National Cancer Institute

Radiation Epidemiology Course

Nuclear accidents (dose assessment)

Andre Bouville
DCEG / REB

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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
National Institutes of Health

Outline

- List of accidents
- Pathways of exposure
- Importance of ^{131}I
- Dosimetry methods and dose estimates:
  - Chornobyl (thyroid)
  - Kazakhstan
  - Marshall Islands
  - Goiania
  - Chornobyl workers (leukemia)

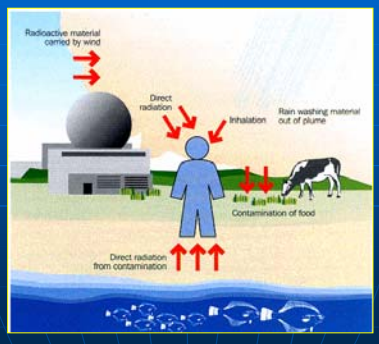
Nuclear "accidents"

- Reactor accidents:
  - Windscale
  - Three-Mile Island
  - Chernobyl (or Chornobyl)
- Nuclear weapons tests:
  - Nevada
  - Semipalatinsk
  - Marshall Islands
  - Japan
- Large environmental releases:
  - Hanford
  - Mayak (air and water)

Other nuclear "accidents"

- Orphan sources:
  - Goiania (^{137}Cs)
  - Taiwan (^{60}Co)
  - London (^{210}Po)
- Transportation:
  - Palomares (Pu)
  - Thule (Pu)
- Potential:
  - Dirty bombs (^{137}Cs?)

Exposure Pathways

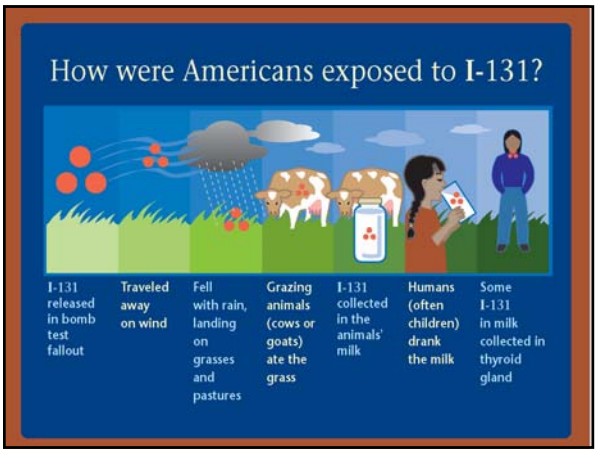


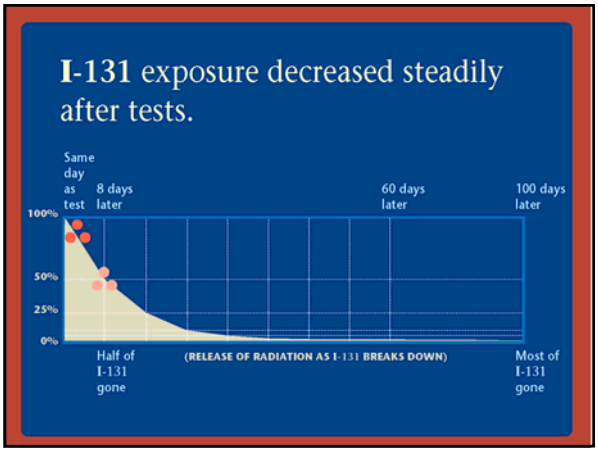
Pathways of exposure

- **External irradiation:**
  - **passage of the cloud;**
  - **ground deposition.**
- **Internal irradiation:**
  - **inhalation;**
  - **ingestion.**

Major environmental releases of ^{131}I, PBq

Hanford (1940s)	15
Mayak (1950s)	15
Global tests (1960s)	650 000
NTS tests (1950s)	5 500
Windscale (1957)	1
TMI (1979)	0.001
Chernobyl (1986)	1 800
Reactors worldwide	0.04





Modes of intake of ^{131}I

- Consumption of fresh cow's milk.
- Consumption of leafy vegetables.
- Inhalation.

Variation of the thyroid dose from ^{131}I as a function of age

- 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.

