Radiation Effects on Non-Human Biota:
Do we ***really*** need more data?

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Institut de Radioprotection et de Sûreté Nucleairé

IOP PUBLISHING JOURNAL OF RADIOLOGICAL PROTECTION

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INVITED EDITORIAL

Mike Thorne
Mike Thorne and Associates Limited

Protecting humans and the environment

More than a decade later, there has been much debate, various international projects, formation of a new ICRP Committee, but, as yet, there is no agreed position to be carried forward into safety standards. Why is this? Is this issue so intractable? Or is it, as some cynics have suggested, a non-problem talked up by radioecologists to give them something to do as work related to the Chernobyl accident has declined?

Do we *really* need more data?

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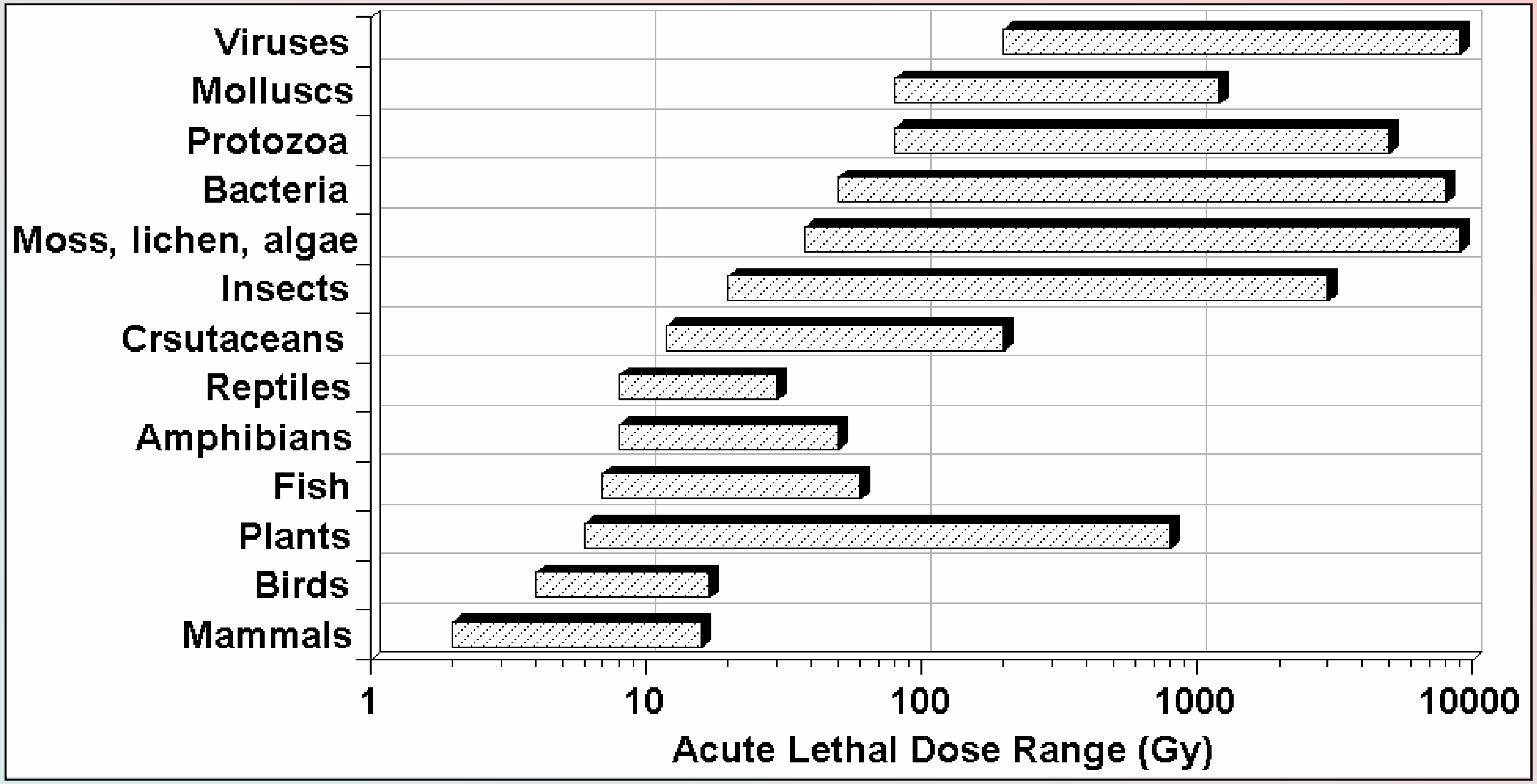
If we protect humans then all other things are protected as well....

