

U.S. Nuclear Regulatory Commission  
Office of Nuclear Regulatory Research  
25<sup>th</sup> Anniversary of the Chernobyl Accident

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# Chernobyl Health Effects

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Vanderbilt University Medical Center  
April 26 , 2011

# Chernobyl

## Summary - Health Effects

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### Emergency Workers

- early deaths from acute radiation sickness
- skin burns from beta particles
- cataracts

### Recovery Workers (Liquidators, Cleanup Workers)

- possible cataracts
- psychological effects, report of suicide increase

### Public

- thyroid cancer following childhood radioiodine
- psychological effects

# Informative Reviews



## SOURCES AND EFFECTS OF IONIZING RADIATION

United Nations Scientific Committee on the  
Effects of Atomic Radiation

UNSCEAR 2008  
Report to the General Assembly  
with Scientific Annexes

VOLUME II

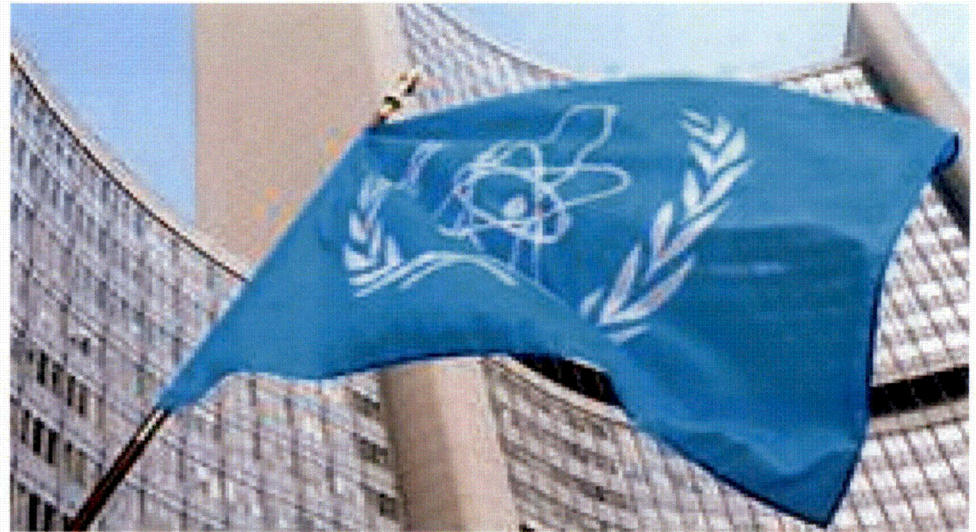
Annex D  
Health effects due to radiation from the Chernobyl accident

UNSCEAR 2011 (Feb)



UNITED NATIONS  
New York, 2011

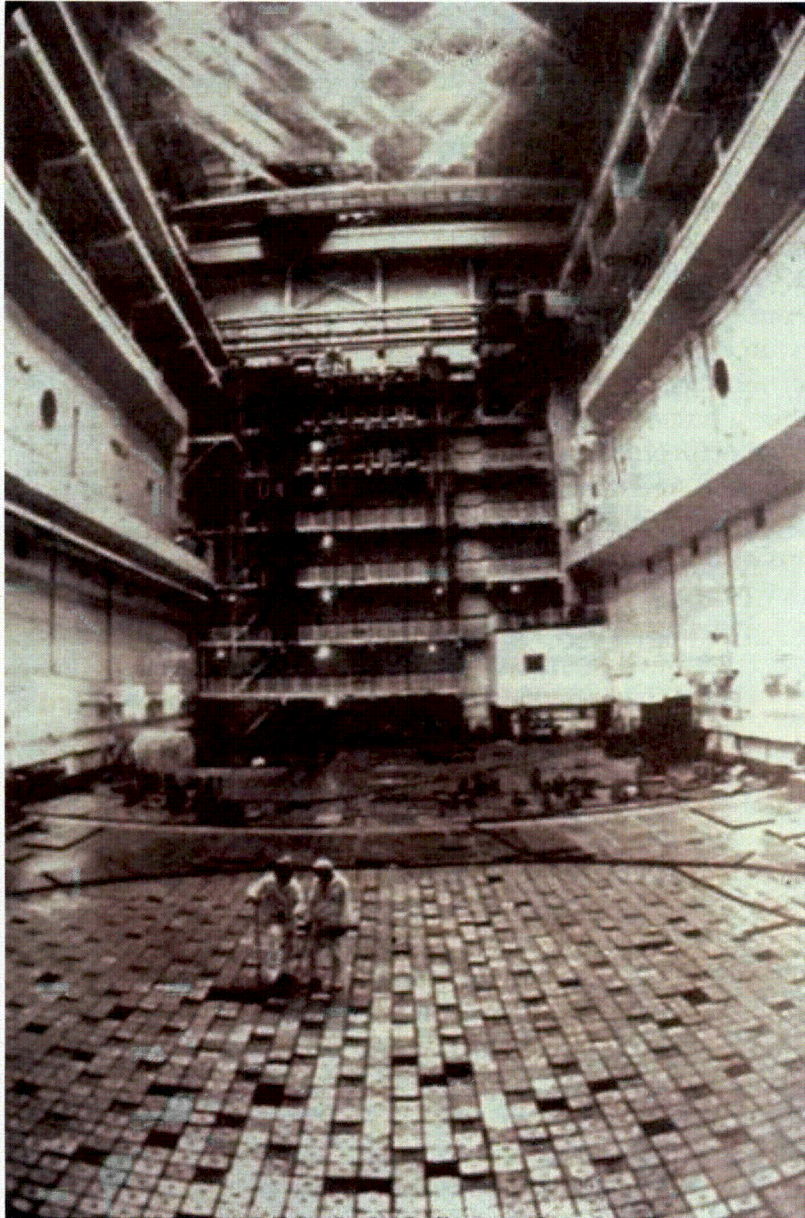
ADVANCE COPY



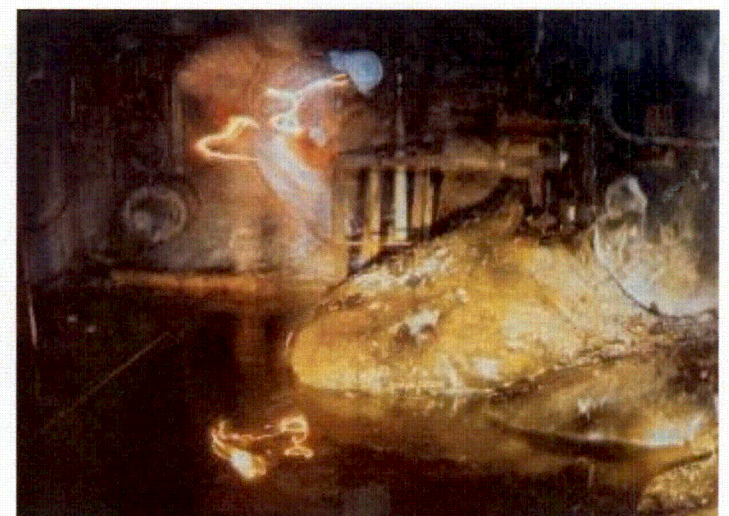
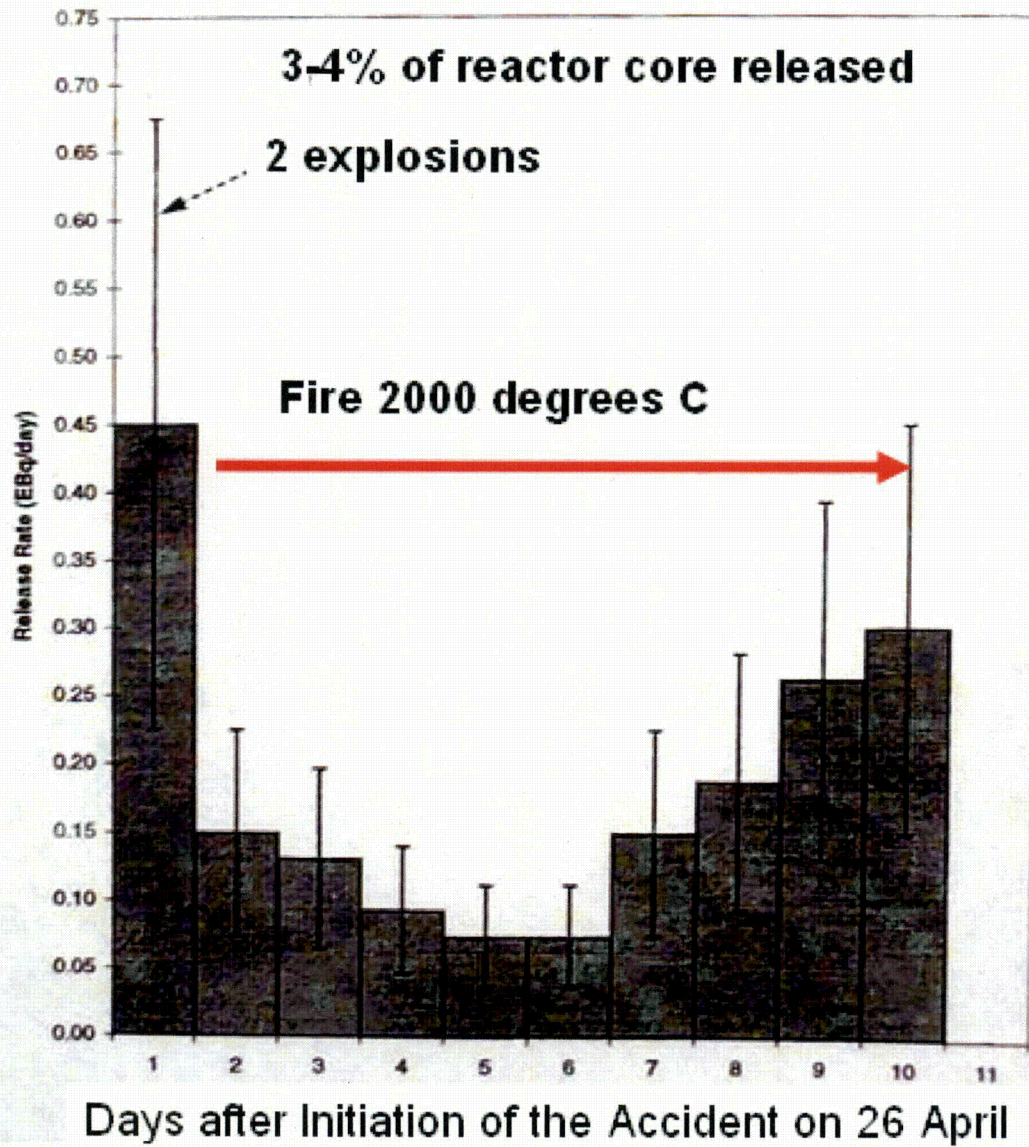
- Christodouleas et al *NEJM* 2011
- Wakeford *J Radiol Prot* 2011
- *Health Physics* Vol 93, 2007
- Chernobyl Forum 2006
- One Decade after Chernobyl 1996
- Intl Chernobyl Project 1991