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

Internal irradiation: from release to intake

Release	Source term
Ground-level air concentration	Atmospheric dispersion
Ground deposition density	Deposition velocity
Concentrations in foodstuffs	Radioecology
Foodstuffs consumption rates	Age dependency
Intake	Activity entering the body

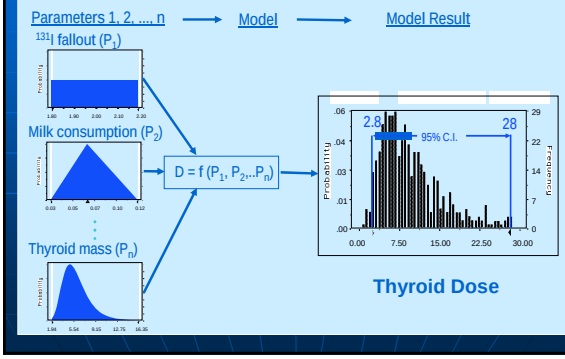
Internal irradiation: from intake to dose

Intake	Lung or gut
Activity in blood	HRT or HAT model
Activities in organs	Biokinetic models
Radiation transport	Radionuclide dependent
Dose rate	Use of phantoms
Dose estimate	W/ or w/o uncertainty

Types of dose

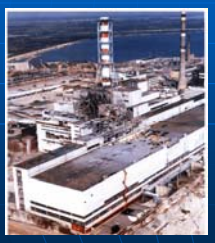
- **For a specified individual (use of personal interview).**
- **For an unspecified individual, representative of a group (use of generic values).**

Estimating Uncertainty for an Individual

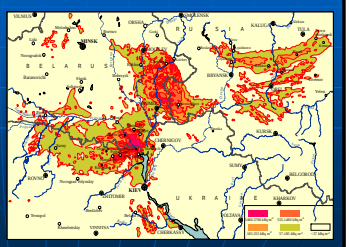


Chornobyl Accident – 1986

Reactor site



^{137}Cs fallout



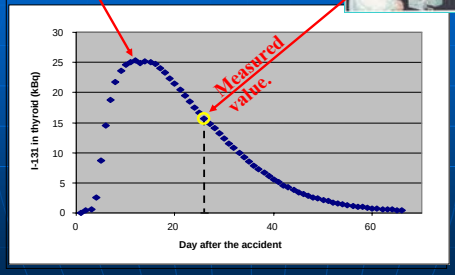
Chornobyl thyroid study

- About 25,000 individuals exposed as children: 12,000 in Belarus and 13,000 in Ukraine.
- Lived in contaminated areas and underwent thyroid activity measurements.
- Exposed mainly to internal irradiation: consumption of fresh milk contaminated with ^{131}I.

Chornobyl: crude estimates of thyroid and whole-body doses (mGy)

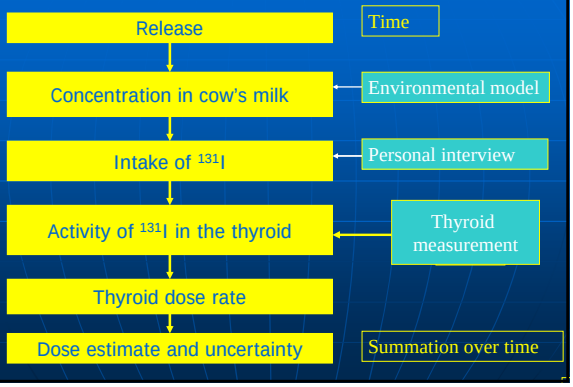
Source	Thyroid	Whole-body
^{131}I	590 (70 – 3000)	1
^{133}I + ^{132}Te	20	0.1
Other (internal)	4	4
External exposure	8	8
All	620	13

Curve derived from ^{131}I models plus data from questionnaire.