Acute Lethal Dose Ranges

(Whicker and Schultz, 1982)



Do we *really* need more data?

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Journal of Environmental Radioactivity 80 (2005) 1–25

JOURNAL OF ENVIRONMENTAL RADIOACTIVITY

www.elsevier.com/locate/jenvrad

Comparative radiation impact on biota and man in the area affected by the accident at the Chernobyl nuclear power plant

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...a test to see if radiation standards that protect man adequately protect biota as well

Fesenko et al. 2005.

Radiation Impact Factor (RIF) for both humans and biota

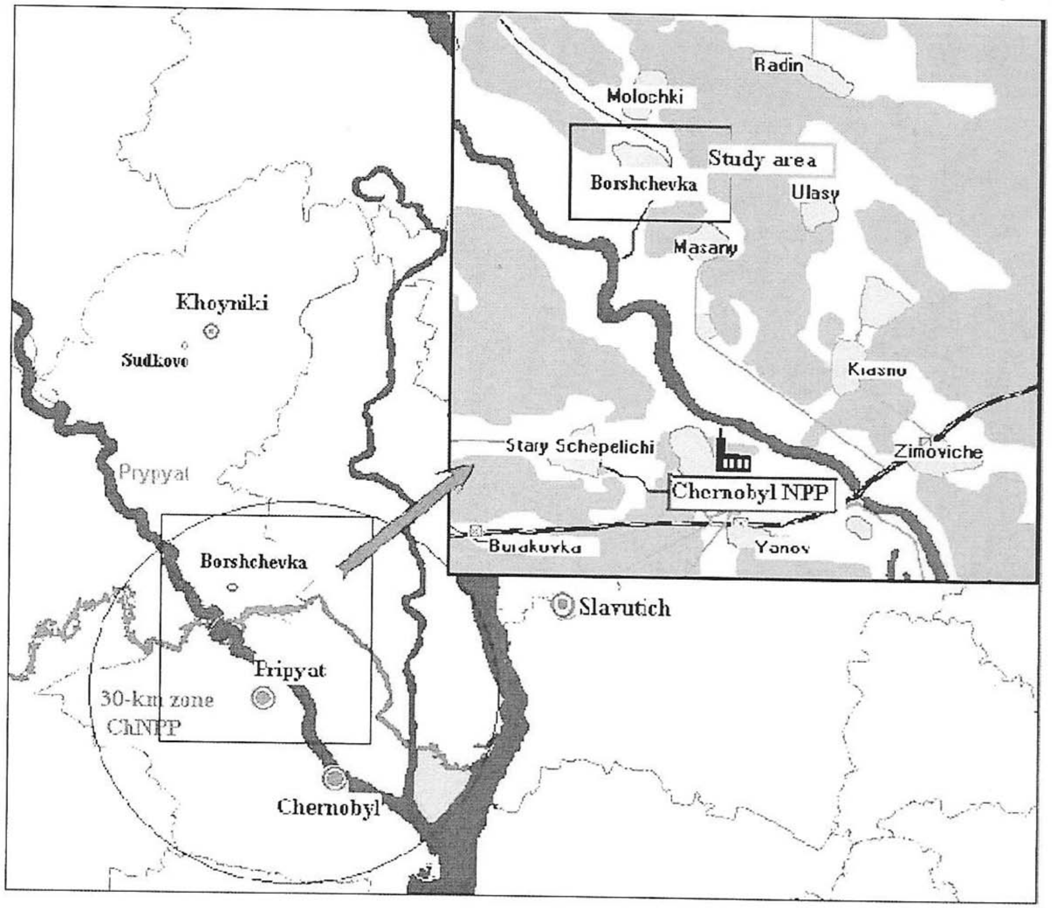


Fig. 1. Location of the study area.

RIF = Ratio of Actual Dose / Critical Dose

Compared RIF for humans and biota in 1986 and 1991.

