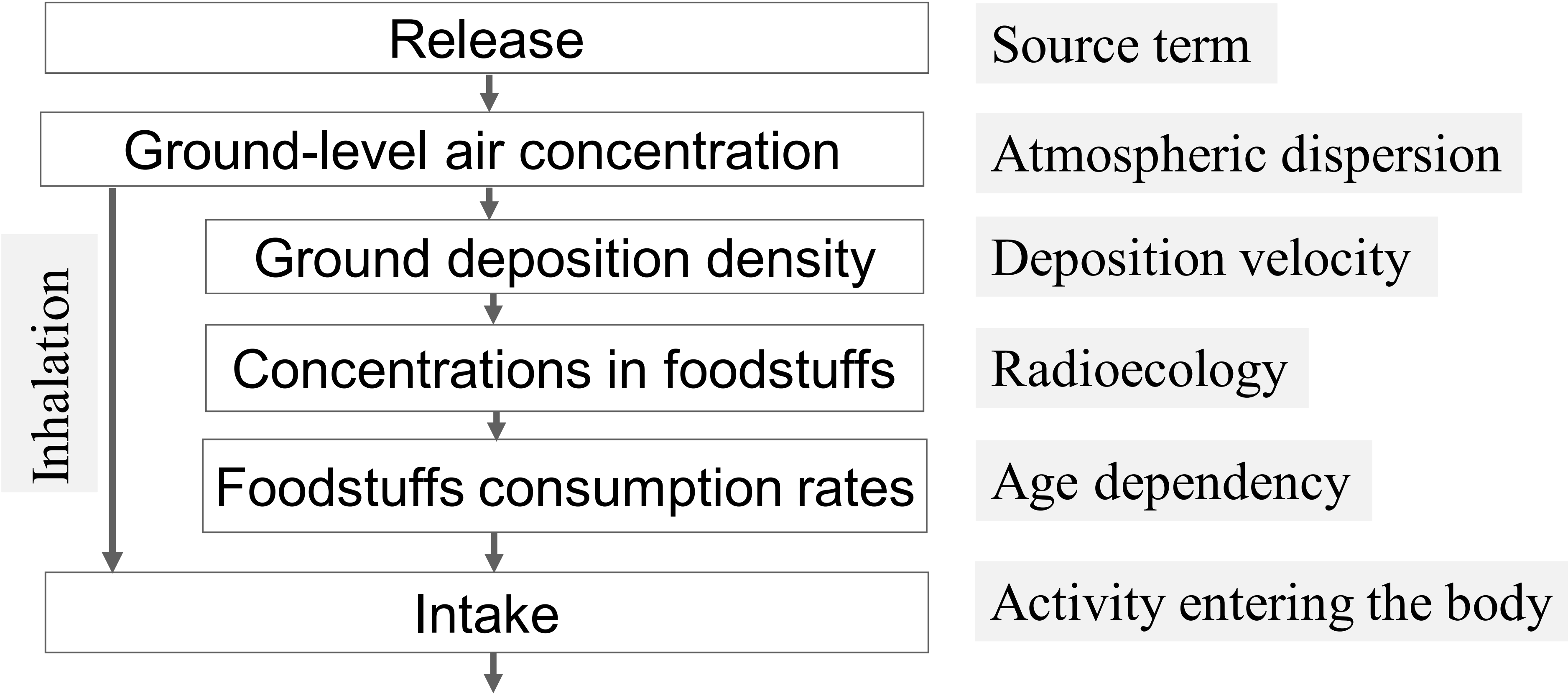
Types of Dose

- For a specified individual:
  - Use of personal interview to collect information on individual whereabouts and consumption history
  - Use of personal dosimeter measurements for external exposure, if available
  - Use of measurements of radioactivity in humans for internal exposure, if available
- For an unspecified individual, representative of a group:
  - Use of generic values

External Exposure

Release	Source term
Ground-level air concentration	Atmospheric dispersion
Ground deposition density	Deposition velocity
Monte Carlo simulation of radiation transport	Use of phantoms
Type of residence and behavior	Age, gender
Dose estimates	W/ or w/o uncertainty

Internal Exposure



Internal Exposure (2)

Activities in blood and in organs

↓

Monte Carlo simulation of radiation transport

↓

Dose estimates

Radionuclide-dependent biokinetic models

Use of phantoms

W/ or w/o uncertainty

Why is it Necessary to Evaluate the Dosimetry Uncertainties?

