Dosimetry during the Chornobyl Accident

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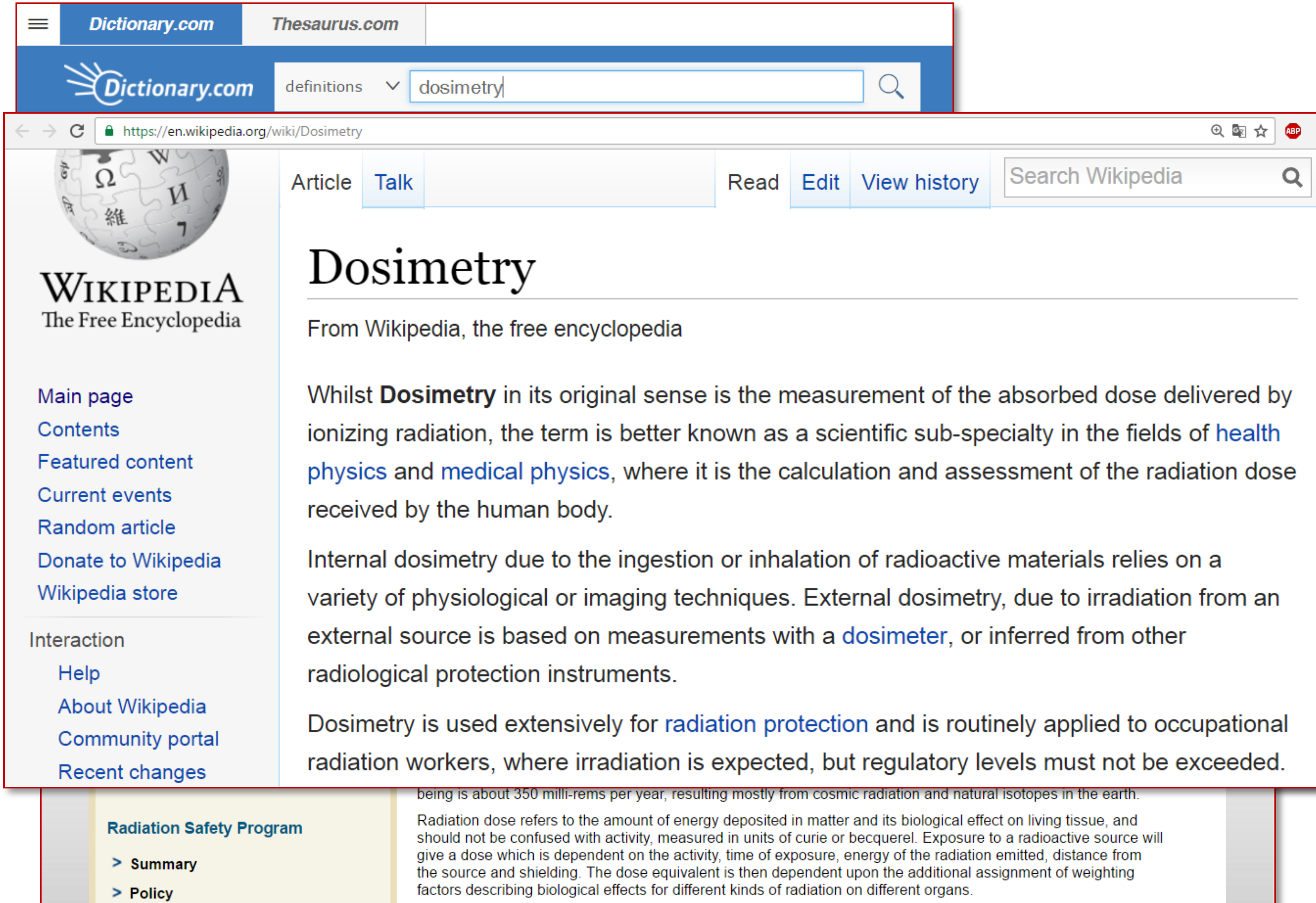
First – definitions

what is this talk about…

Dosimetry



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Dosimetry
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Whilst Dosimetry in its original sense is the measurement of the absorbed dose delivered by ionizing radiation, the term is better known as a scientific sub-specialty in the fields of health physics and medical physics, where it is the calculation and assessment of the radiation dose received by the human body.
Internal dosimetry due to the ingestion or inhalation of radioactive materials relies on a variety of physiological or imaging techniques. External dosimetry, due to irradiation from an external source is based on measurements with a dosimeter, or inferred from other radiological protection instruments.
Dosimetry is used extensively for radiation protection and is routinely applied to occupational radiation workers, where irradiation is expected, but regulatory levels must not be exceeded.
being is about 350 milli-rems per year, resulting mostly from cosmic radiation and natural isotopes in the earth.
Radiation Safety Program
> Summary
> Policy
Radiation dose refers to the amount of energy deposited in matter and its biological effect on living tissue, and should not be confused with activity, measured in units of curie or becquerel. Exposure to a radioactive source will give a dose which is dependent on the activity, time of exposure, energy of the radiation emitted, distance from the source and shielding. The dose equivalent is then dependent upon the additional assignment of weighting factors describing biological effects for different kinds of radiation on different organs.

In the context of this talk term ‘dosimetry’ means:

Measurements conducted at the time of the accident and used for assessment of individual doses of persons exposed due to Chornobyl accident

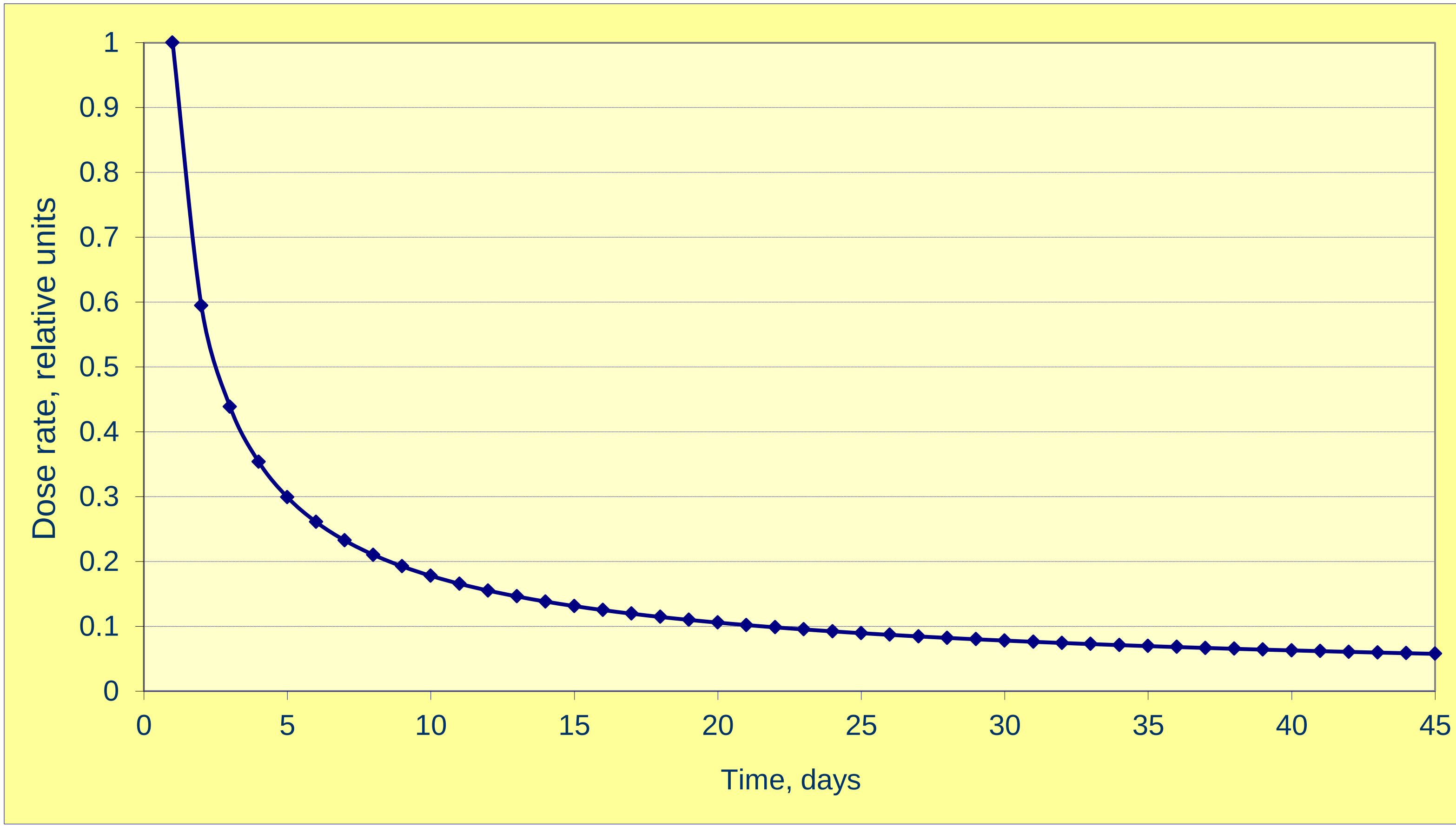
Affected populations in Chernobyl: some numbers