Before

After (200–400 rads)/hr

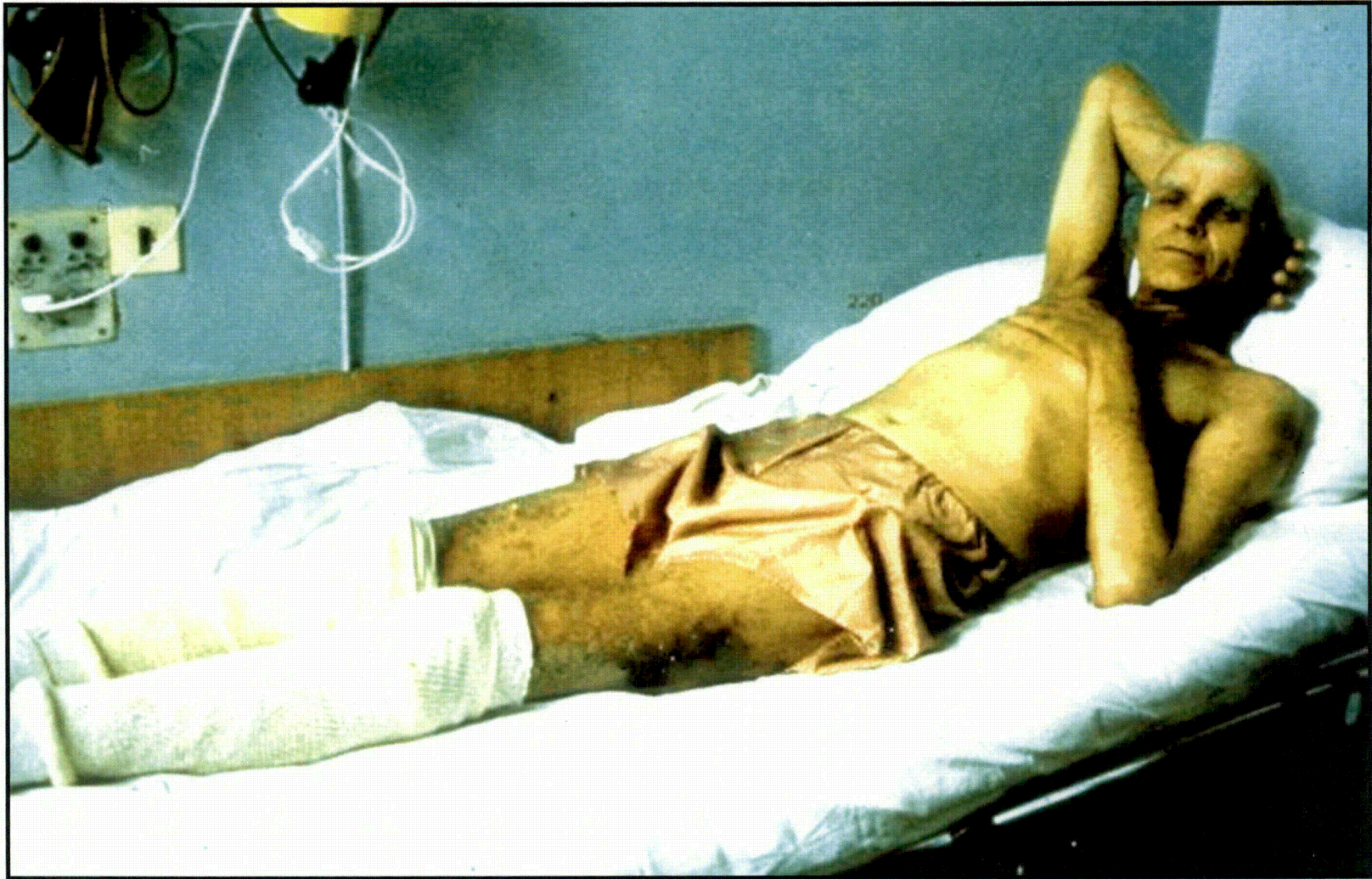


# Radioactivity Release Rate (EBq/day)



134 workers had Acute Radiation Syndrome with doses over 2 Gy (200 rads), some had doses over 10 Gy (1000 rads), highest 16 Gy (1600 rads)

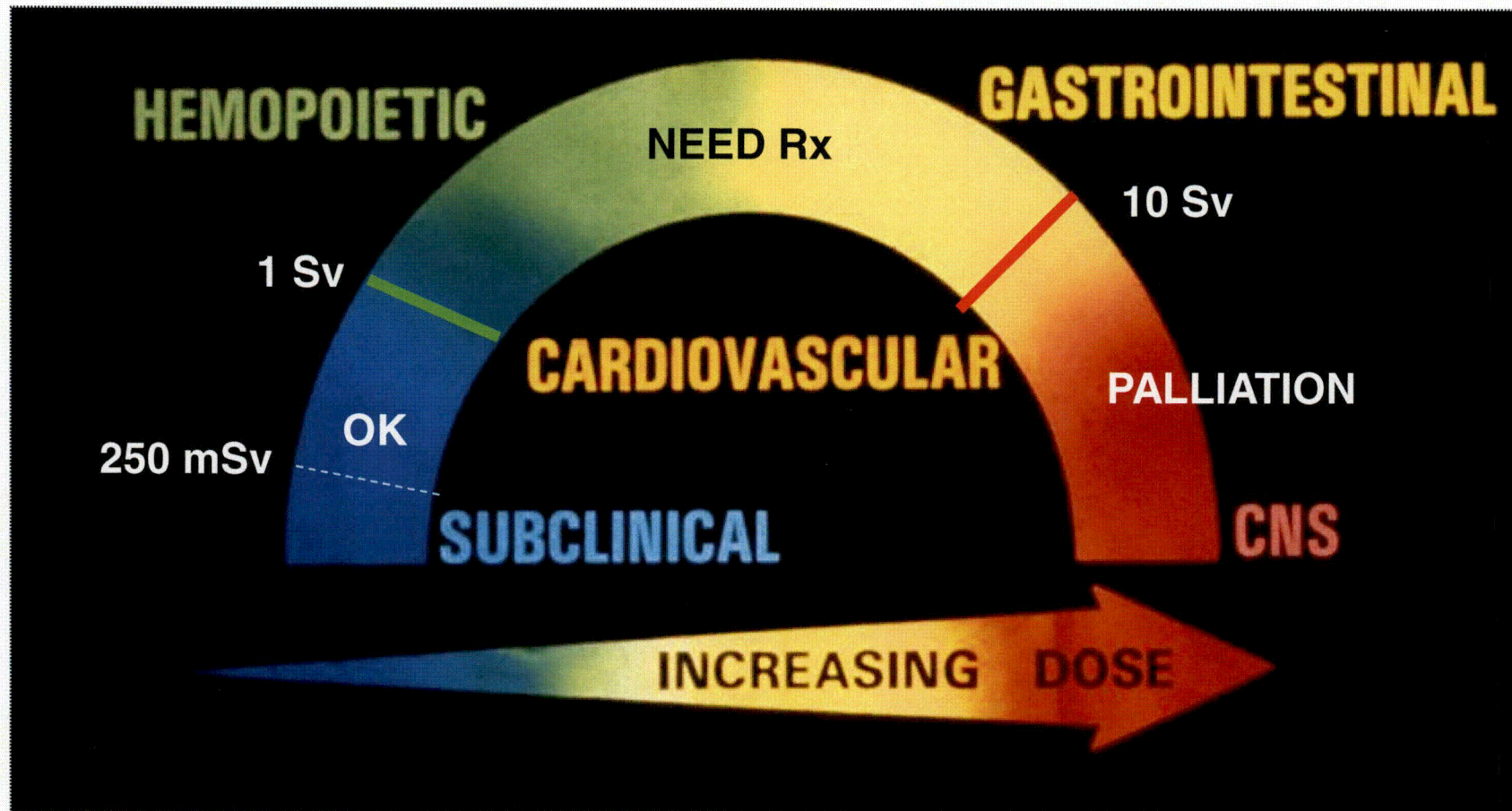
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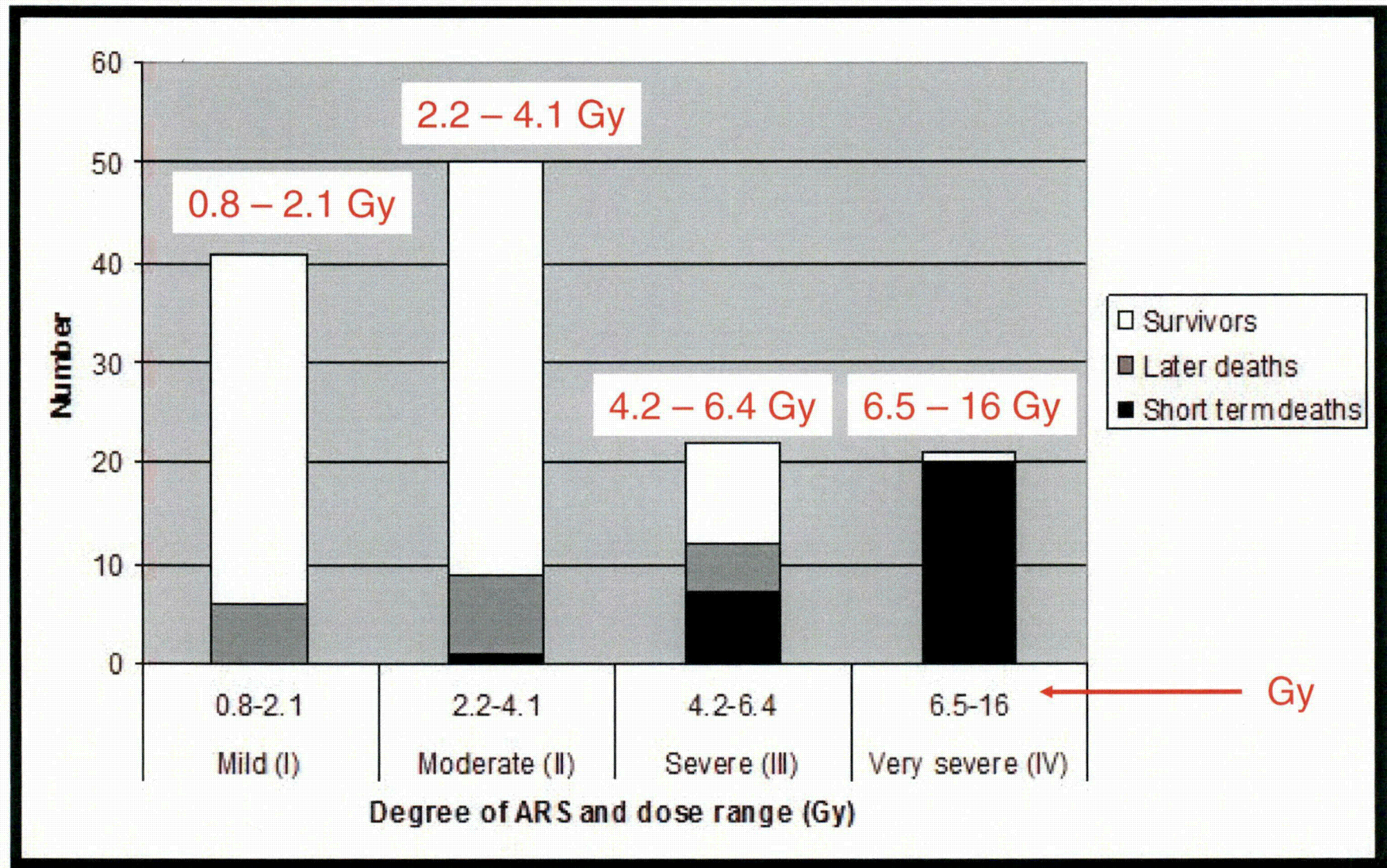
Chernobyl fireman