- They are fairly large: uncertainties give information on the reliability of the point estimate of the dose
- They bias risk estimates
- The uncertainty assessment shows where the accuracy of the dose estimates can be improved
- Reviewers of manuscripts request information on uncertainties

Major Sources of Uncertainties

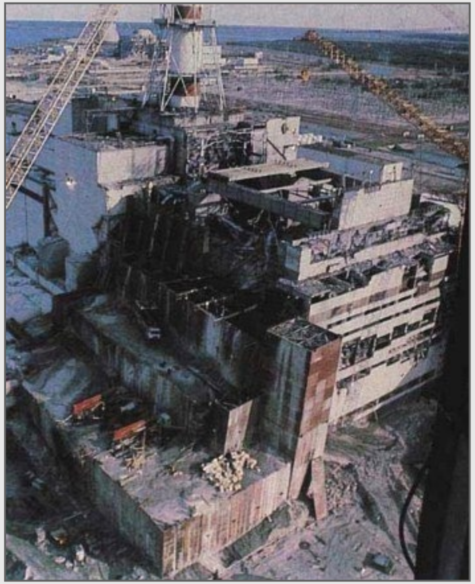
- Stochastic variability of the parameters used in the exposure assessment
- Uncertainty due to lack of knowledge about true values of parameters
- Measurement errors
- Low reliability of questionnaire data on individual behavior during radiation exposures that occurred a long time ago

Steps in Uncertainty Assessment

- Document sources and quality of all input data
- Establish dosimetry errors’ structure
- Assign probability distribution for each model parameter
- Calculate stochastic doses to obtain the overall uncertainty in the dose estimates
- Sensitivity analysis

Stochastic Doses

- Simple 1DMC:
  - Set of individual stochastic doses; no correlation between subjects; no distinction between variability and uncertainty
- Accounting for shared or unshared errors:
  - Solid matrix of individual stochastic doses; inter-individual correlation; account either for variability or uncertainty
- 2DMC:
  - Solid matrix of individual stochastic doses; inter-individual correlation; account both for variability and uncertainty