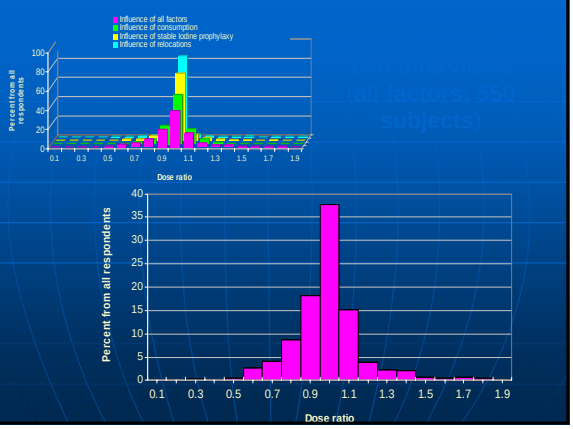
Thyroid dose is pro-portional to area beneath curve.

Doses from ^{131}I (Chernobyl; cohort study)



Personal data

- **Residence history during the first two months following the accident.**
- **Origin of milk, milk products, and leafy vegetables that were consumed.**
- **Consumption rates of milk, milk products, and leafy vegetables.**
- **Iodine prophylaxis (if conducted).**



Countermeasures

- Evacuation.
- Distribution of stable iodine for thyroid blockade.
- Relocation.
- Ban on milk consumption.
- Distribution of uncontaminated foodstuffs.

Effect of countermeasures on the I-131 thyroid doses (mGy)

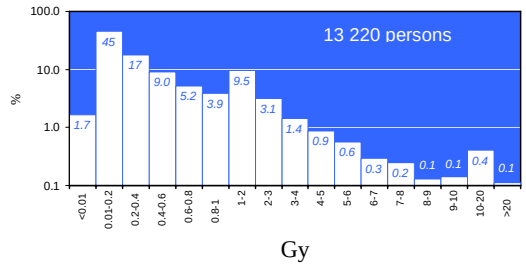
KI pills	Mainly indoors	Often outdoors
Yes	45 (40)	115 (9)
No	96 (7)	301 (15)

Thyroid dose estimates (medians; Gy)

Dose (Gy)	Belarus Number	Belarus %	Ukraine Number	Ukraine %
0 – 0.3	5,039	43	7,589	57
0.3 – 1	3,438	29	3,404	26
>1	3,273	28	2,227	17
Total	11,750	100	13,220	100

Likhtarev et al., Radiat. Prot. Dosim. 105: 593-599 (2003)

Distribution of cohort subjects in Ukraine according to individual thyroid dose

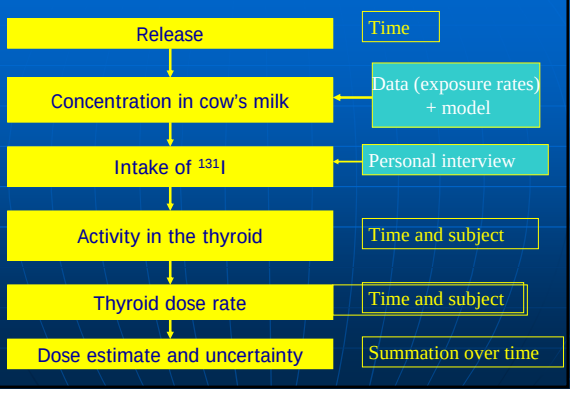


Fallout from atmospheric nuclear weapons testing in Kazakhstan

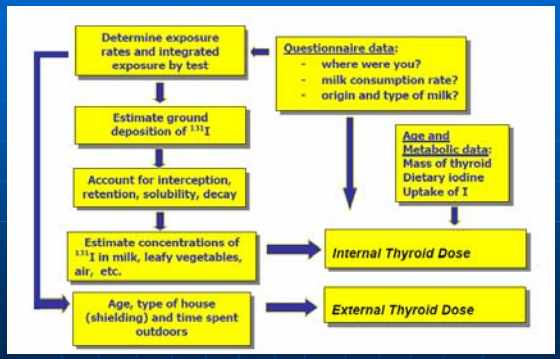
- More than 100 atmospheric nuclear weapons tests conducted between 1949 and 1963.
- Cohort study of about 3,000 residents.
- Estimation of individual thyroid doses.