- 2 persons died in course of the accident
- 28 died within four months after the accident due to radiation injures (doses up to 16 Gy)
- 134 had Acute Radiation Syndrome (dose >0.8 Gy)
- 600 workers exposed within the first day
- 115,000 evacuated in 1986
- Some 440,000 worked in 1986-1987
- 600,000 official liquidators in 1986-1990 (about 300,000 – Ukrainians)
- 6,400,000 residents of contaminated (above 37kBq m^{-2} by ^{137}Cs) areas in Ukraine, Belarus and Russia

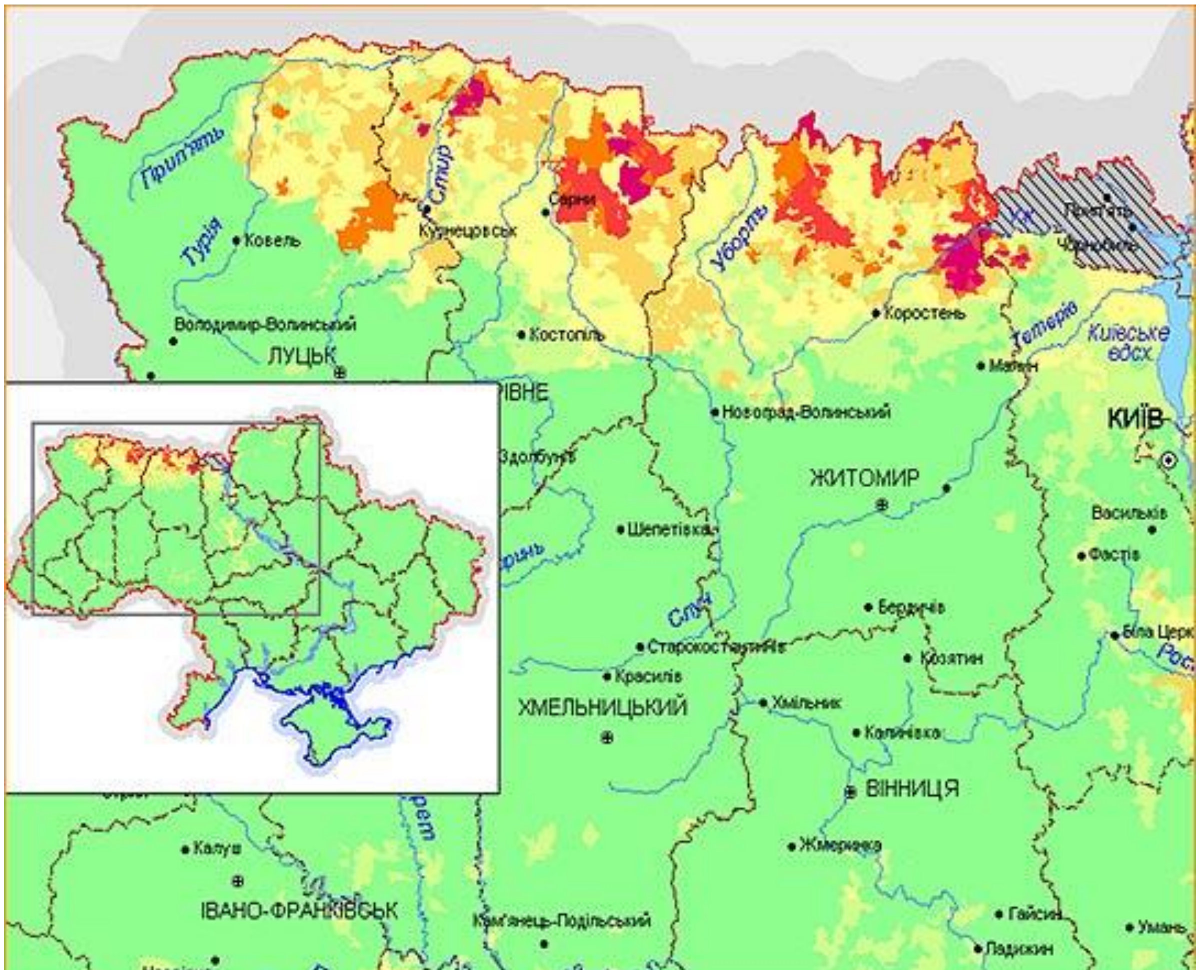
Radioactive mix in the release

- Noble (inert) gases – ^{85}Kr, ^{133}Xe
- Volatile elements – ^{129m}Te, ^{132}Te, ^{131}I, ^{133}I, ^{134}Cs, ^{136}Cs, ^{137}Cs
- Elements with intermediate volatility - ^{89}Sr, ^{90}Sr, ^{103}Ru, ^{106}Ru, ^{140}Ba
- Refractory elements (including fuel particles) - ^{95}Zr, ^{99}Mo, ^{141}Ce, ^{144}Ce, ^{239}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{242}Cm