Sites of environmental exposure

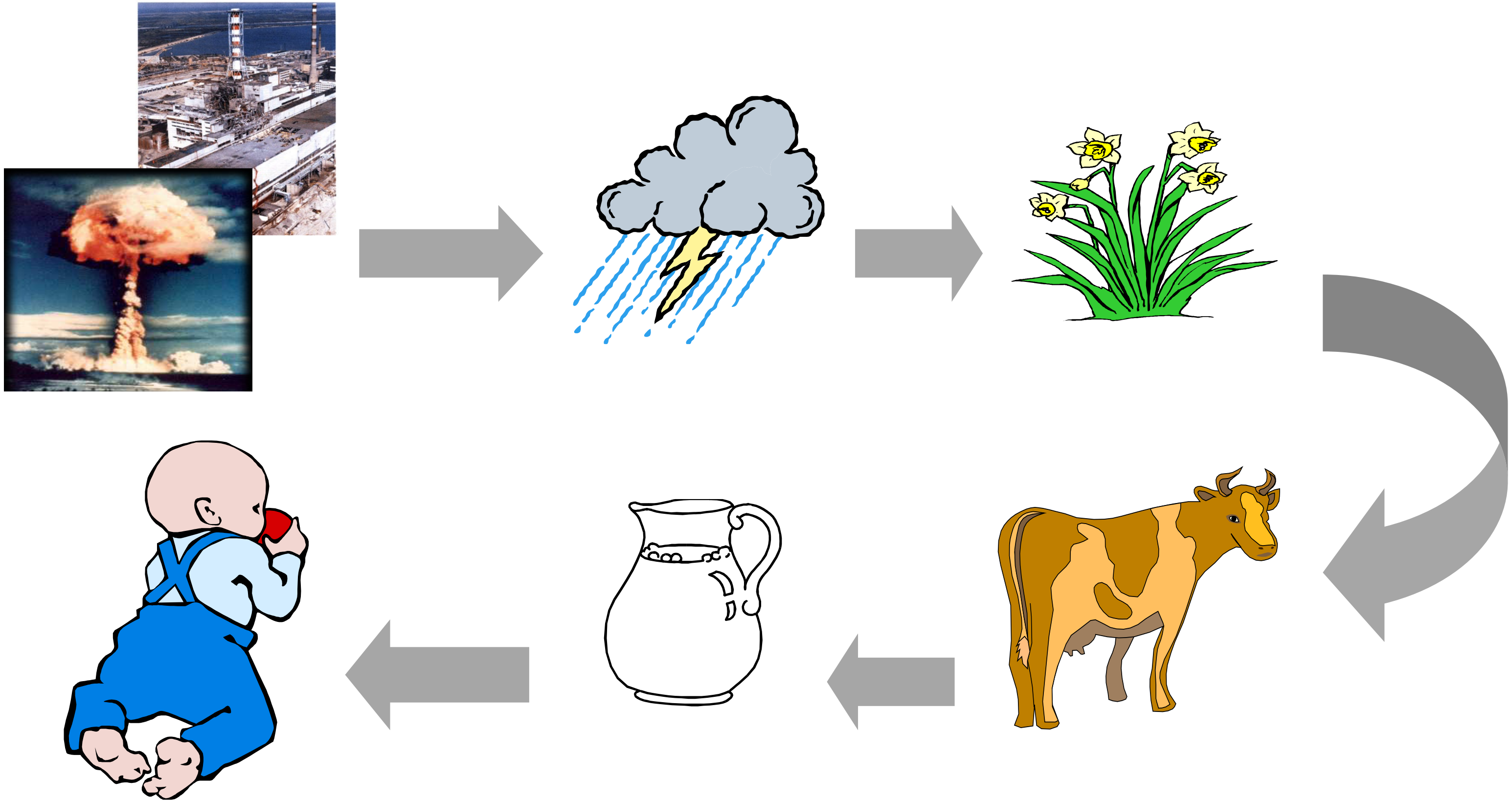
Important Radionuclides

Radionuclide	Half-time	External exposure	Internal exposure
Short-term exposure			
^{131}I	8.02 d	+	+
^{132}Te + ^{132}I	3.204 d	+	+
^{133}I	20.8 h	+	+
^{140}Ba + ^{140}La	12.75 d	+	
^{95}Zr + ^{95}Nb	64.03 d	+	
Long-term exposure			
^{134}Cs[a]	2.06 y	+	+
^{137}Cs	30.17 y	+	+
^{90}Sr	28.9 y		+

Selected Sites of Environmental Exposure

Site	Predominant exposure pathways	Radionuclide (target organ)
Hanford, Mayak	Ingestion (milk)	^{131}I (thyroid)
Weapon tests: - NTS, Kazakhstan - Marshall Islands	 Ingestion (milk) Ingestion	 ^{131}I (thyroid) ^{133}I, ^{131}I, ^{132}Te+^{132}I (thyroid)
Techa River	External, ingestion	^{90}Sr (RBM),^{137}Cs (WB)
Windscale	Ingestion (milk)	^{131}I (thyroid)
Chernobyl	Ingestion (milk)	^{131}I (thyroid)
Fukushima Daiichi	External, inhalation, ingestion	^{131}I (thyroid), ^{137}Cs (WB)

Importance of ^{131}I



Importance of ^{131}I (2)

- Iodine accumulates in the thyroid gland
- As a first approximation, the thyroid dose from ^{131}I is proportional to the consumption of milk and inversely proportional to the thyroid mass
- Because the thyroid mass increases with age, from 1-2 g in infants to about 20 g in adults, the average thyroid dose decreases with increasing age

Major Releases of ^{131}I to the Atmosphere

Time period	Location	^{131}I released (PBq, Bq x 10^{15})
1946-1962	Global atmospheric nuclear weapons tests	650,000
1986	Chernobyl (USSR)	1,800
2011	Fukushima Daiichi (Japan)	160
1940s	Hanford (WA, USA)	15
1950s	Mayak (USSR)	15
1957	Windscale (UK)	0.74
1979	Three Mile Island (PA, USA)	0.0006