Map, fallout tracks, villages

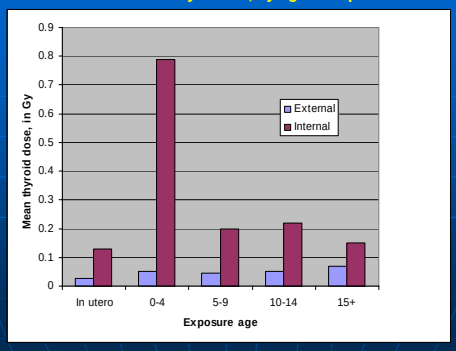
Doses from ^{131}I (Kazakhstan)



Estimation of thyroid doses (Kazakhstan)



Mean estimated external and internal thyroid dose (Gy) in Kazakhstan study cohort, by age at exposure



Fallout from nuclear weapons testing in the Marshall Islands (BRAVO)

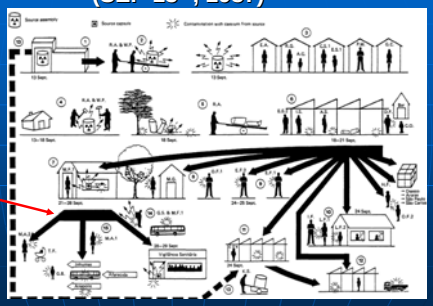
Marshall Islands: lifestyle and dietary habits

Marshall Islands: age-weighted doses (Gy)

	North: high	North: medium	North: low	South: low	South: very low
Bone marrow	2.7	0.32	0.13	0.015	0.0043
Thyroid	88	13	2.9	0.27	0.075
Stomach	12	1	0.21	0.019	0.01
Colon	79	8.9	1.2	0.11	0.022

DESCRIPTION OF THE GOIANIA INCIDENT

(SEP 13th, 1987)



FIRST SCREENING OF THE POPULATION

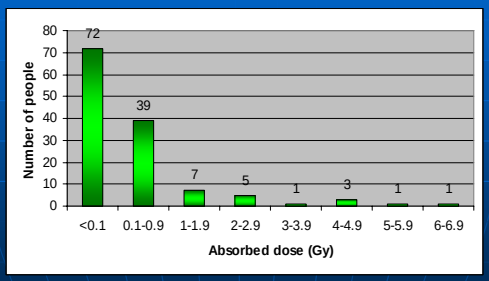
- 112,000 monitored persons:
  - 249 contaminated people:
    - 120 people had their clothes and shoes contaminated;
    - 129 people had external and internal contamination.

INDIVIDUAL MONITORING

- Cytogenetic Dosimetry:
  - Chromosome aberration analysis.
- Internal Dosimetry:
  - Excreta analysis (urine and feces);
  - Whole body measurements (after the first 2 months).

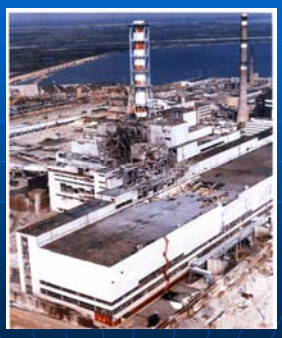
DOSE DISTRIBUTION

PATIENTS AND THEIR FAMILIES: 129 PEOPLE



Chornobyl Accident – 26 April 1986

The most severe accident that ever occurred in the nuclear power industry.



Clean-up workers (Ukrainian cohort)

- About 100,000 workers (1986-1990).
- Exposed mainly to external irradiation.
- Assigned to a variety of tasks.
- Were sent by various military and civilian organizations.

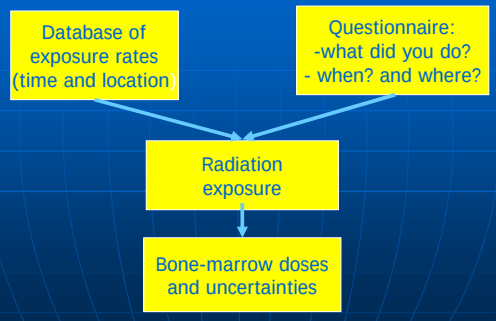
Information on recorded doses in the Registry

Dose (mGy)	1986	1987	1988-1990
<150	3,488	12,068	12,376
150-550	12,949	2,853	99
>550	115	23	13
# with doses	16,552	14,944	12,488
Total #	61,105	21,640	16,886
% missing	72	31	26