RIF < 1 is desired

Table 6
RIF_b values calculated for non-human species in the study area, dimensionless

Biota species	1986	1991
Terrestrial ecosystems		
Coniferous trees (pine)	9.3	0.08
Herbaceous plants (meadow grasses)	5.0	0.013
Herbaceous plants (cereals)	2.7	0.013
Cattle	3.0[a] (2.7)	0.10
Mouse-like rodents	1.5	0.15
Soil invertebrates	5.1	0.17
Aquatic ecosystems		
Phytoplankton	0.020	1.1×10^{-4}
Zooplankton	0.072	2.5×10^{-4}
Zoobenthos	0.78	0.26
Fish	0.67	0.067

[a] Dose to the thyroid.

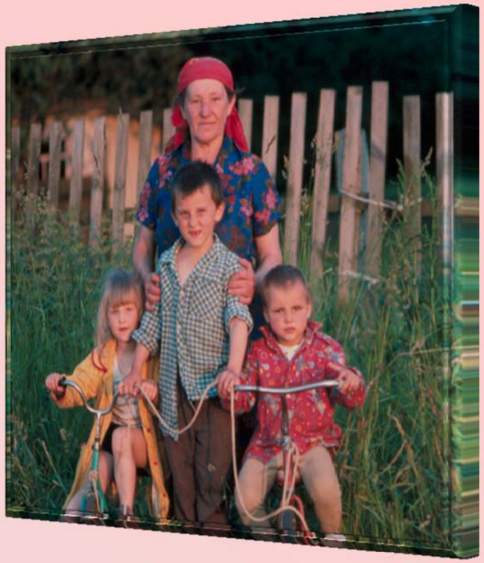
Table 5
RIF_h values calculated for population of the study area, dimensionless

CDV_h	1986		1991	
	Before evacuation (May 4, 1986)	26.04–15.09	With countermeasures	No countermeasures
1 mSv/a	–	–	21.4	38.0
5 mSv/a	–	–	4.3	7.6
50 mSv/a	1.1 (0.64[a])	5.9 (0.9[a])	–	–
100 mSv/a	0.54 (0.64[a])	2.9 (0.9[a])	–	–

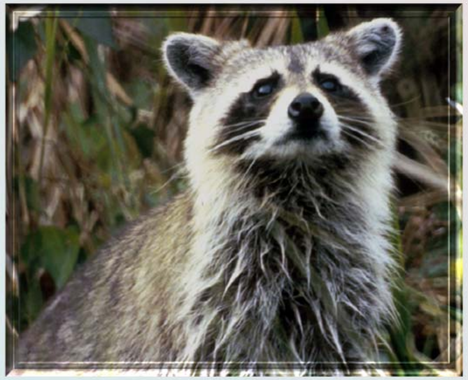
[a] Dose to the thyroid.

protected from ionising radiation". A considerable excess of RIF_h compared to RIF_b in the long term after the accident (1991) ($RIF_b < 1$ and $RIF_h > 1$) suggests that in the case considered in the current study (long term after the accident) man is not protected from irradiation and biota species, on the contrary, are protected, i.e. the thesis "if man is protected then biota are also protected" proves to be correct. At the same time, it should be stressed that this stems from the conservatism of standards currently adopted in the radiation protection of man.

Do we *really* need more data?



Humans are thought to be protected
at a dose rate of
1 mGy / *year* …



…populations of terrestrial biota are
thought to be protected at a dose rate of
1 mGy / *day*

(1 mGy / d = 365 mGy / year)

Thus, by limiting radiological exposures such that humans are protected, the terrestrial animals benefit from a 365-fold “protection buffer”.

Do we *really* need more data?

Four reasons why we DO need more data

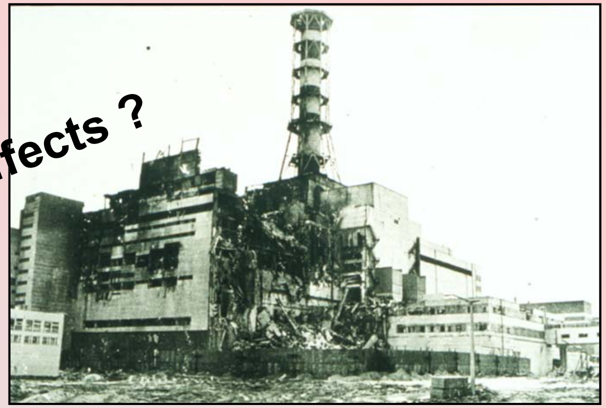
Controversy and data gaps

A hallmark of Chernobyl information has been <u>CONTROVERSY</u>….