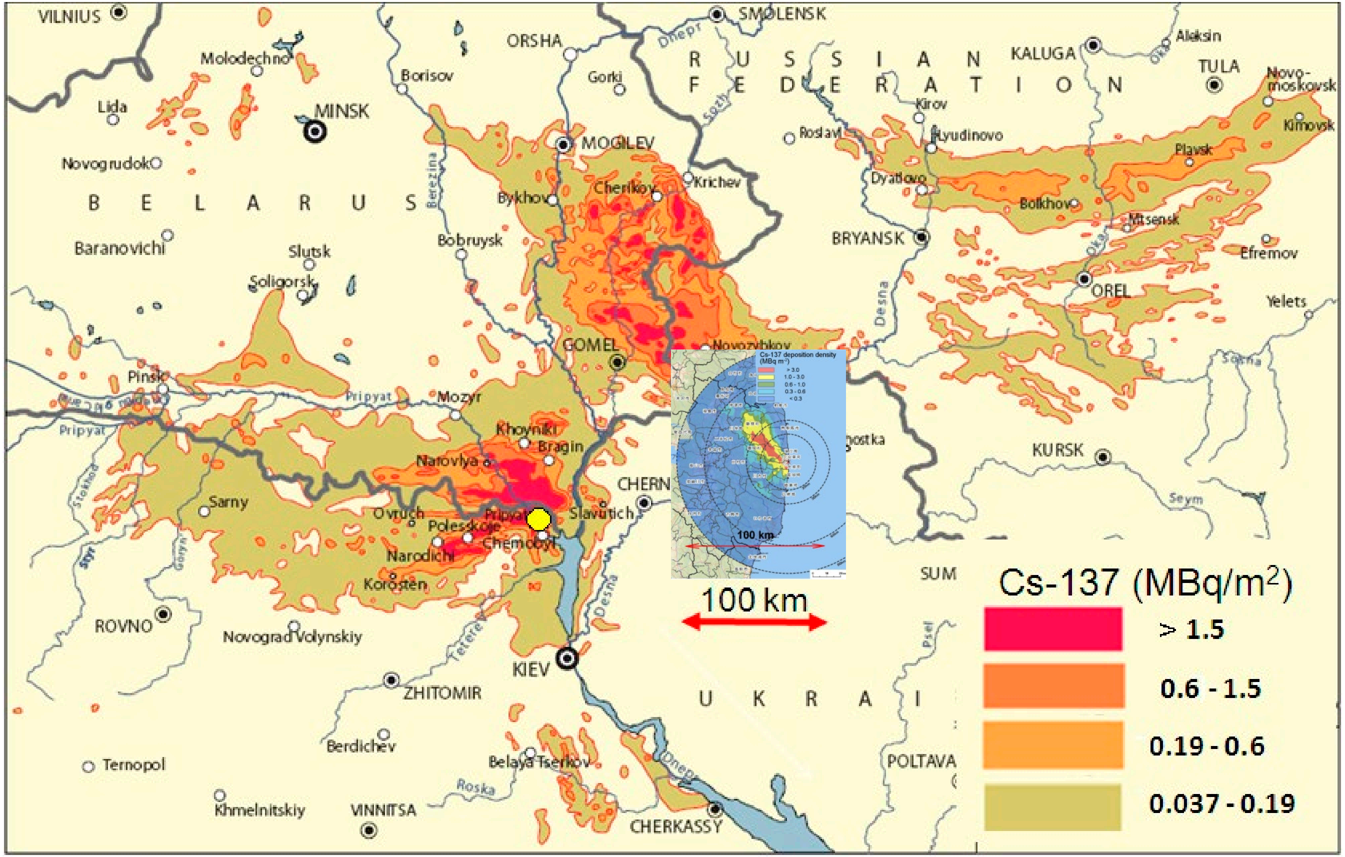
Dose Estimates (mGy)

Site	Target organ	Median dose	Mean dose	Maximal dose
Chernobyl	Thyroid (Belarus)	270	680	39,000
Semipalatinsk NTS	Thyroid (+ external)	-	280	4,200
Hanford	Thyroid	100	170	2,800
NTS (Utah)	Thyroid	55	120	1,400
Windscale	Thyroid	-	2	160
Fukushima Daiichi	Thyroid (Fuk prefecture)	2	3	48

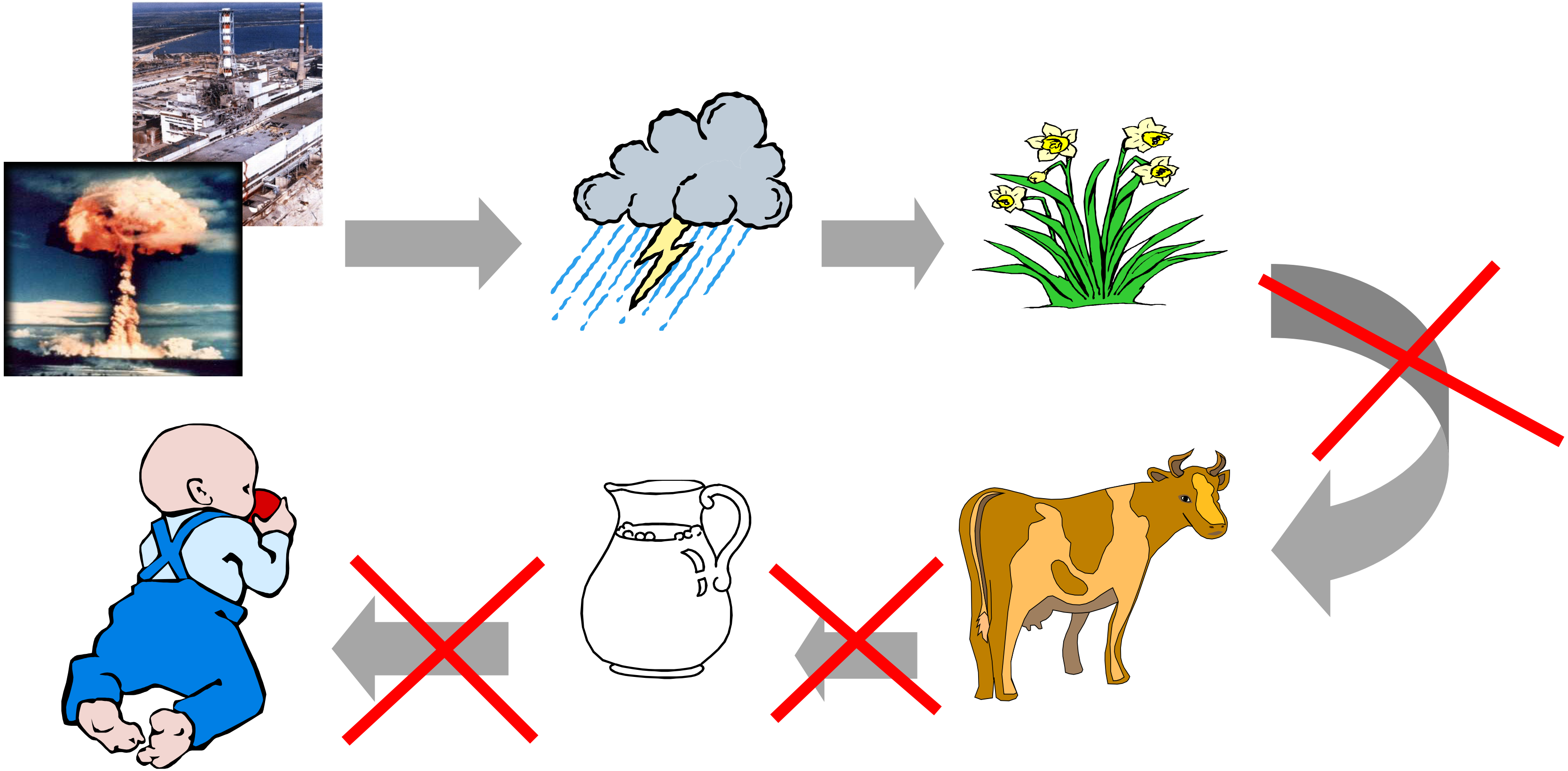
Lower Radiation Doses to Population at Fukushima