# Acute Radiation Syndrome from whole body penetrating radiation

28 died of  
ARS within  
4 months



# Outcome for 134 Workers with ARS





Chernobyl ARS survivor and physicians  
> 6 Gy (600 rads), bone marrow transplant  
but his own marrow recovered

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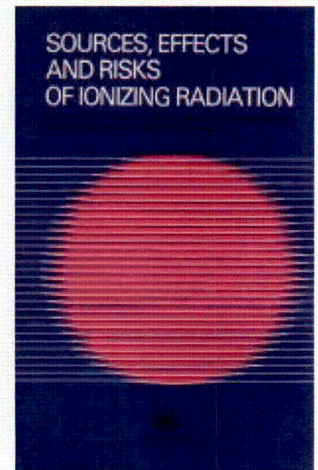
A memorial in Slavutyich, Ukraine,  
for those who died from radiation exposure  
(city built in 1986 for evacuated Pripyat families )

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# Chernobyl fireman healed beta burns

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# Acute Radiation Sickness and Beta Burns

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**Table C3. Relationship of ARS severity grade and percentage of skin burns and skin dose in Chernobyl patients [A8, B38]**

Number of patients	ARS severity grade	Percentage of skin radiation burn			Approximate absorbed skin dose (Gy)
		1-10%	10-50%	50-100%	
31	I	2	1	0	8-12
43	II	2	9	1	12-20
21	III	3	15	3	20-25
20	IV	1	10	9	>20

*Note: A red circle highlights the 10-50% and 50-100% burn columns for ARS grades III and IV, with an arrow pointing to the text '> 2000 rads'.*

37 / 41 had > 10% burns

12 / 41 had > 50% burns

# CATARACTS

Many of the ARS survivors have needed cataract surgery

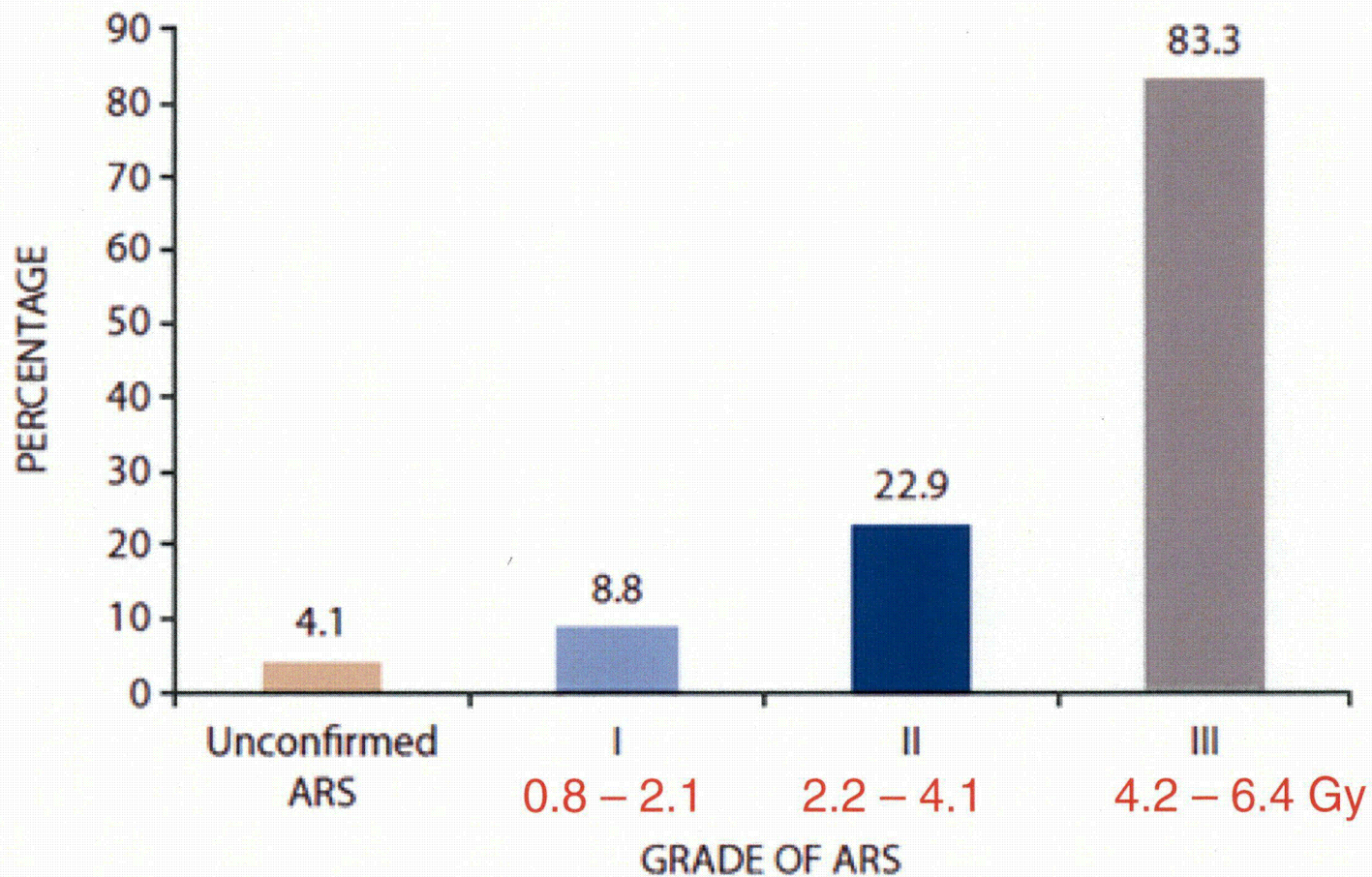
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# CATARACTS

Frequency of Cataracts by 2006 by Grade of ARS

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# Late Health Effects in ARS Survivors Emergency Workers

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- The major health consequences remain skin injuries and cataracts
- Over 1987–2006, 19 ARS survivors died from tuberculosis, liver cirrhosis, cardiac arrest, trauma, 4 solid cancers, 3 MDS, 1 AML, 1 CML
- Apparent increase in hematological malignancies
- Other deaths probably due to ageing and other factors not related to radiation exposure