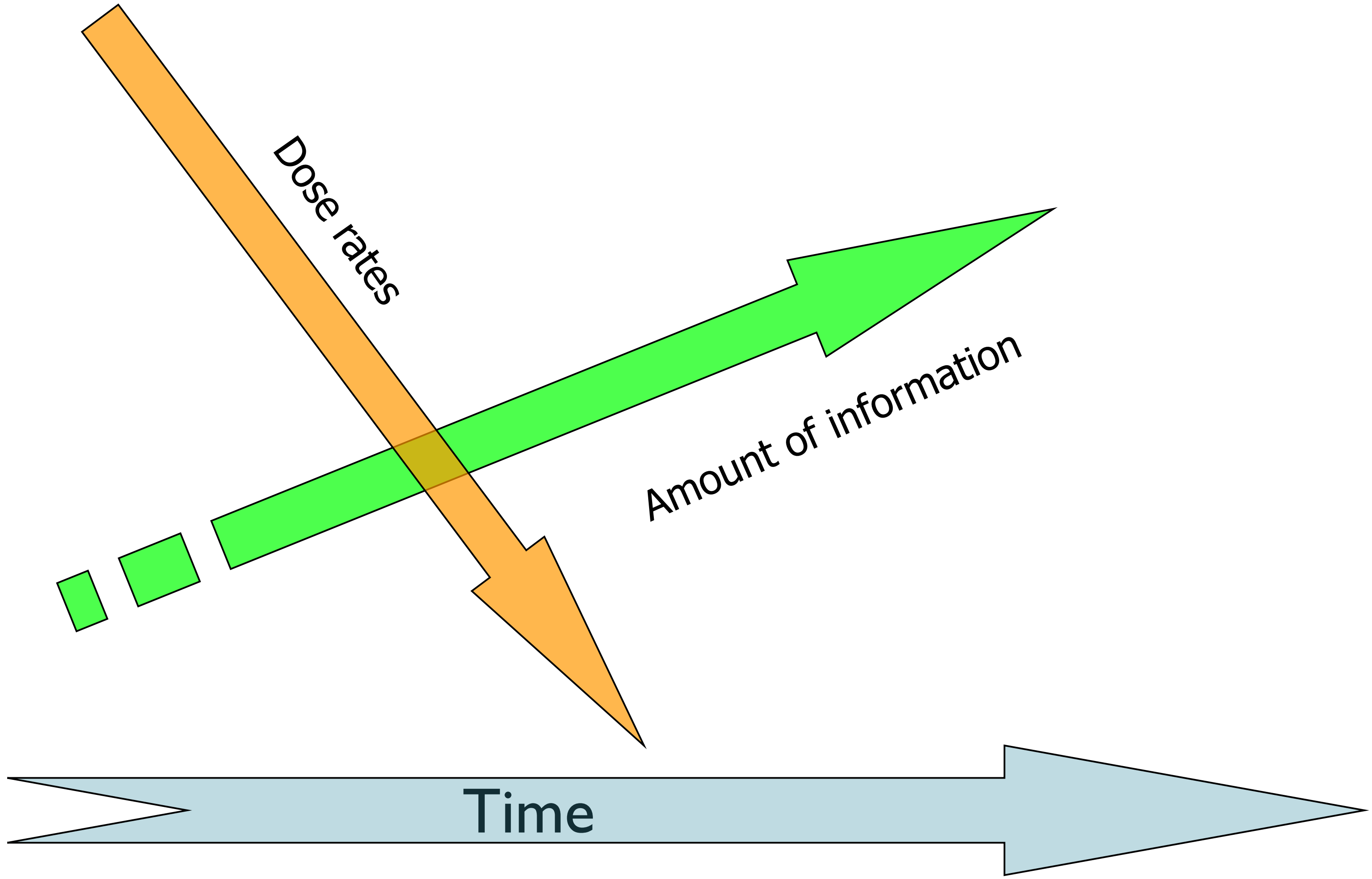
Decline of dose rate after reactor mix release



Spatial variation of doses



General rule



Dosimetric features of different phases of a reactor accident

- Initial phase – continuing release and rapidly changing radiation conditions, great uncertainty about dose rate and concentration levels, lack of measurements => lack of information about individual and collective doses
- Early (acute) phase – most significant pathways are external exposure and intake of radioactive iodine by ingestion and inhalation, thyroid doses depend on time course of intake and stable iodine administration
- Intermediate (stabilization) phase – external exposure by short-lived radionuclides, ingestion via root intake
- Late (recovery) phase – chronic internal and external exposure due to long-lived radionuclides (^{137}Cs, ^{90}Sr, ^{241}Am)

Main contingents affected by the accident

- Emergency workers: facility staff, early respondents
- Clean-up workers
- Evacuees (residents of the adjacent areas)
- Other public (population of the contaminated territories)

Main demands for dose estimations

- Radiation protection
- Decision making
- Countermeasures
- Health detriment predictions
- Epidemiological studies
- Legal issues: categorization, social benefits
- Optimization

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Dosimetry of liquidators

Chernobyl clean-up workers (liquidators):

- Total number (Ukraine):
  - > 300,000
  - ca. 200,000 included into the State Registry of Ukraine (SRU)
- Demographical structure:
  - Age at time of clean-up – 20-40 years
  - Healthy at time of exposure
  - Predominantly (95%) - male
- Dose level – moderate
- Mode of exposure – protracted (several hours to several years)
- Epidemiological relevance - high

Periods of dosimetry of clean-up workers

Period	Time interval	Characteristics
Pre-accidental	1978-26.04.1986	Normal operation of ChNPP, radiation safety in compliance with NRB-76
Initial	26.04-ca.10.05.1986	Failure of routine dosimetry service, use of wartime approaches for troops
Interim	Ca.10.05-01.06.1986	Development of unity in radiation safety, establishing dosimetric facilities
Main	June-October 1986	Operation of three dosimetry services (ChNPP, AC-605, military) using different approaches
Routine	Since November 1986	Gradual return to normality, reduction of dose limits (1987-1988)

Dosimetry services in Chernobyl

Service	Responsibility domain	Period of operation	Quality of results
ChNPP	ChNPP personnel Temporary assigned to ChNPP Sent on mission to the 30-km zone	May 1986-present	reasonable
AC-605	Personnel of AC-605 (civil and military)	June 1986 – 1987	high
Military	Troops	April 1986 - 1990	low
PA “Combinat” and successors	Workers in the 30-km zone	November 1986 - present	reasonable

Radiation safety legislation

Dose limits:

- Initial phase: 250 mSv (NRB-76) for emergency workers, 500 (250) mSv for troops
- Since 21.05.1986 – 250 mSv for all liquidators
- Since February 1987 – differential: 50, 100 and 250 mSv
- Since February 1988 – 50 mSv

Harmonization of dosimetry:

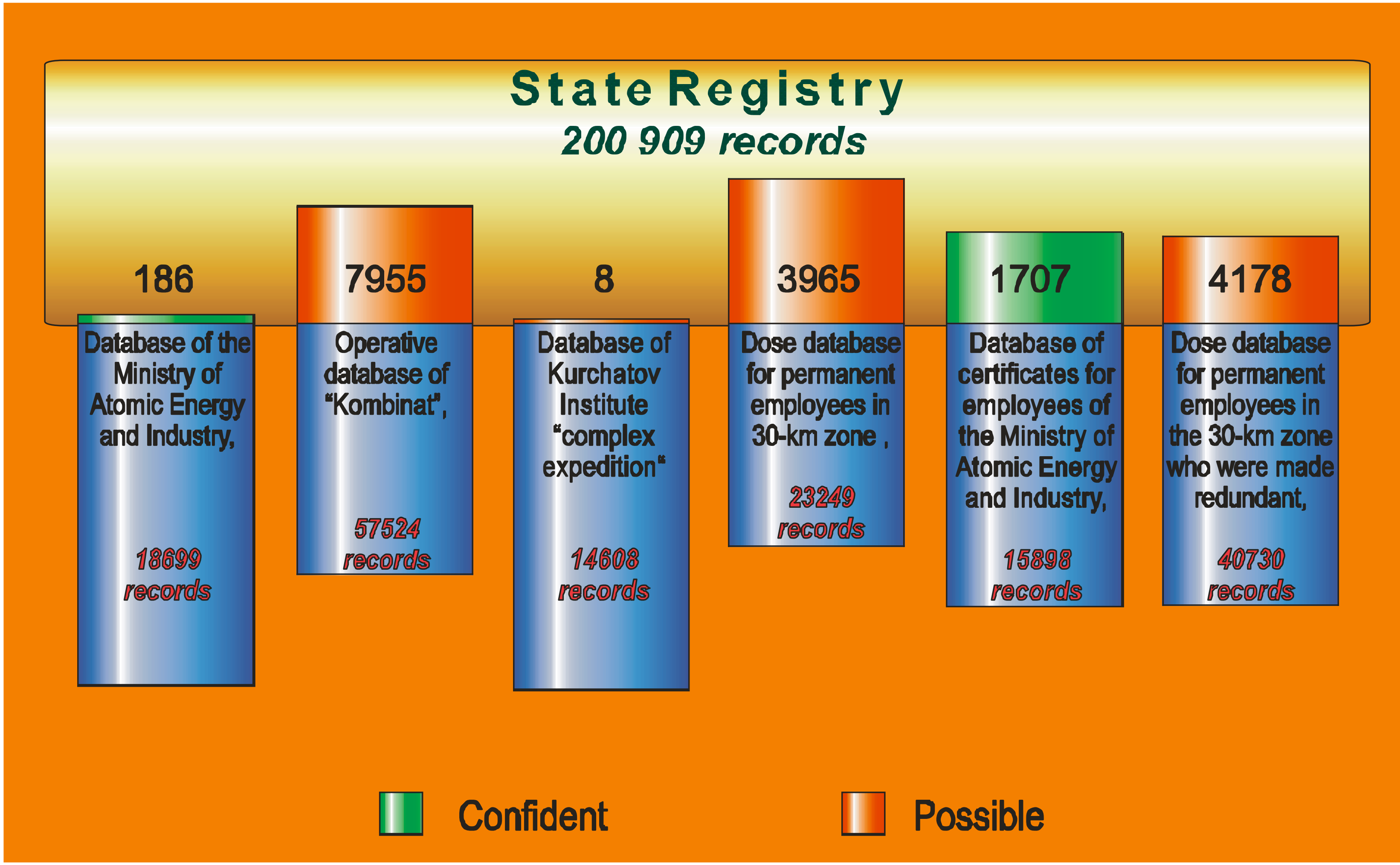
- Dosimetric monitoring of civilians was regulated by the Statute of 31.05.1986 – full coordination and harmonization never achieved
- Military had stand-alone regulation and dosimetry

Dosimetry methods

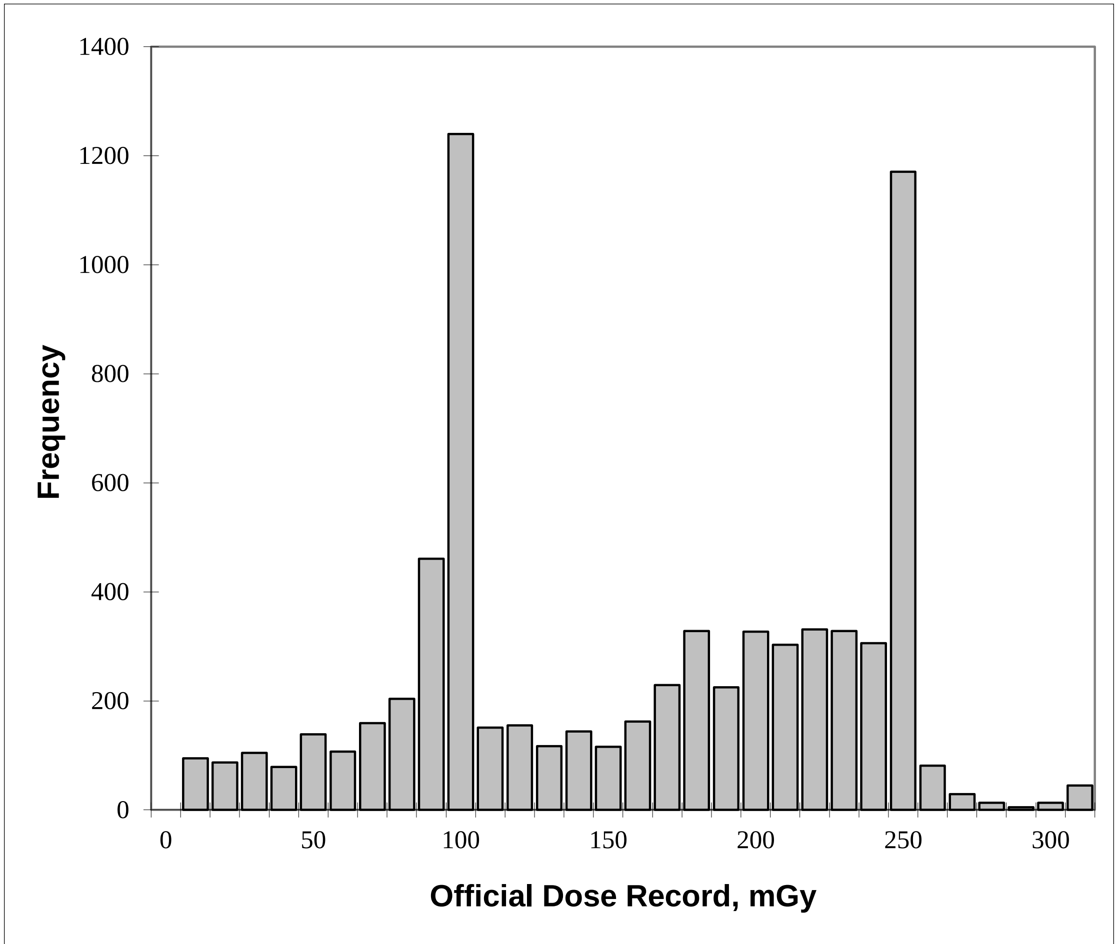
- Individual monitoring (TLD, RFL, film)
- "group-dosimetry" – one dosimeter per group of workers
- "group-estimation" – one pre-calculated dose to a whole group of workers