- 10-times smaller release and deposition of radionuclides
- Accident occurred during the winter
- Little cow's milk and dairy products consumption in Japan
- Quick countermeasures: evacuation, sheltering, food restriction, monitoring

^{137}Cs Deposition (MBq m^{-2}) at Fukushima and Chernobyl



Fukushima: Reduction of Doses from ^{131}I



NCI Chernobyl Studies

NCI Chernobyl studies

- Cohort studies of thyroid cancer and other thyroid diseases in persons who were exposed in Belarus and Ukraine:
  - in childhood
  - *in utero*
- Case-control studies in Ukrainian cleanup workers of:
  - leukemia and related disorders
  - thyroid cancer
- Parental irradiation in Chernobyl cleanup workers and evacuees and germline mutations in the offspring (Trios)

Thyroid Cohorts Study among exposed in childhood

- Age 0-18 y at the time of the accident
- Resided in most contaminated regions
- Subject to measurements of ^{131}I activity in the thyroid gland (direct thyroid measurements)
- Size: 11,732 in Belarus and 13,204 in Ukraine

Most Important Components of Dosimetry

- Measurements of ^{131}I activity in the thyroid (“direct thyroid measurements”)
- ^{131}I ground deposition in the settlements
- Interviews for all cohort members or their relatives
- Ecological and biokinetic models
- Values of thyroid masses