530,000 Recovery Workers (liquidators) were used in the cleanup over 3 years

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# What are the total 20 year doses? 530,000 Recovery Workers

**Table 2. Summary of updated dose estimates for the main population groups exposed**

<i>Population group</i>	<i>Size (thousands)</i>	<i>Average thyroid dose in 1986 (mGy)</i>	<i>Average effective dose in 1986-2005 (mSv)</i>	<i>Collective thyroid dose in 1986 (man Gy)</i>	<i>Collective effective dose in 1986-2005 (man Sv)</i>
Recovery operation workers	530	— <sup>a</sup>	117 <sup>b</sup>	—	61 200
Evacuees	115	490	31 <sup>c</sup>	57 000	3 600
Inhabitants of contaminated areas <sup>d</sup> of Belarus, Russia and Ukraine	6 400	102	9 <sup>c,e</sup>	650 000	58 900
Inhabitants of Belarus, the Russian Federation and Ukraine	98 000	16	1.3 <sup>c,e</sup>	1 600 000	125 000 <sup>e</sup>
Inhabitants of distant countries <sup>f</sup>	500 000	1.3	0.3 <sup>c,e</sup>	660 000	130 000 <sup>e</sup>

11.7 rem (ave)  
up to 100 rem

Global average effective dose from natural background for 20 years = 24 mSv



# Recovery Workers – Probable Health Effects

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- **Cataracts:**

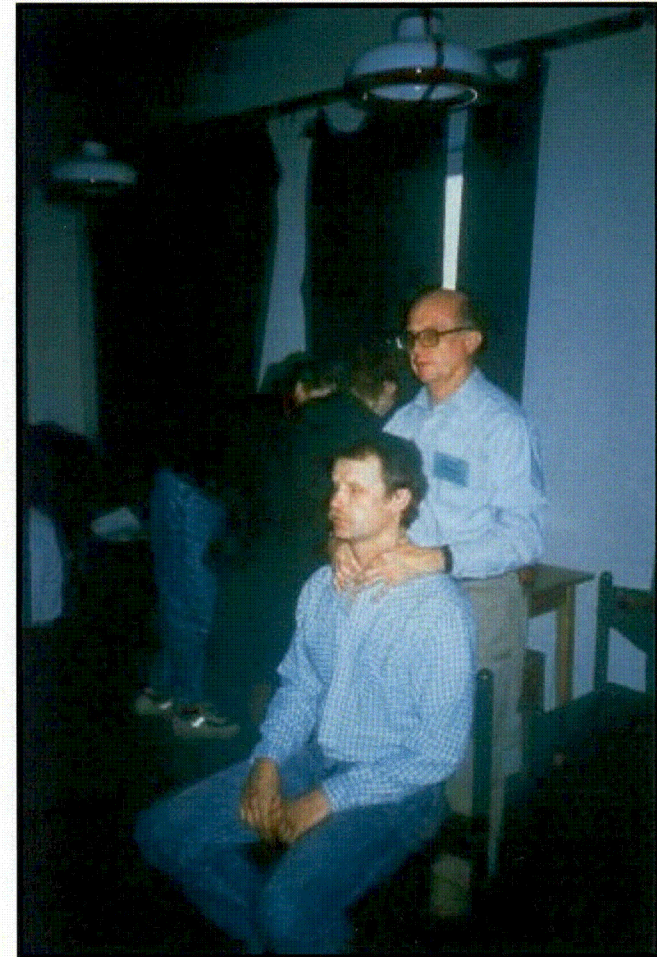
- Recent *The Ukrainian–American Chernobyl Ocular Study* (Worgul et al 2007) indicates that lens opacity in workers is related to the dose; dose threshold is lower than expected.

- **Psychological - Suicide:**

- Estonian Cleanup workers had a significant increase of suicide based on 78 deaths (Rahu et al 2006).

# Recovery Workers from Baltic Countries

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## Cancer Incidence and Mortality Among Chernobyl Recovery Workers from Estonia, 1986-2009

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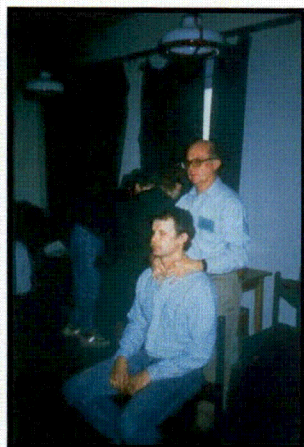
Site or type (ICD9)	Obs	RR	95% CI
All cancers (140-208)	205	1.08	0.9 - 1.2
Thyroid gland (193)	2	1.69	0.2 - 6.1
Leukemia (204-208)	6	1.18	0.4 - 2.7
<b>Suicide (E950-959)</b>	<b>79</b>	<b>1.27</b>	<b>1.0 - 1.6</b>
Total deaths (001-E999)	910	1.01	0.9 - 1.1

Rahu et al., 2006a, 2006b, 2011

# Chernobyl Thyroid Study

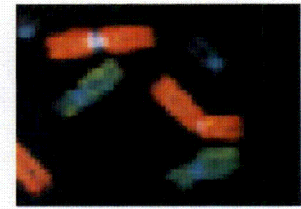
## 1,979 Estonian Workers Examined

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	Dose (rem)				
	0-	5-	10-	20-73	Total
Number Examined	410	516	567	219	1,979
% Nodules	12.7	8.3	10.4	9.6	10.1
RR	1.0	0.6	0.8	0.7	0.8

# Chromosome Studies - Estonian Chernobyl Worker Study



Persons	Cohort	Laboratory	Metaphases	Translocations per 1000 genome equivalents
118	Cleanup worker	LLNL, STUK, ORISE	179,324	6.99
29	Estonian control	ORISE	45,908	7.03

Had these men received an average whole-body dose of **10-11 rem**, as chronic or acute exposures, an increase in the mean frequency of chromosome translocations of more than 40-65% would have been observed in their lymphocytes compared to findings in non-irradiated controls. It is likely that recorded doses for these cleanup workers are **overestimated...**and **suggest that future studies may not be sufficiently powerful to detect increases in leukemia or cancer**, much less distinguish differences between the effects of chronic compared to brief radiation exposures.”



# Recovery Worker Studies - Concerns

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- Studies of Chernobyl liquidators are not straightforward.
- Many doses have to be reconstructed, and uncertainties are substantial.
- Interest in these workers has also led to better ascertainment of health effects leading to a possibility of bias if a comparison is made with the general population

Wakeford 2011, UNSCEAR 2011



Figure 1. Chernobyl nuclear power plant, Ukraine. Photograph taken in 1989.

# Recovery Workers - Unsubstantiated Health Effects

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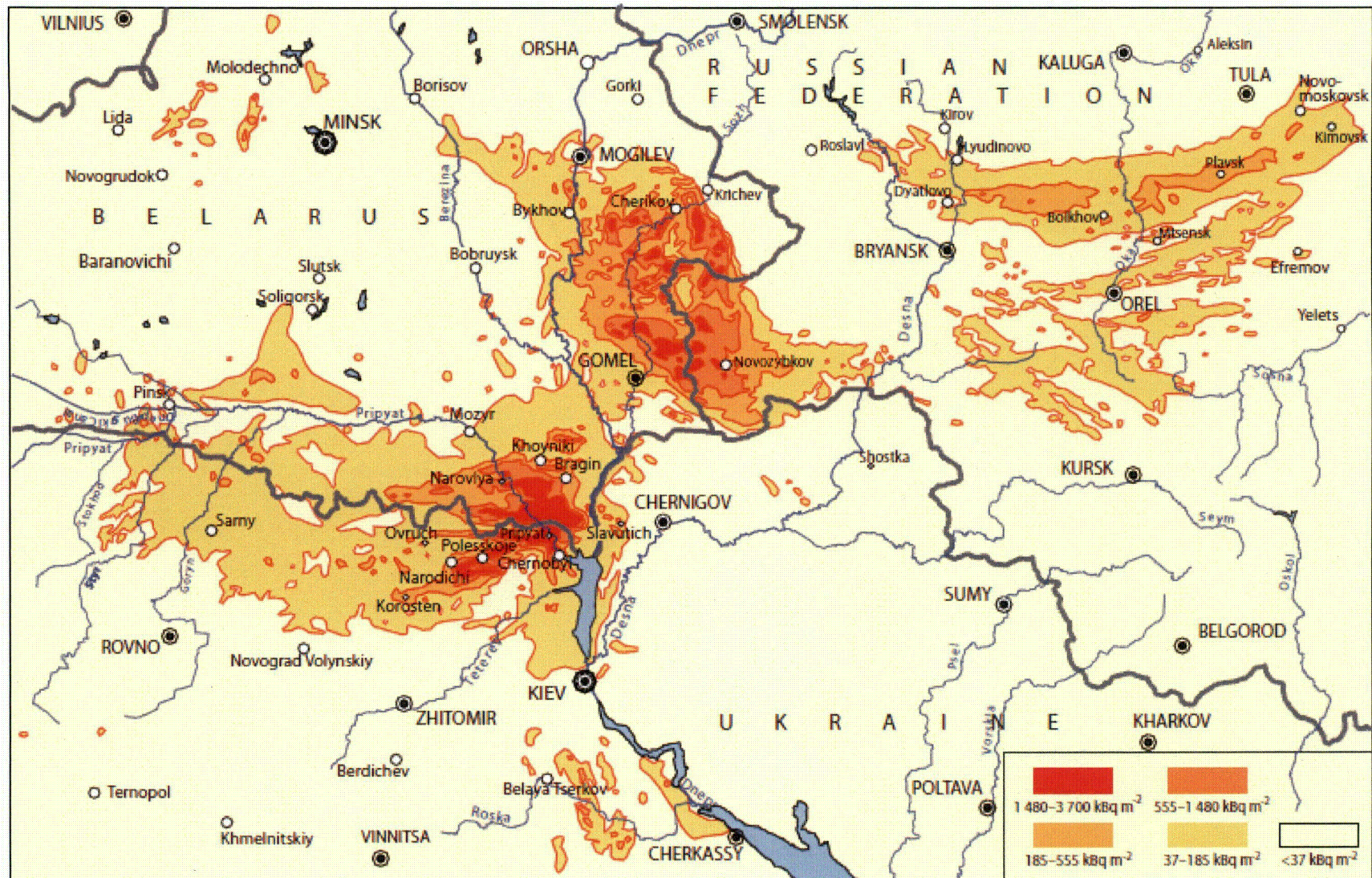
- **Leukemia**: excess predominantly for CLL, a leukemia not associated with radiation
- **Circulatory Diseases**: reports among Russian workers should be interpreted with caution because of the likely influence of other factors