Outcome: recorded individual doses, so-called 'official dose records' - ODRs

Applicability of Chornobyl ODRs: linkage with SRU

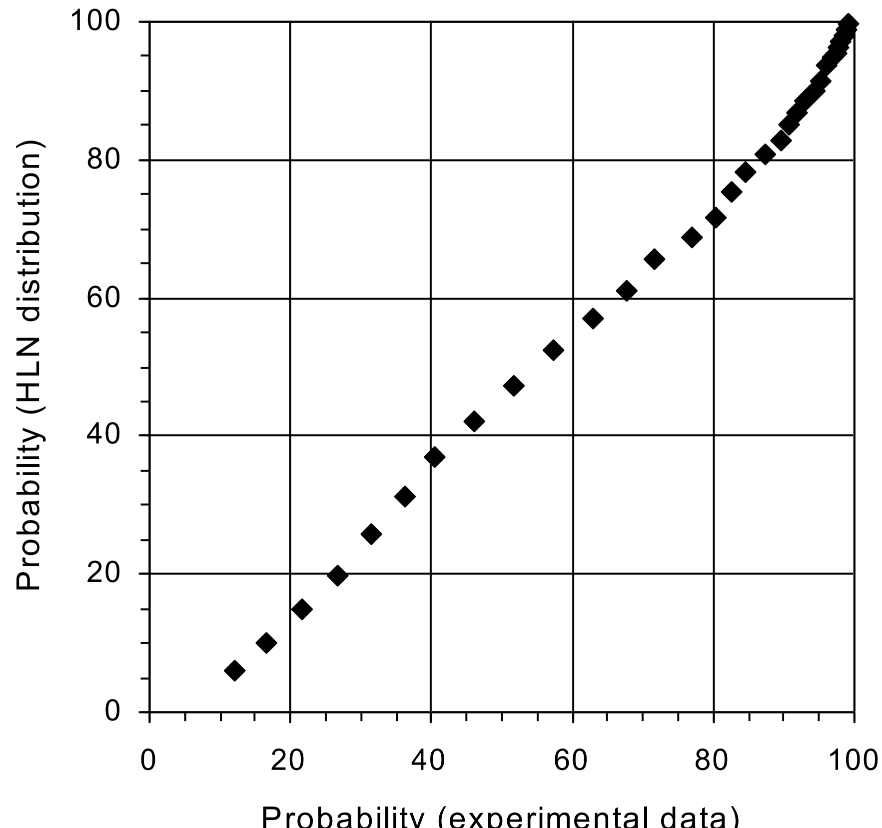


Distribution of Official Dose Records



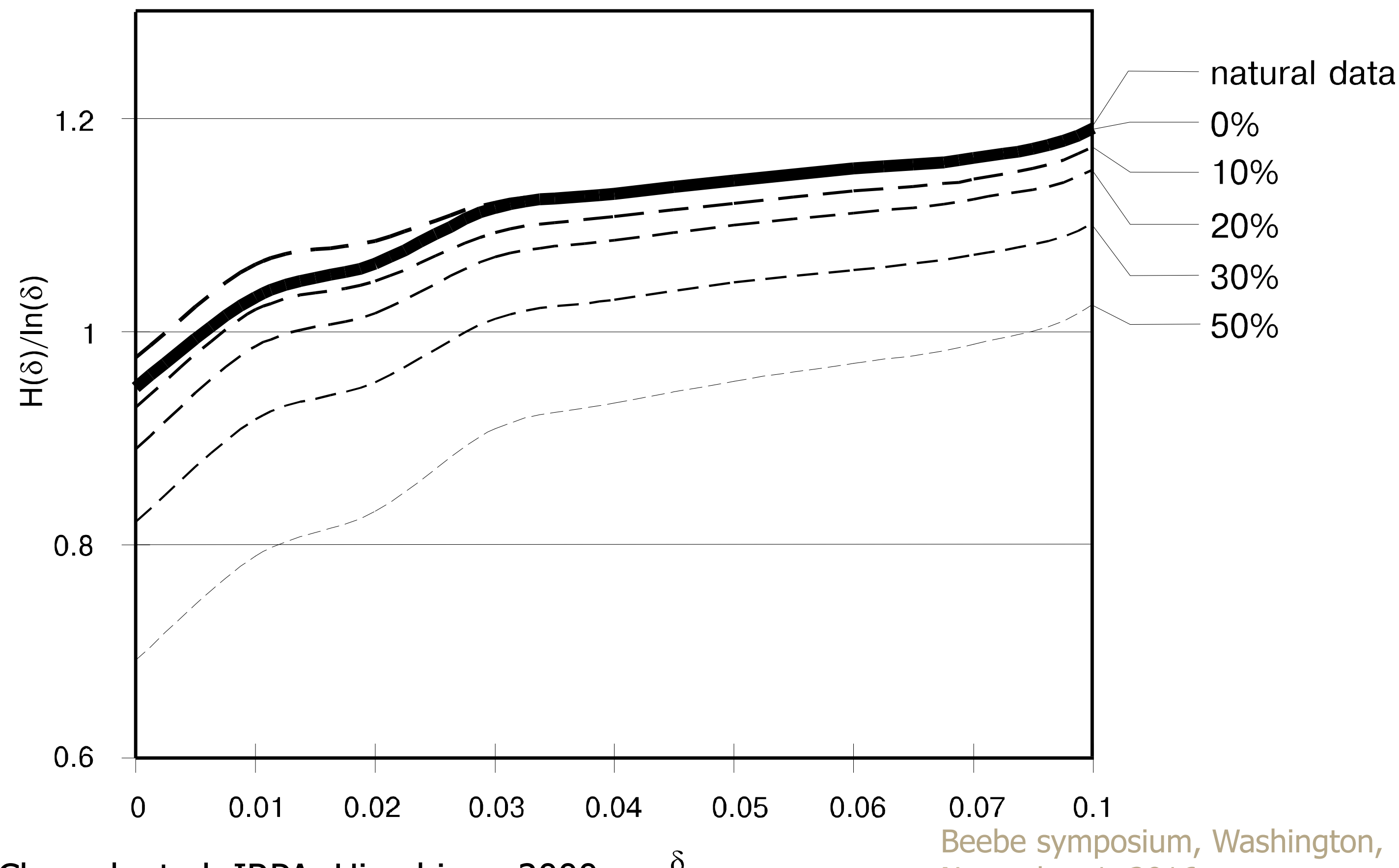
Chumak et al, IRPA, Hiroshima, 2000

Normalized probability plot for distribution of daily doses of military liquidators ("partisans") of 1986 (HLN hypothesis)



Chumak et al, IRPA, Hiroshima, 2000

Experimental dependence of entropy coefficient on increment of histogram δ (solid line) and modeled calibration dependencies



Chumak et al, IRPA, Hiroshima, 2000

Retrospective assessment of bias and uncertainty of ODR (2002)

- 92 subjects with group assessment ODR (military liquidators of 1986-1987)
- EPR used as a reference (point dose estimate)
- Ratio ODR/EPR is considered as model uncertainty distribution
- Parameters of distribution
  (2003 data for 119 subjects):

GM	–	0.39	(0.43)
GSD	–	2.14	(2.05)

Findings of the study of official dose records:

- Most (95%) of official dose records are related to military liquidators
- Unusual shape of dose distribution is caused by unique dose management practice
- There is no evidence of mass falsification of dose values
- Recorded doses are likely to be biased upwards

Conclusion: Official dose records can be used for epidemiological studies only after verification and adjustment ("retrospective calibration")

Lessons of dosimetric support of clean-up activities

Positive experience:

- Successful radiation safety program for multi-thousand contingents
- Efficient dosimetric monitoring program at AC-605

Negative experience:

- Lack of preparedness for operation under conditions of large scale radiation emergency
- Lack of harmonization and coordination between dosimetry services
- Deficiencies in instrumentation and methods
- Insufficient attention to retention of dosimetric information

Causes of failure or insufficient success of dosimetric monitoring:

- inadequate dose range of regular film badge dosemeters at ChNPP
- emergency relocation of dosimetry laboratory from ChNPP site to temporary camp (‘Skazochny’ site)
- overwhelming scale of the accident
- wartime equipment of the troops was inadequate for occupational monitoring
- absence of personal dosemeters to measure skin, lens doses as well as beta exposure
- lack of harmonization between different dosimetry facilities
- problems with registration and retention of the results of dosimetric monitoring

This resulted in the following problems with ODR of liquidators:

- insufficient coverage of liquidator population with individual dosimetric monitoring, particularly in 1986 and 1987 (when the doses were the highest)
- often dose records do not cover the whole period of occupational exposure, in particular, the doses related to early (most dose intense) periods are missing
- the keys for identification of liquidator's affiliation (and thus quality of existing dosimetric data) are missing in the State Chernobyl Registry of Ukraine (SRU)

Dosimetry of evacuees

Evacuees:

Population of Pripyat (49,360 residents), Chernobyl (13,700 residents) and 62 other settlements within the 30-km exclusion zone, who were evacuated in April-May 1986 as a first response to the radiological emergency.