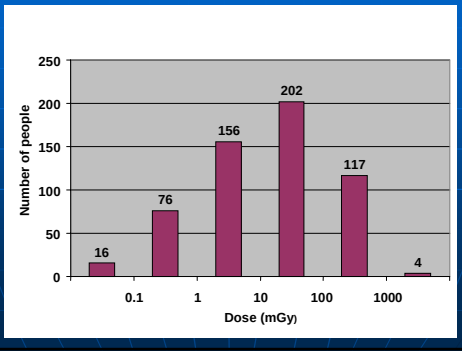
Strategy of bone-marrow dose reconstruction

- Time-and-motion analysis (RADRUE)
- Electron paramagnetic resonance (EPR)
- Fluorescence in-situ hybridization (FISH)
- Official dose records (ODR)

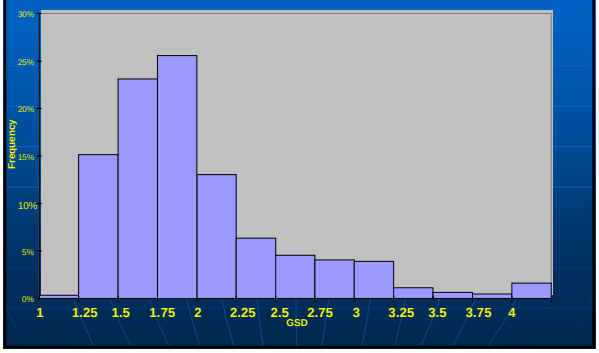
Time-and-motion analysis (RADRUE)



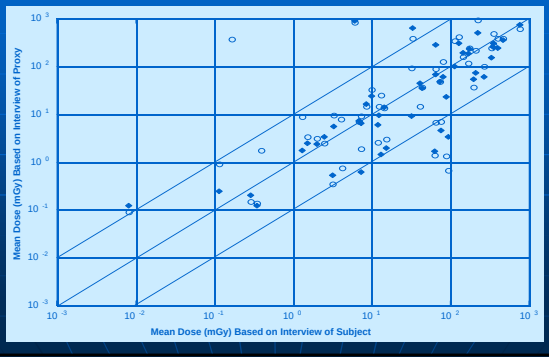
Distribution of the average bone-marrow doses for the 571 study subjects

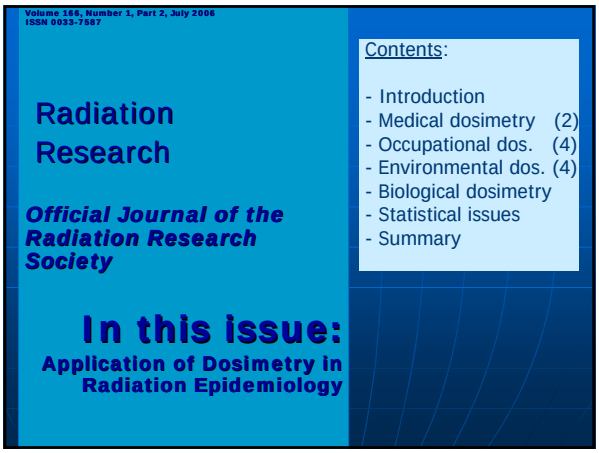


Distribution of uncertainties (GSDs)



Results of proxy vs. subject comparison

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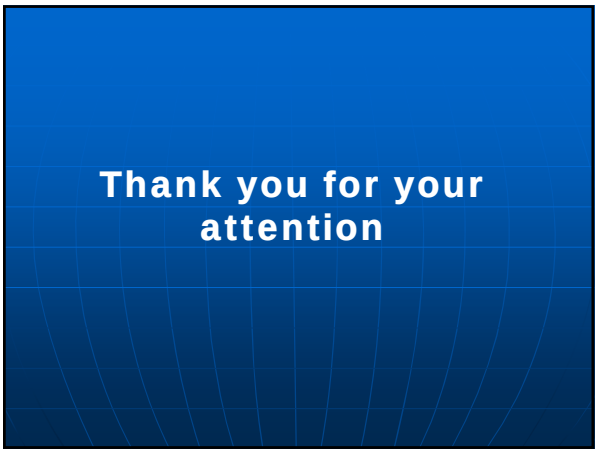
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