# The General Population

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# $^{137}\text{Cs}$ Deposition Levels in Belarus, Russian Federation, Ukraine, 1989



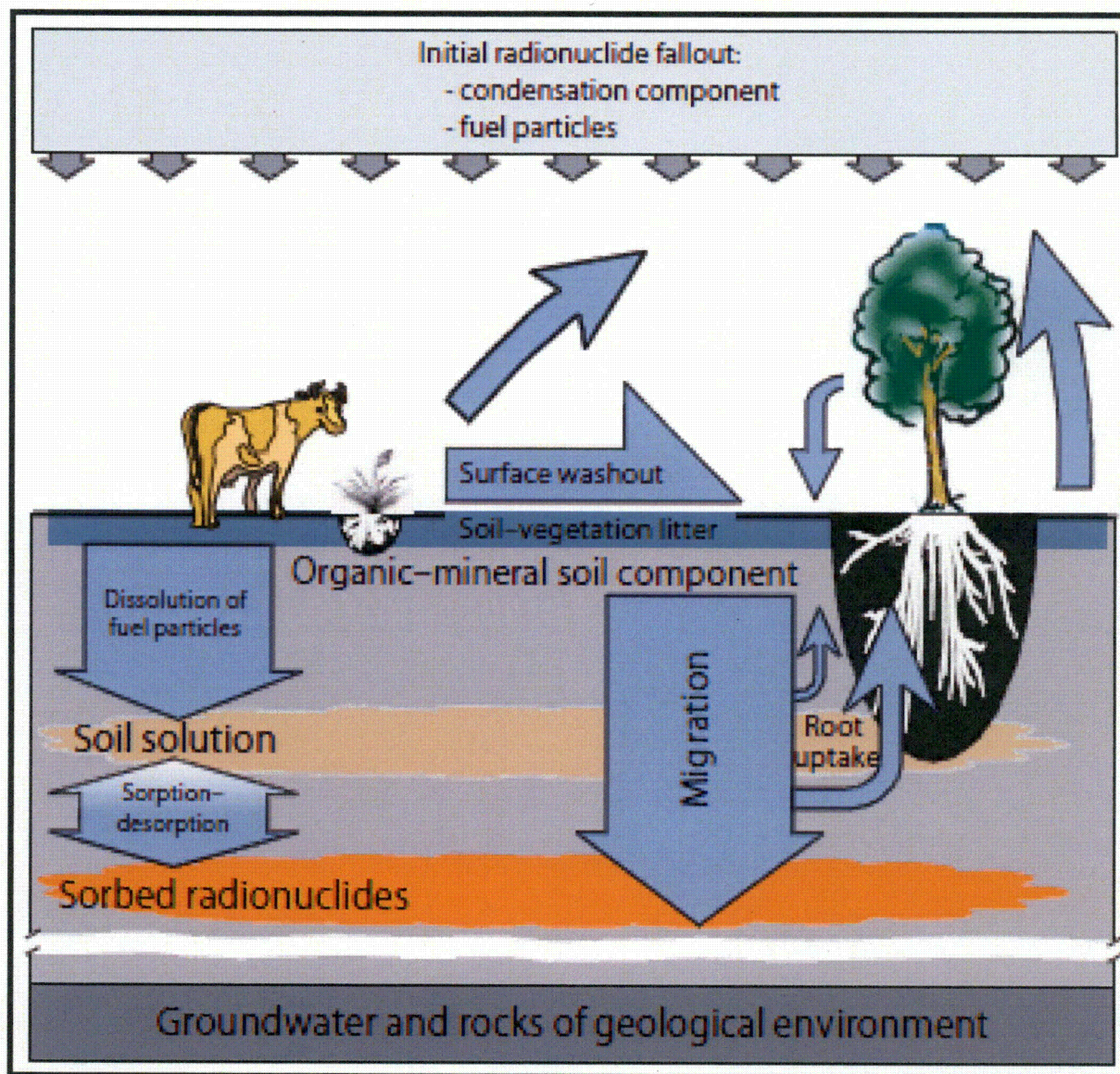
# Pripyat within 3 km of Chernobyl

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Dose rates were up to 5 mGy (0.5 rad) / hr outside  
Evacuation required 800 buses for 49,360 people on April 27th

Figure III. The main transfer pathways of radionuclides in the terrestrial environment [S13]



# Iodine-131 and other beta-activity in milk over time, Brest Oblast, Belarus (kBq/L)

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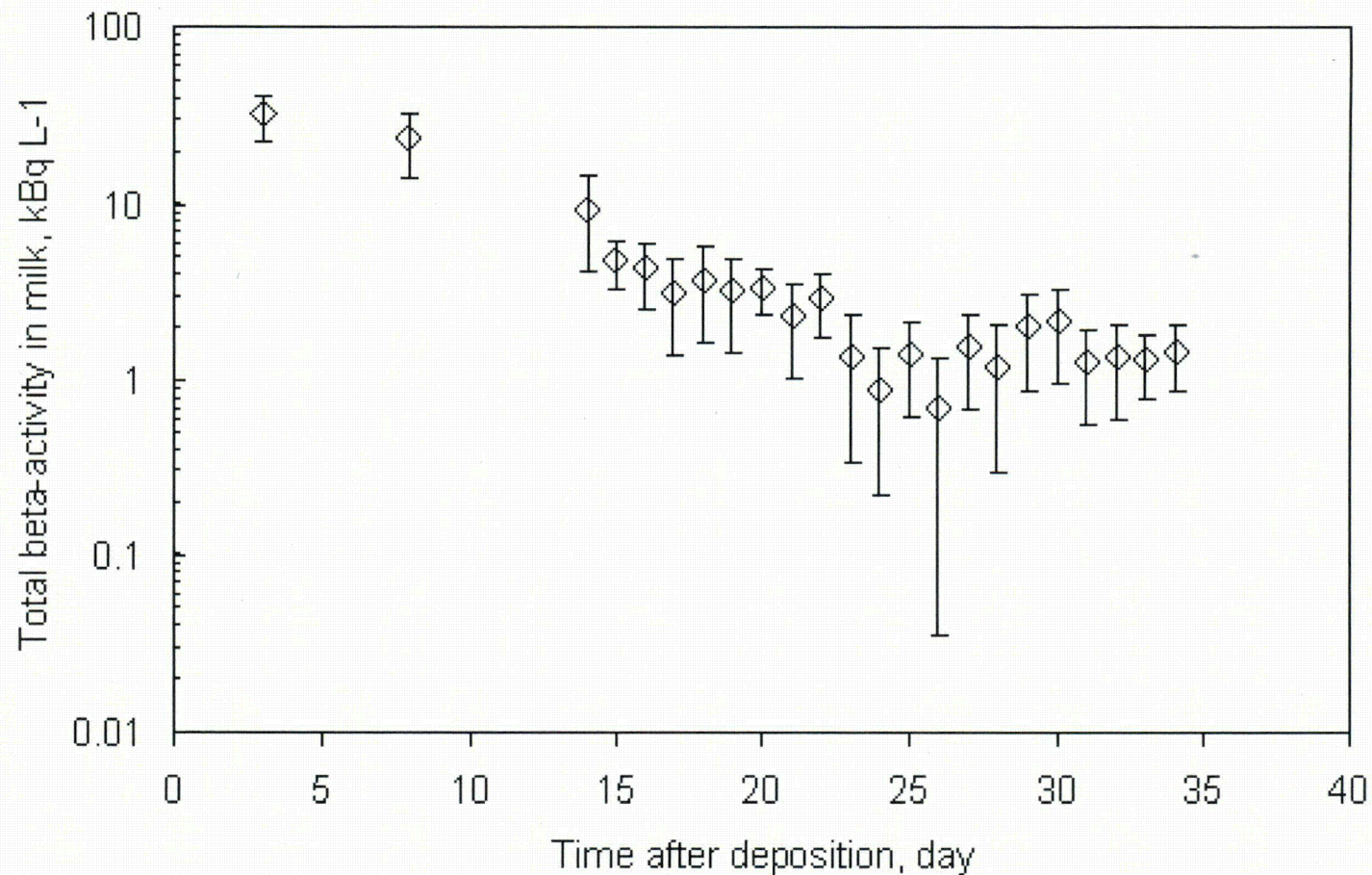


Fig. 1. Daily average total beta-activity in milk (kBq L<sup>-1</sup>) in Brest Oblast (Belarus)