Direct Thyroid Measurements

Curve derived from models plus data from questionnaire

Thyroid dose is proportional to area under the curve

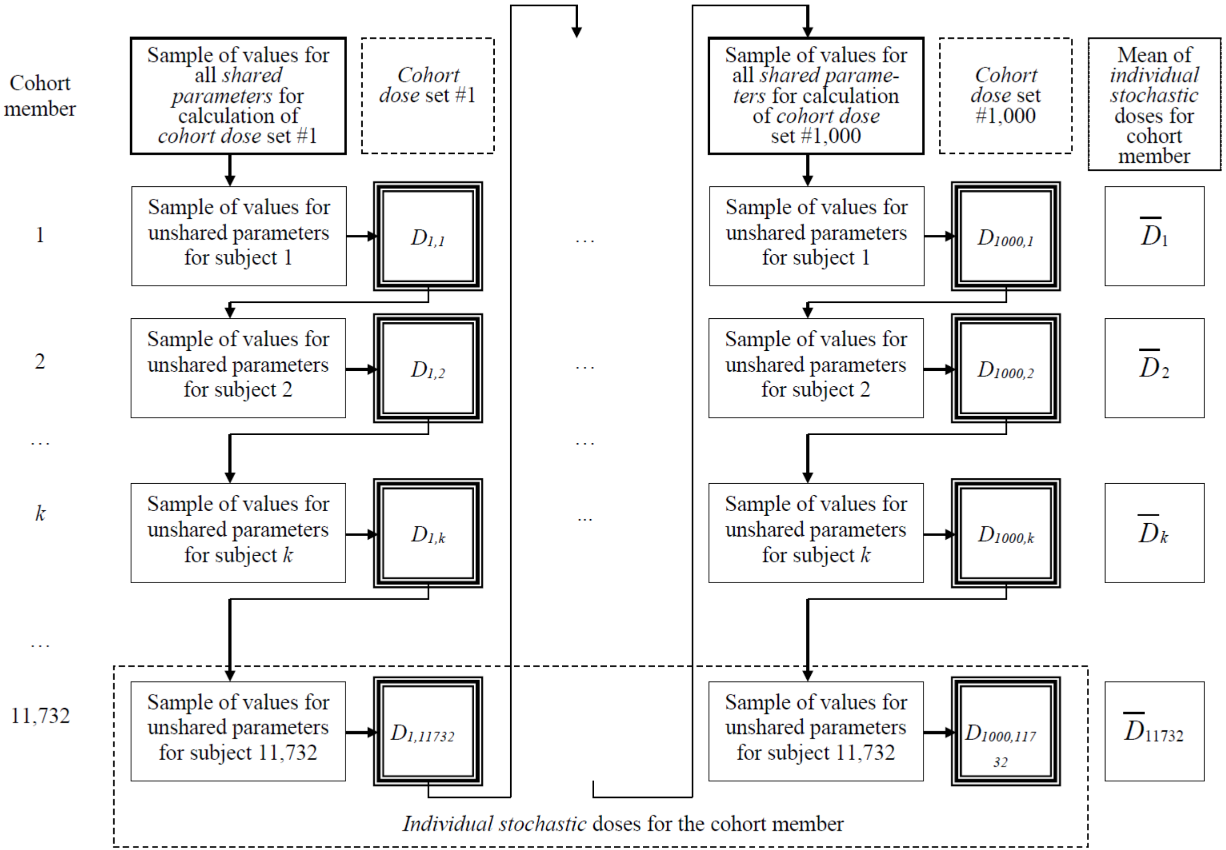
Personal Interview Data

- Face-to-face interview with the cohort member or his/ her mother (if cohort member was < 10 y ATA)
- Residence history during the first two months following the accident
- Consumption rates and origin of milk, milk products, and leafy vegetables
- Stable iodine administration
- Additional interview with women who breastfed their children

Uncertainties

- Shared / Unshared errors
- Different levels of sharing: from entire cohort to small subgroups
- 1,000 sets of cohort thyroid doses:
  - Ecological, i.e. based on ecological model, and
  - Instrumental, i.e. base on direct thyroid measurements

Scheme of calculation of cohort doses



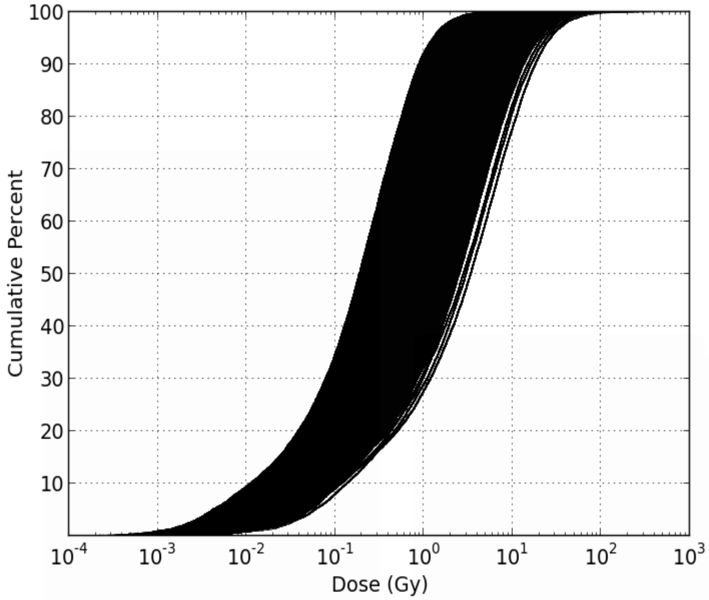
Individual Stochastic Thyroid Doses from ^{131}I Intake (Gy)

Cohort	Mean	Median	Range
Belarus	0.68	0.27	~0 – 39
Ukraine	0.56	0.18	~0 – 39

Uncertainty in Thyroid Doses

GSD range	Belarus		Ukraine	
	N	%	N	%
< 1.5	4,015	34.2	7,982	60.5
1.5 – 1.99	6,477	55.2	4,711	35.7
2 – 2.99	1,015	8.7	294	2.2
≥3	225	1.9	217	1.6
Mean GSD	1.8		1.6	