Totally about 116,000 residents were evacuated, including ca.89,000 from the Ukrainian (southern) part of the 30-km zone

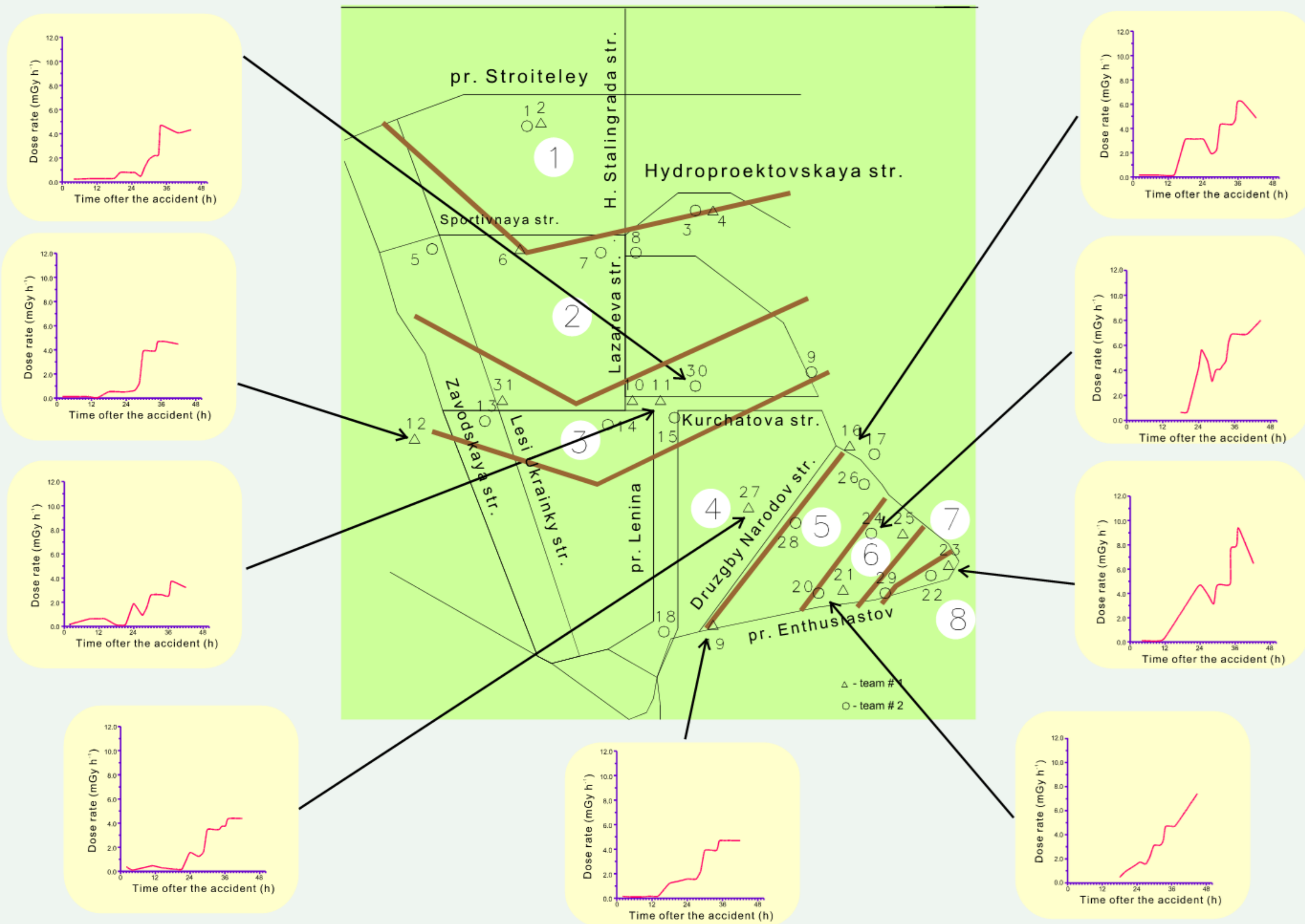
Measurements prior to evacuation:

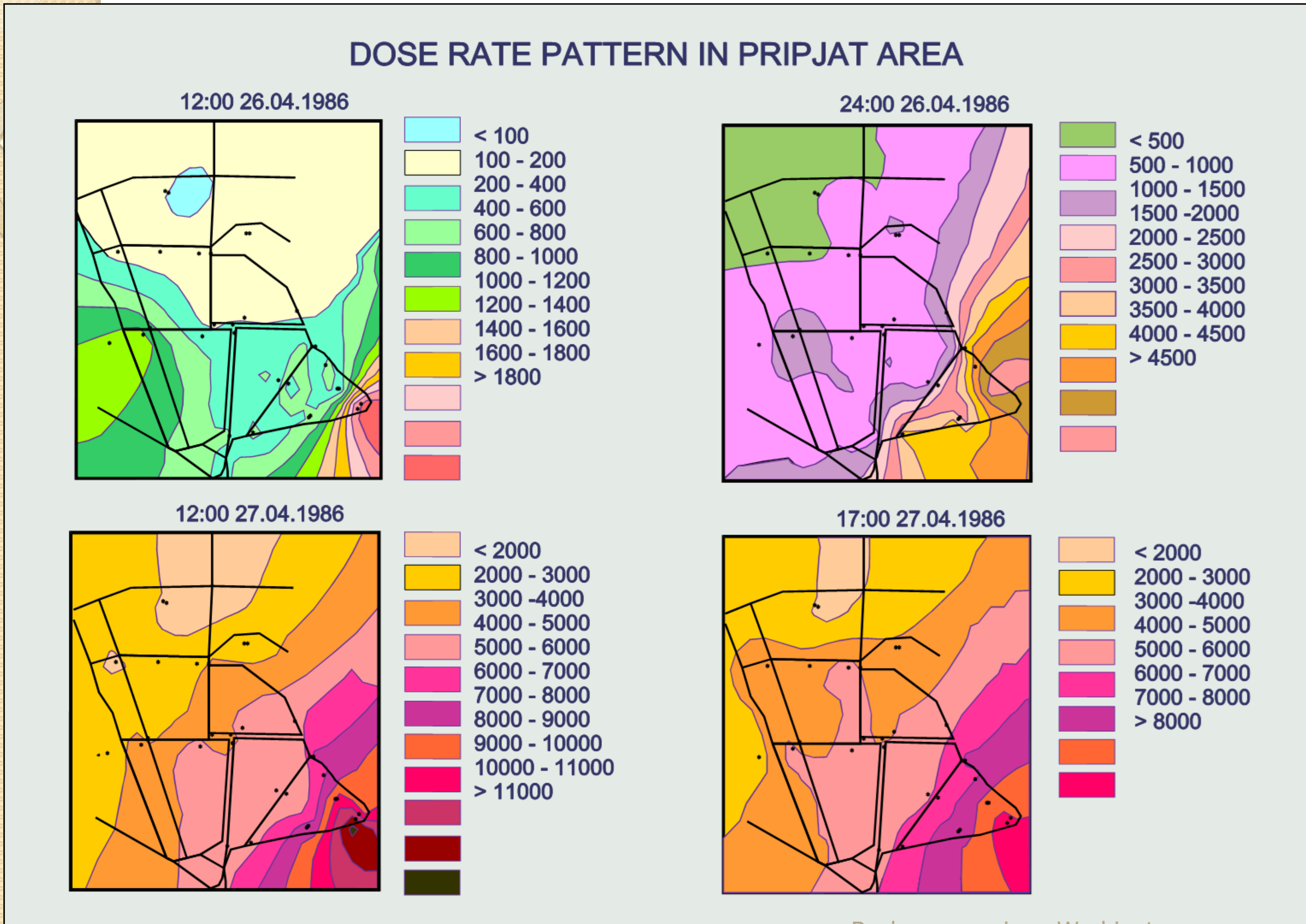
No individual dosimetric monitoring of the population was undertaken over the time before evacuation.