Courtesy of **Vladimir Drozdovitch**

# What are the total 20 year doses? General Population

49.0 rad – Thyroid – 115,000 evacuees

3.1 rem – effective dose

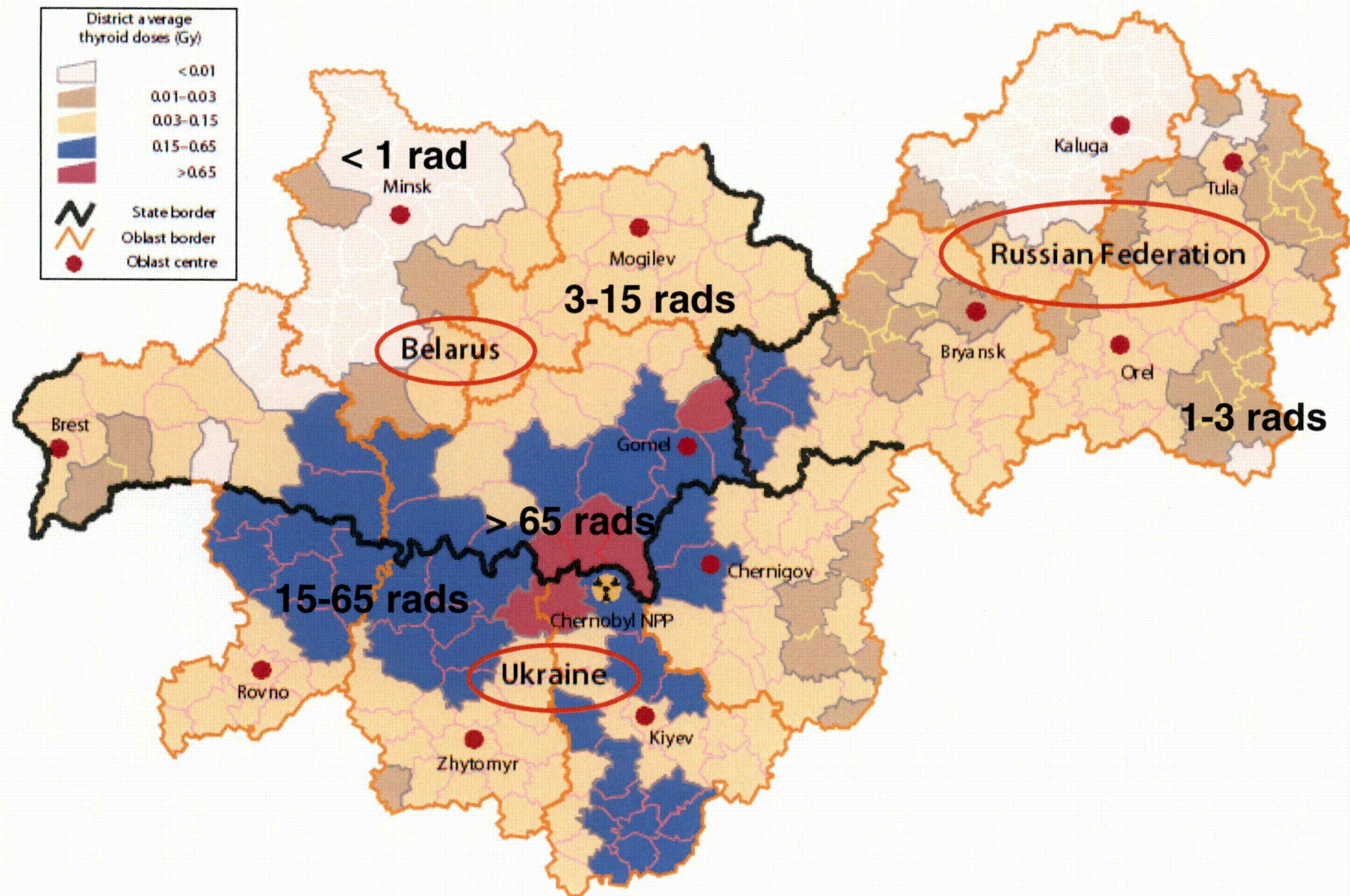
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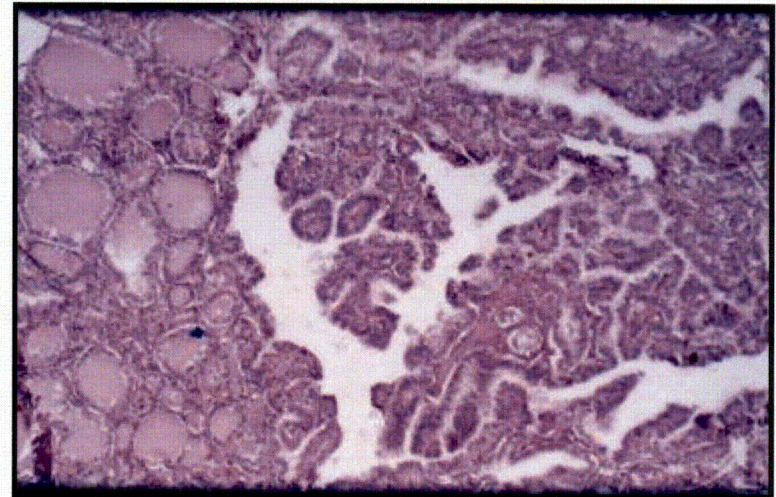


Figure V. The estimated average thyroid doses to children and adolescents living at the time of the accident in the most affected regions of Belarus, the Russian Federation and Ukraine [I14, K22, K25, L4, Z4]

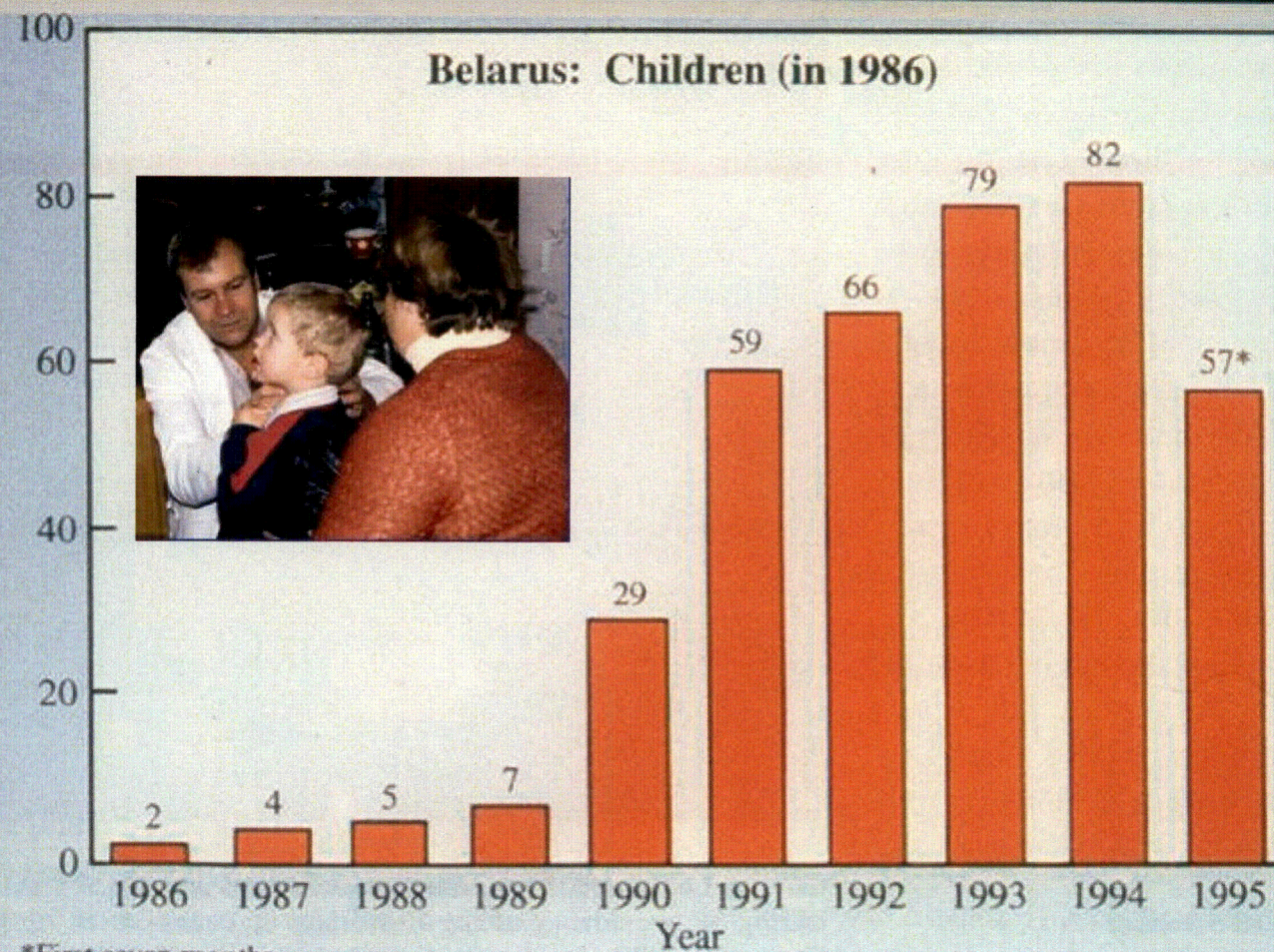


# Thyroid Cancer

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# Thyroid Cancers in Children in Belarus