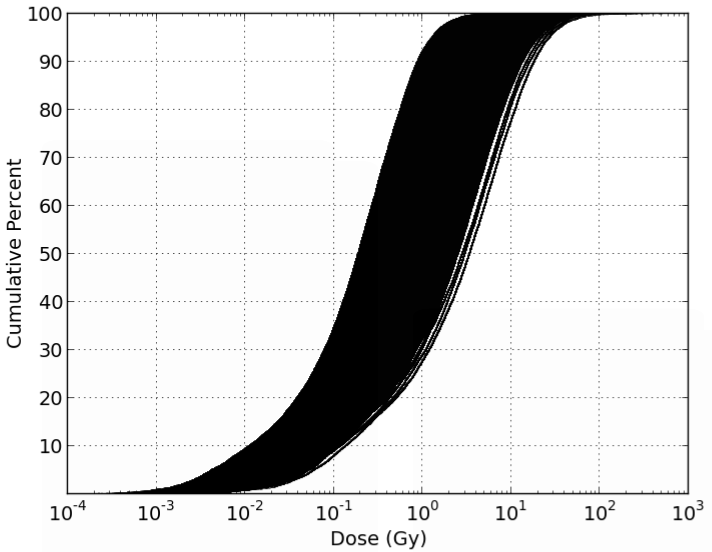
Alternative Dose Vectors (Cohort Dose Realizations)



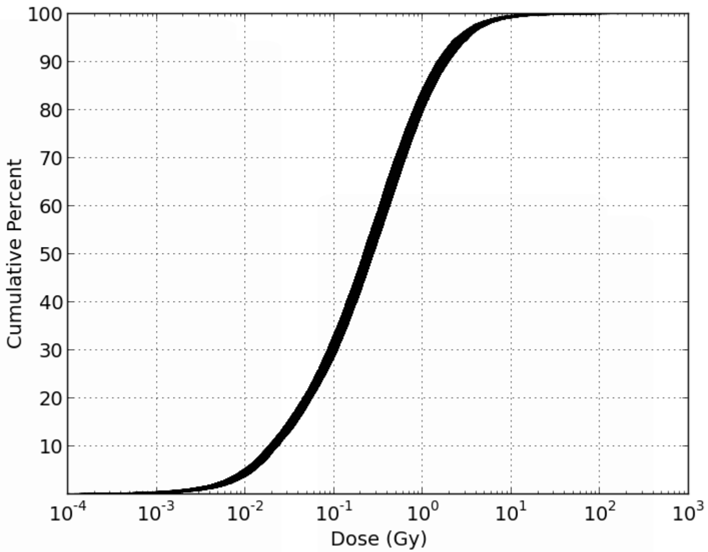
Ecological doses

- Wide distribution indicates that sources of shared errors are important contributors to the uncertainty in <u>ecological</u> doses

Shared / Unshared Errors



Ecological doses



Instrumental doses

- Calibration of the modeled <u>ecological</u> dose has virtually eliminated all sources of shared uncertainty associated with the parameters of the <u>ecological</u> model

Reliability of Questionnaire-Based Doses

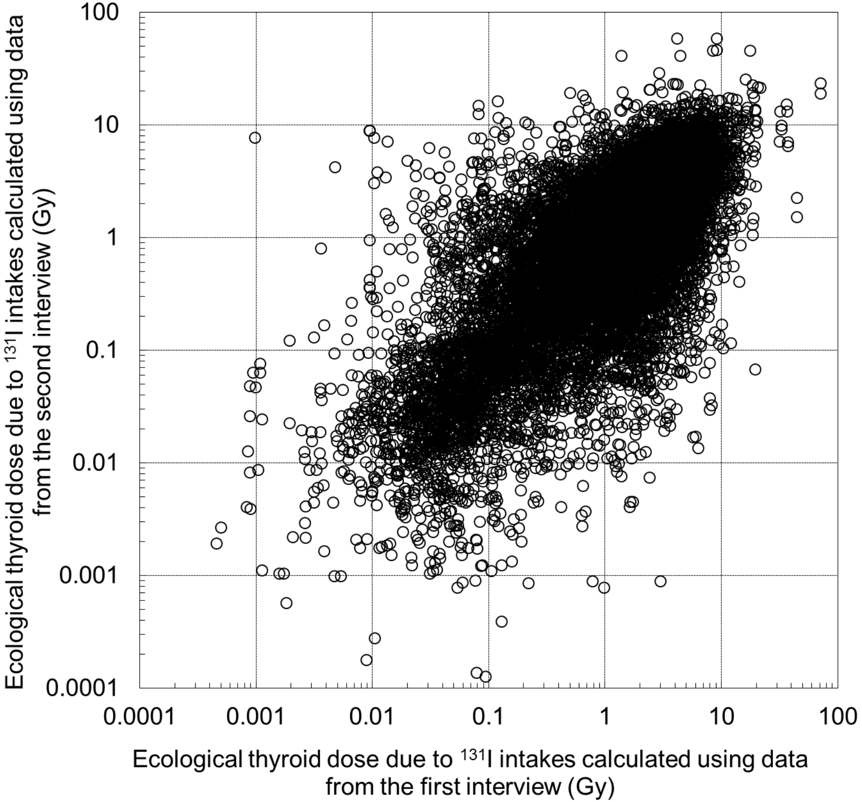
- Ideally: Behavior and dietary data completely and precisely reflect what happened in the distant past
- Reality: Poor memory recall leads to low quality questionnaire data, including missing answers
- Majority of cohort members or his / her relatives were interviewed at least two times
- Opportunity to evaluate consistency in answers and influence on ecological and instrumental doses