Dose rate measurements in Pripyat (31 monitoring points, average inter-measurement interval – 3.5 h, last measurement taken 94 hours after the accident)

and the settlements of the 30-km zone (91 monitoring points, variable inter-measurement interval – usually daily with some gaps and gradual termination of measurements in the evacuated places, last measurement was taken on May 28, 1986).

DOSE RATE MEASUREMENTS IN PRIPJAT




DOSE RATE PATTERN IN PRIPJAT AREA
12:00 26.04.1986
< 100
100 - 200
200 - 400
400 - 600
600 - 800
800 - 1000
1000 - 1200
1200 - 1400
1400 - 1600
1600 - 1800
> 1800
24:00 26.04.1986
< 500
500 - 1000
1000 - 1500
1500 -2000
2000 - 2500
2500 - 3000
3000 - 3500
3500 - 4000
4000 - 4500
> 4500
12:00 27.04.1986
< 2000
2000 - 3000
3000 -4000
4000 - 5000
5000 - 6000
6000 - 7000
7000 - 8000
8000 - 9000
9000 - 10000
10000 - 11000
> 11000
17:00 27.04.1986
< 2000
2000 - 3000
3000 -4000
4000 - 5000
5000 - 6000
6000 - 7000
7000 - 8000
> 8000

WIDE SCALE PUBLIC SURVEY OF EVACUATED POPULATION

DESIGN OF THE SURVEY:

- public survey of evacuees who were included into the National Registry
  - contact people at their new locations 2-3 years after the accident
  - acquire individual behavior and migration information using formalized questionnaires

FQ FOR PRIPJAT CASE

Resolution:

- one hour in time
  - sector (1 of 8) in space

Dwelling data:

- type of the building
- floor
- address in Pripjat

Additional information:

- personal data (age, gender, profession)
- stable iodine intake (with day discretion)
- emergency countermeasure practice
- route of evacuation

Covered period:

FQ FOR THE 30-KM ZONE CASE

Resolution:

- one day in time
  - settlement in space

Dwelling data:

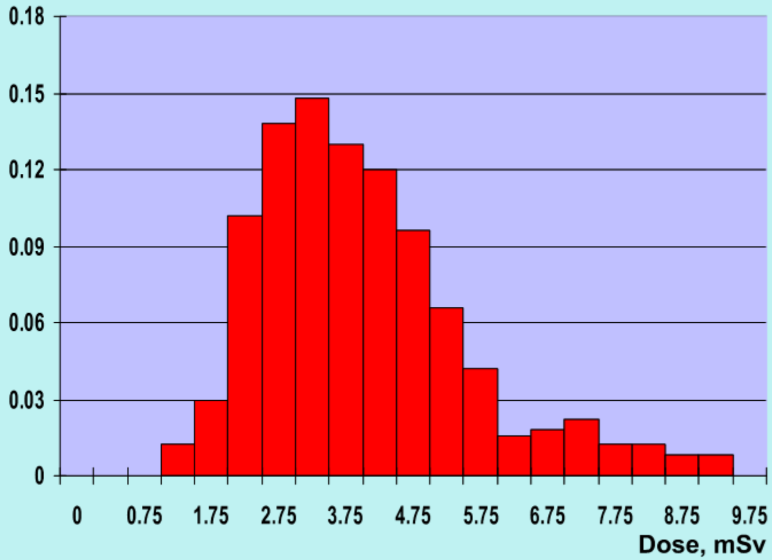
- type of the house

Additional information:

- personal data (age, gender, profession)
- source of water supply
- stable iodine intake
- consumption of local foodstuffs
- route of evacuation

Covered period:
20 days

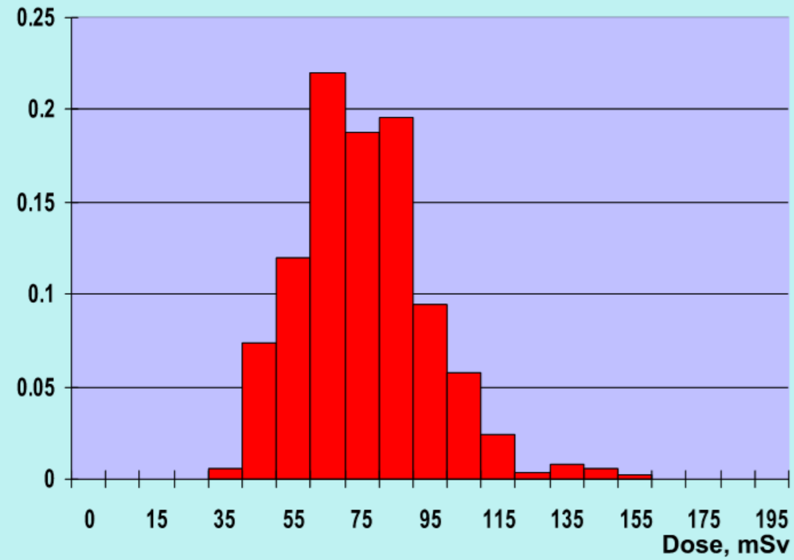
DOSE DISTRIBUTIONS FOR TWO INDIVIDUALS FROM PRIPJAT
(horisontal scale is different)



Iindividual N 555

A child was born 1980, lived in sector 1, evacuated after 36 hours, was only for one hour outdoors

Median: 3.8 mSv, 95 percenticle: 7.9 mSv



Individual N 15219

A male worker, born 1955, lived in sector 4, evacuated after 44 hours, worked outdoors in sector 7.

Median: 75 mSv, 95 percentile: 107 mSv.