— By Bruce W. Wachholz, Ph.D.  
National Cancer Institute

# Thyroid Cancer Incidence Among Children and Adolescents Exposed in 1986

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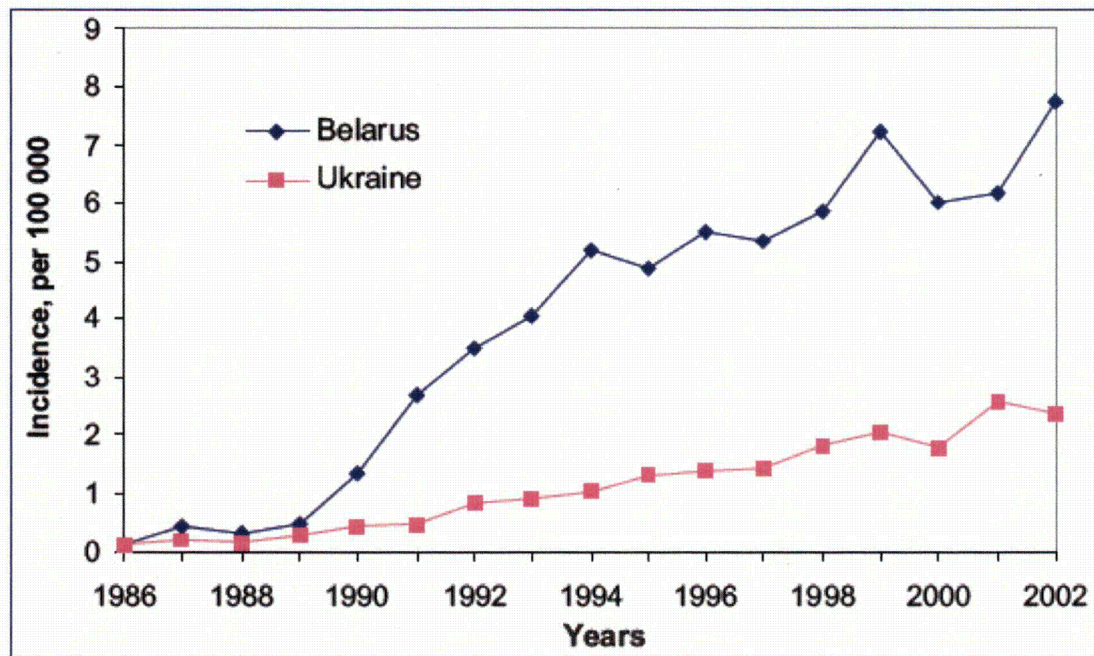


FIG. 3. Incidence rate of thyroid cancer in children and adolescents exposed to  $^{131}\text{I}$  as a result of the Chernobyl accident (after Jacob et al., 2005).

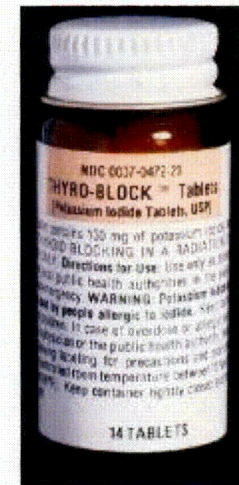
# Thyroid Cancer (IARC 2005)

## Risk Varies by KI and Endemic Goiter

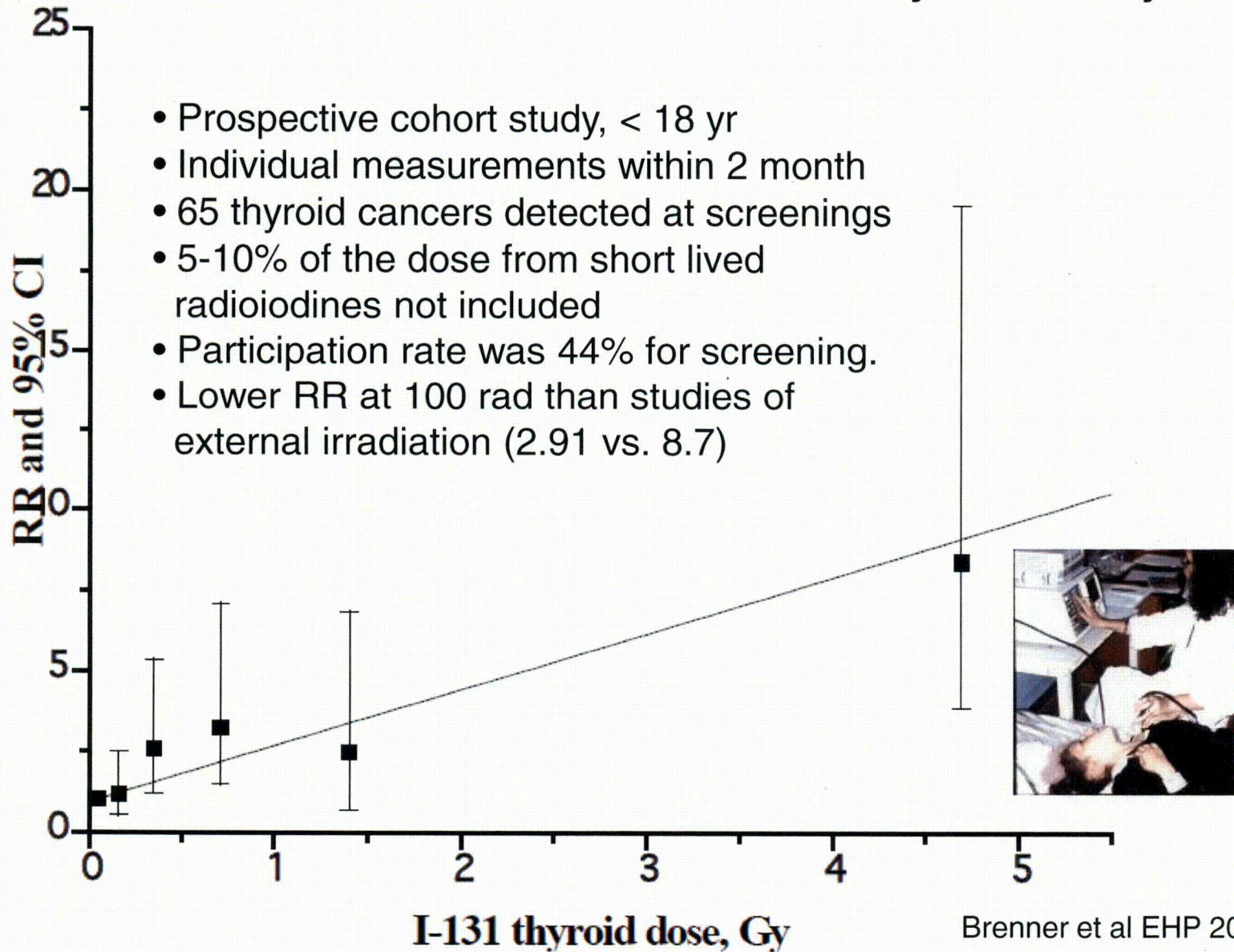
Consumption of potassium iodide	RR at 100 rad (95% CI)	
	Highest two tertiles of soil iodine	Lowest tertile of soil iodine
<b>No</b>	<b>3.5 (1.8 to 7.0)</b>	<b>10.8 (5.6 to 20.8)</b>
Yes	1.1 (0.3 to 3.6)	3.3 (1.0 to 10.6)

Lower risk seen among children with normal levels of stable iodine in diet.

Cardis *et al.* JNCI 97:724, 2005



# Ukrainian – American Thyroid Study



- Prospective cohort study, < 18 yr
- Individual measurements within 2 month
- 65 thyroid cancers detected at screenings
- 5-10% of the dose from short lived radioiodines not included
- Participation rate was 44% for screening.
- Lower RR at 100 rad than studies of external irradiation (2.91 vs. 8.7)

# Thyroid Cancer and Chernobyl

## Cautions in Interpreting

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- Increased thyroid cancer in children (6,000 cases)
- 15 deaths due to thyroid cancer
- Intense screening
- Short-lived radioiodine exposures
- Limited individual dosimetry (ecological, dietary recall)
- Diets deficient in iodine [associated with more active thyroid glands (mild goiter)] – enhance risk
- Potassium Iodide supplementation
- Caution in generalizing to other populations



# Psychological, Mental and Nervous System Effects

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- Consensus

- Psychological effects are the largest public health impact from the accident
- High levels of anxiety and unexplained medical complaints continue up to the present