Consistency of Questionnaire Data

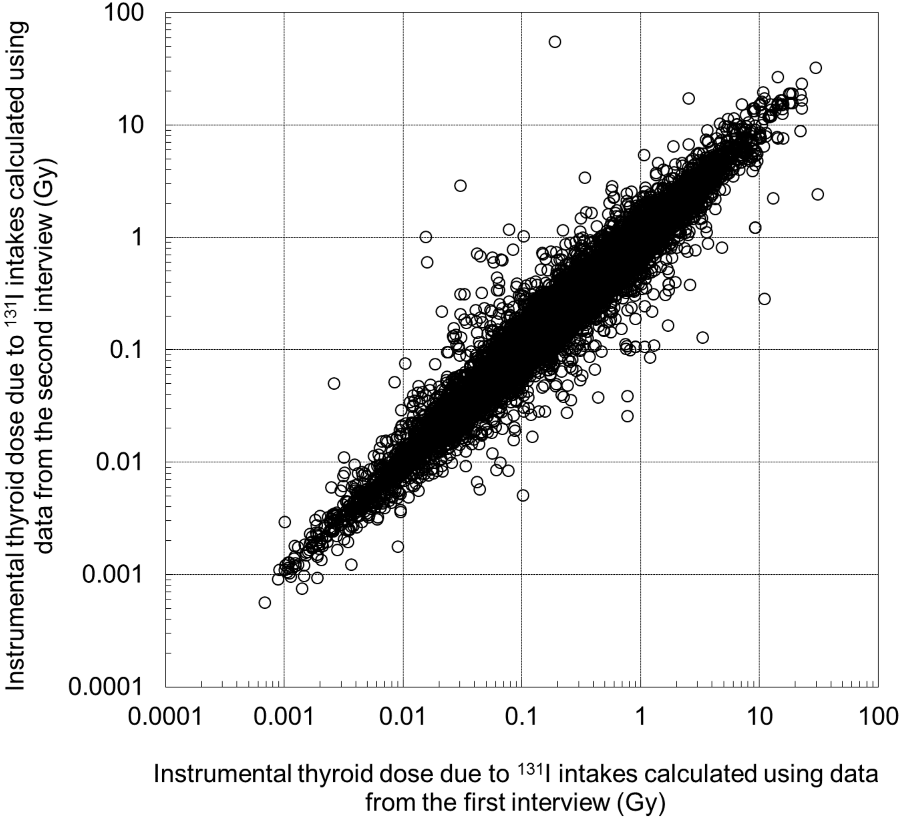
Question	Agreed (%)	k
Date of first relocation	42	0.33
Consumption rate of privately owned cow milk	54	0.33
Consumption rate of milk from trade network	75	0.43
Stable iodine administration (Yes/No)	75	0.49
Date of stable iodine administration	26	0.21

Kappa-statistics: k< 0 – no agreement
k= 0.00-0.20 – slight agreement
0.21-0.40 – fair agreement
0.41-0.60 – moderate agreement
0.61-0.80 – substantial agreement
0.81-1.00 – almost perfect agreement

Reliability of Ecological Doses



Reliability of Instrumental Doses



Reliability of Questionnaire-Based Doses

- Dose-related measurements: The quality of individual behavior and dietary data has, in general, a small influence on the results of the retrospective dose assessment

- No dose-related measurements: High quality individual behavior and dietary data are required to provide realistic and reliable dose estimates

Summary

- At the local and regional scales, reactor accidents and atmospheric nuclear weapons tests have resulted in relatively large doses among population groups
- Scenario of exposure and behavior and dietary pattern of exposed population define approach to estimate radiation doses
- Results of measurements in environment and humans should be used as wide as possible

Summary (2)

- Uncertainties in dose estimates should be evaluated as they are fairly large for environmental exposure
- "Gold standard" behavior and dietary data are required to provide realistic and reliable dose estimates

Quiz 1

- Major release of ^{131}I to the atmosphere occurred after

  A: Chernobyl accident

  B: Fukushima-Daiichi accident

  C: Three-Mile Island accident

  D: None above

Quiz 1

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Quiz 2

- What is the best situation for assessment of individual doses? The following data are available for a person:

  A: Radiation measurement

  B: Individual behavior and dietary data

  C: Both, radiation measurement and individual behavior and dietary data

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