Dosimetry of evacuees: summary

Individual doses were estimated to:

- 16,193 residents of Pripjat (33% of pre-accidental population)
  - Mean dose – 10 mSv
  - 95-percentile – 24 mSv
- 19,605 residents of other settlements of the 30-km zone (49% of pre-accidental population)
  - Mean dose – 16 mSv
  - 95-percentile – 68 mSv

Meckbach and Chumak, EU Chernobyl conference, Minsk, 1996, unpublished data

Thyroid dosimetry

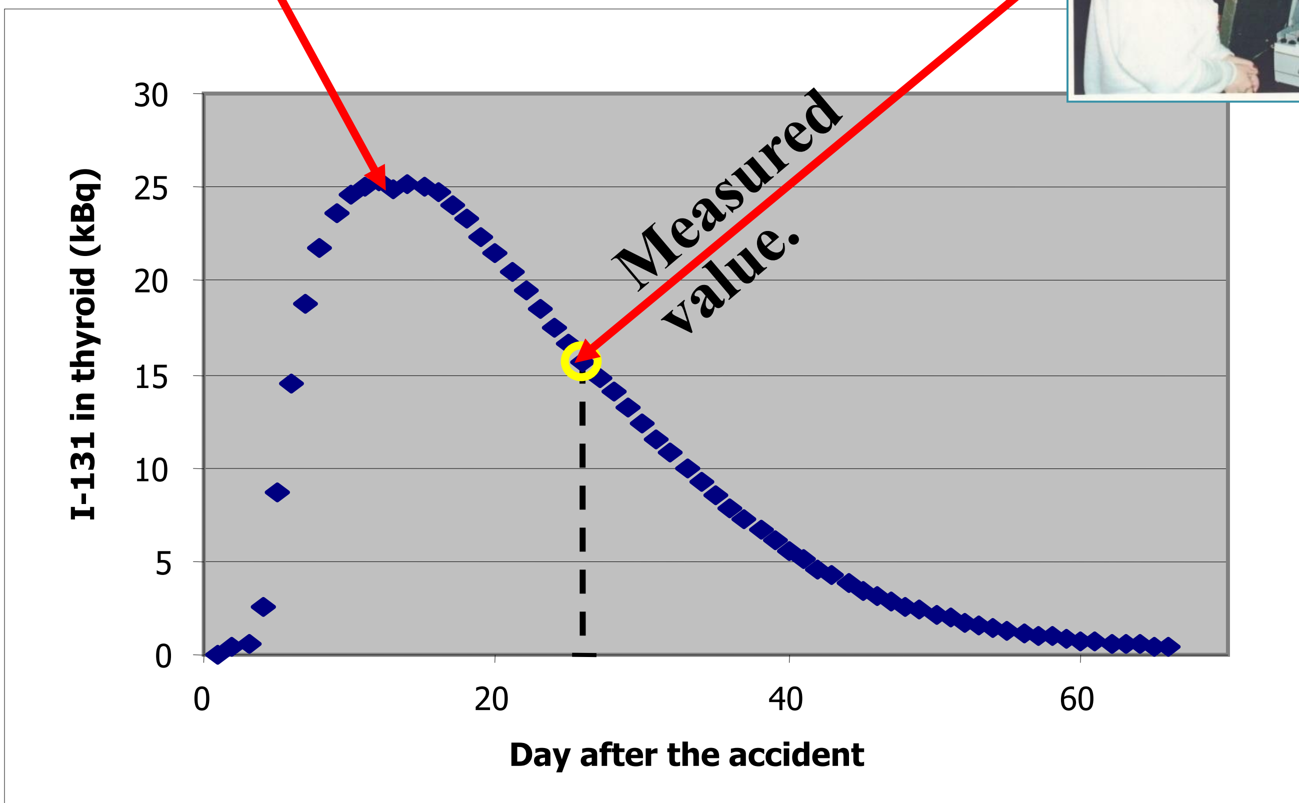
Measurements of ^{131}I Activity in the Thyroid in April-June 1986

Country	N	Method of measurement	Detector type
Belarus	130,000	Exposure rate	GM, NaI(Tl)
Ukraine	150,000	Exposure rate Spectrometry	NaI(Tl)
Russian Federation	46,000	Exposure rate Spectrometry	NaI(Tl)

Gavrilin et al Health Phys 1999; Likhtarev et al Health Phys 1995; Zvonova et al Radiat Prot Dosim 1998

Direct thyroid measurement

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



Thyroid dose is proportio-nal to area under the curve

Thyroid Cohort Studies

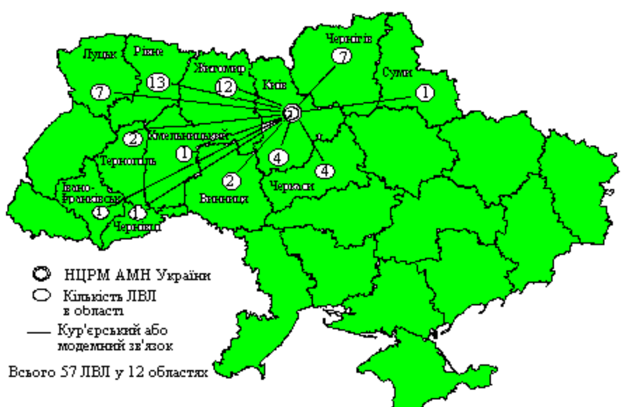
- About 25,000 individuals exposed as children and adolescents (aged 0-18 y): ~12,000 in Belarus, and ~13,000 in Ukraine
- Lived in contaminated areas
- Subjected to direct measurements of exposure rate against the thyroid which have been used to estimate ^{131}I activity in thyroid gland
- Detailed behavior and diet information was collected by means of personal interviews

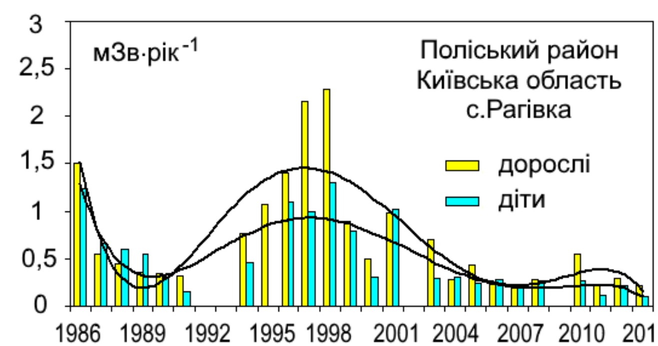
Other measurements related to dose estimations, but not covered by this talk

- Radioactive contamination mapping (aerial survey and soil sampling)
- Radioecological studies – determination of transfer factors, migration of radionuclides, time evolution, effect of countermeasures
- Direct external dose measurements with TLD dosemeters – parameterization of dosimetric models
- WBC measurements of $^{134, 137}Cs$ – verification of dose estimations
- Foodstuff burden measurements – validation of ecological models

Just one example of this auxiliary data: whole body counting

- WBC measurements of $^{134, 137}Cs$ began in July 1986.
- By December 31, 1986 about 23,000 measurements were taken in Kyiv and Zhytomyr oblasts (regions) of Ukraine
- To date about 1,3 Million measurements were taken and recorded by the WBC network covering 57 counters in 12 oblasts of Ukraine





Conclusions

- It is not possible to cover in one 20' talk all aspects of Chornobyl dosimetry (monitoring and dose assessment, including reconstruction): more details can be found in a plentiful literature – national reports, monographs, reviews and original papers
- Despite different causes of the accidents and scale of radioactive contamination, the problems and accomplishments in Chornobyl and Fukushima are pretty much similar
- Chornobyl experience should be studied and preserved for future situations

Thank you!