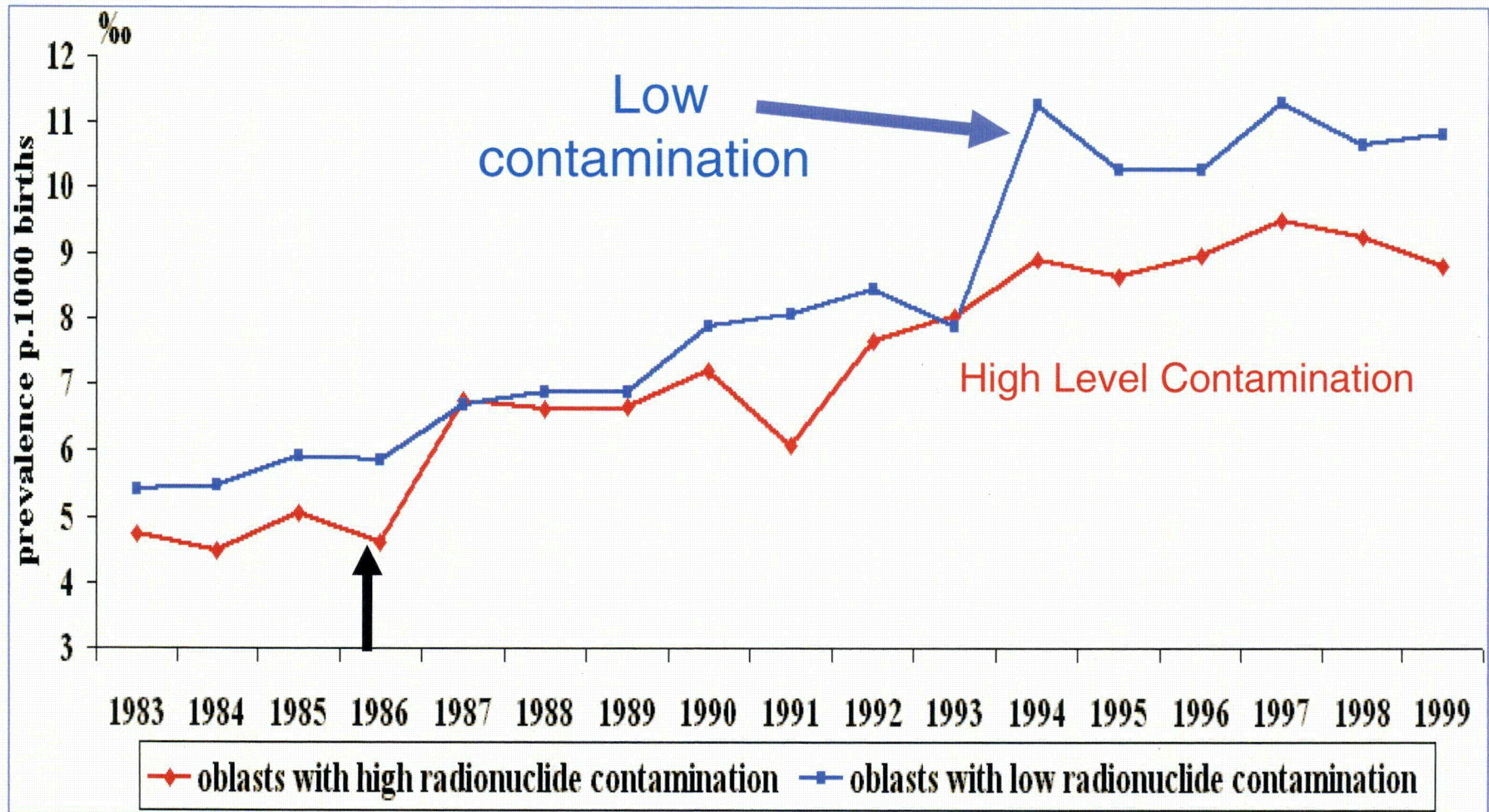


# Unsubstantiated Health Effects General Population

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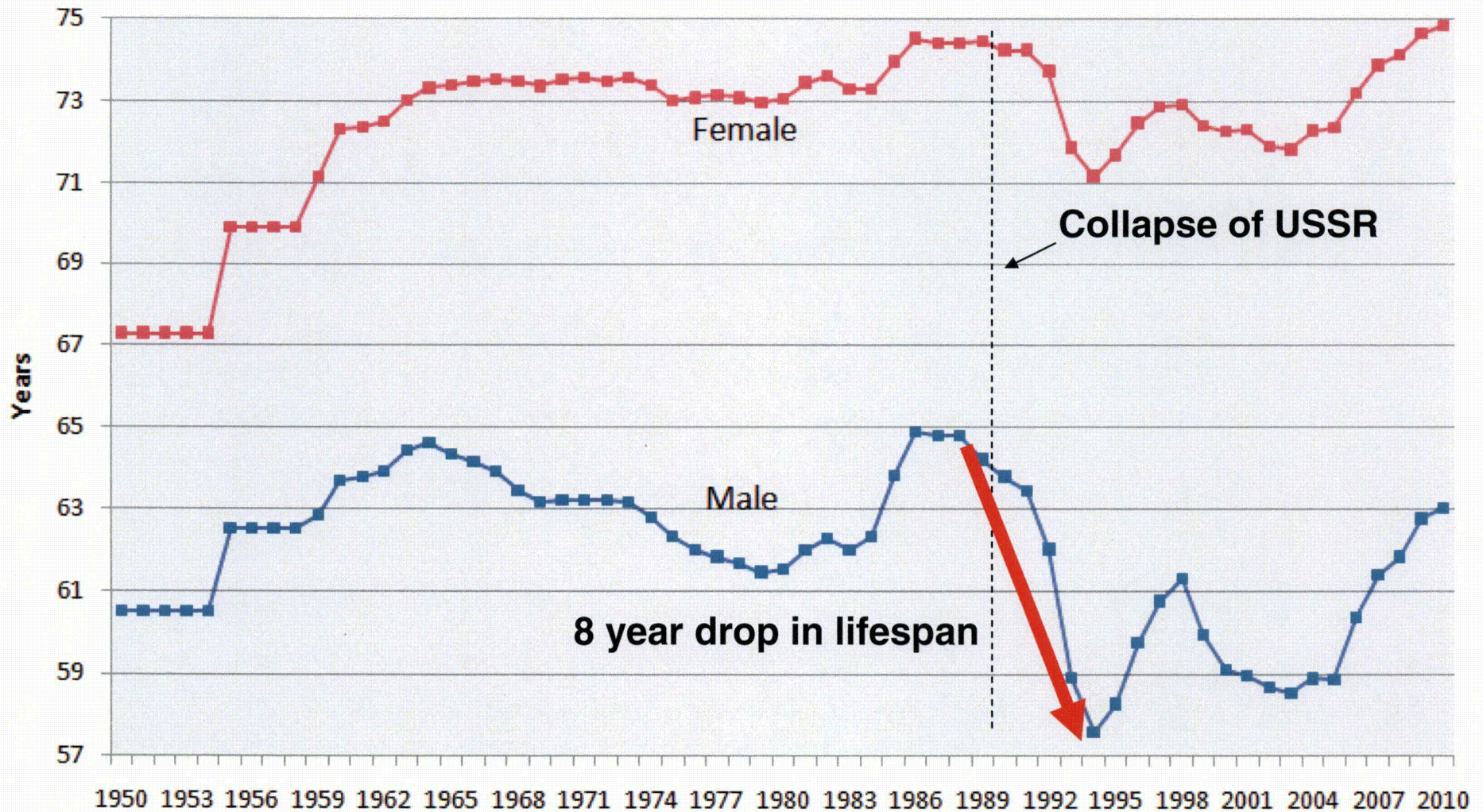
- **Childhood Leukemia**: Analytical and cancer registry studies provide little convincing evidence of an increased risk of childhood leukemia
- **Birth Defects**: Prevalence rates are the same in areas with high and low radionuclide deposition
- **Breast Cancer**: Ecological, no pattern with radionuclide deposition, no temporal pattern, inconsistent results cannot be reliably interpreted.

# Prevalence of congenital malformations in Belarus oblasts has risen but rise is not related to level of radionuclide contamination



# Pronounced Changes in SES and Health

## Russian Life Expectancy



# Effects of Dramatic Health Status Changes

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In Russia there have been pronounced changes in mortality linked to increased **alcohol** consumption following socio-economic crises.

These major influences upon the health of the Russian population illustrate the problems of trying to extract a signal of the Chernobyl accident from a baseline rate that is variable due to the substantial impact of other factors.



# New Knowledge on Health Effects

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- Early deaths from acute radiation sickness
- Significant skin burns on emergency workers
- Higher than anticipated radiosensitivity of the lens of the eye
- Thyroid cancer among children who drank milk contaminated with radioiodines
- Psychological effects

# Continue Studies but ...

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Recovery workers could provide data on the effects of protracted exposure.

However, the difficulties associated with such studies should not be underestimated.

Studies in regions that are susceptible to socio-economic instability are prone to many biases and confounding influences that significantly complicate the interpretation of results

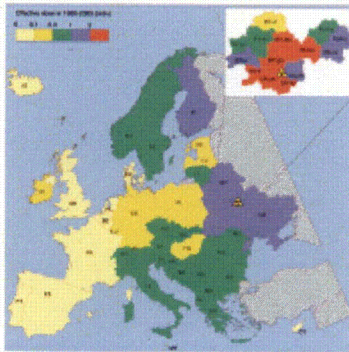


# Dose Comparison Perspective

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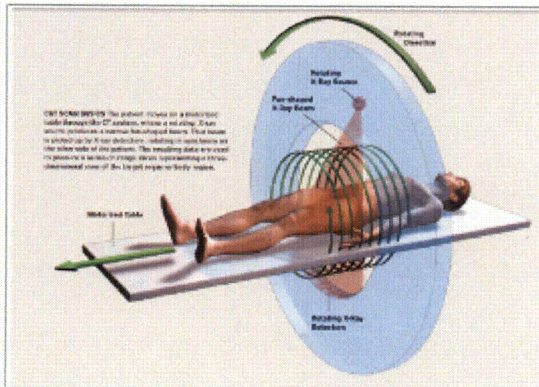
- Worldwide dose from Chernobyl:

400,000 person-Sv



- U.S. dose (2006) from radiology and nuclear medicine:

880,000 person-Sv



# Perspective on Future Studies

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Future Chernobyl studies will confirm and enhance qualitative conclusions

Questionable whether quantitative estimates of risk will be possible that would advance knowledge or change understanding of low dose rate effects

- Estimates of dose highly uncertain
- Difficulties in conducting such studies cannot be overestimated
- Generalization will be problematic

The Major Remaining Question in Radiation Epidemiology

- The level of risk when exposure received over time and not briefly

Barcellos-Hoff MH, Brenner DJ, Brooks AL, Formenti S, Hlatky L, Locke PA, Shore R, Tenforde T, Travis EL, Williams J. Low-dose radiation knowledge worth the cost. Science. 2011 Apr 15;332:305-6.

Being addressed by

- One Million U.S. Radiation Worker Study (DOE, DOD, NRC, medical workers)

**U.S. Low Dose  
Radiation Research  
Program**



# *Special Thanks to*

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