Quantity Initially Released ?

Public evacuation ?

Ecological Effects ?



Long term effects ?

26 April 1986

Costs ?

Remediation ?

Mutation rates ?

Psychological problems ?

Childhood thyroid cancers ?

Human mortality ?

Extent of contaminant dispersal ?

Fuel particle contribution ?

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In 2004 – 2006, the IAEA established the CHERNOBYL FORUM

Goal of reaching international consensus and eliminating the controversy about the effects of the Chernobyl accident

CHERNOBYL FORUM

World Health Organization

International Atomic Energy Agency

United Nations Development Programme

Food and Agriculture Organization

United Nations Environment Programme

United Nations Office for the Coordination of Humanitarian Affairs

United Nations Scientific Committee on the Effects of Atomic Radiation

The World Bank

Belarus

Russian Federation

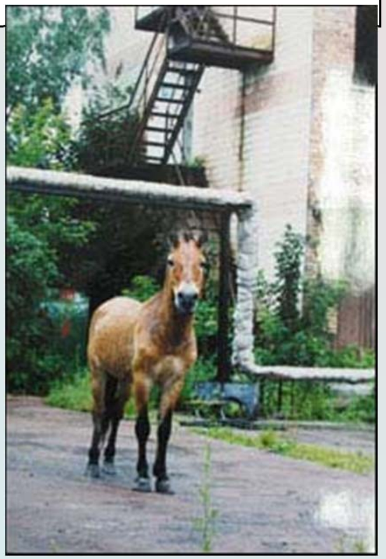
Ukraine

20 April 2006

Wildlife defies Chernobyl radiation

By Stephen Mulvey
BBC News

« It contains some of the most contaminated land in the world, yet it has become a haven for wildlife - a nature reserve in all but name. »



14 August 2007

Chernobyl 'not a wildlife haven'

By Mark Kinver
Science and nature reporter
BBC News

« The idea that the exclusion zone around the Chernobyl nuclear power plant has created a wildlife haven is not scientifically justified, a study says. »

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Controversy Continues

guardian.co.uk

Letters

An unbiased study of the consequences of Chernobyl is needed

The Guardian, Monday 18 January 2010

« …**The widely varying assessments of the numbers of deaths attributable to Chernobyl illustrate the need for a definitive unbiased long-term assessment of the overall consequences of the accident, as well as the need to maintain a sense of perspective**…

…**Fear of radiation thrives on uncertainty, and is exacerbated by concern that reassurances from the nuclear industry cannot be trusted**… »

Pre-Chernobyl...

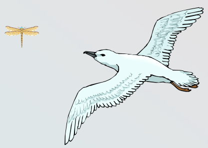
wealth of data about the biological effects of radiation on plants and animals

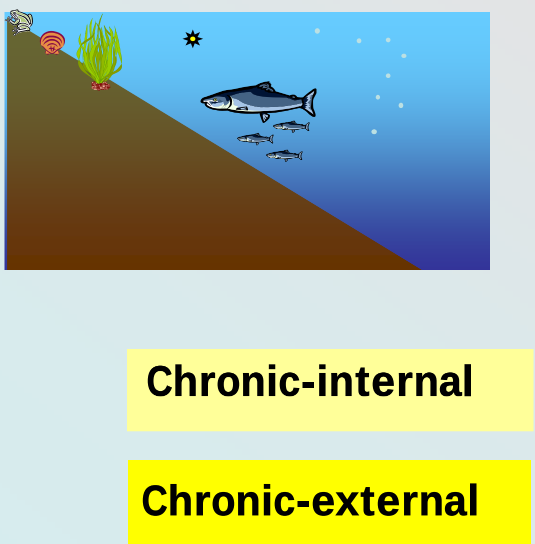
early data came from...

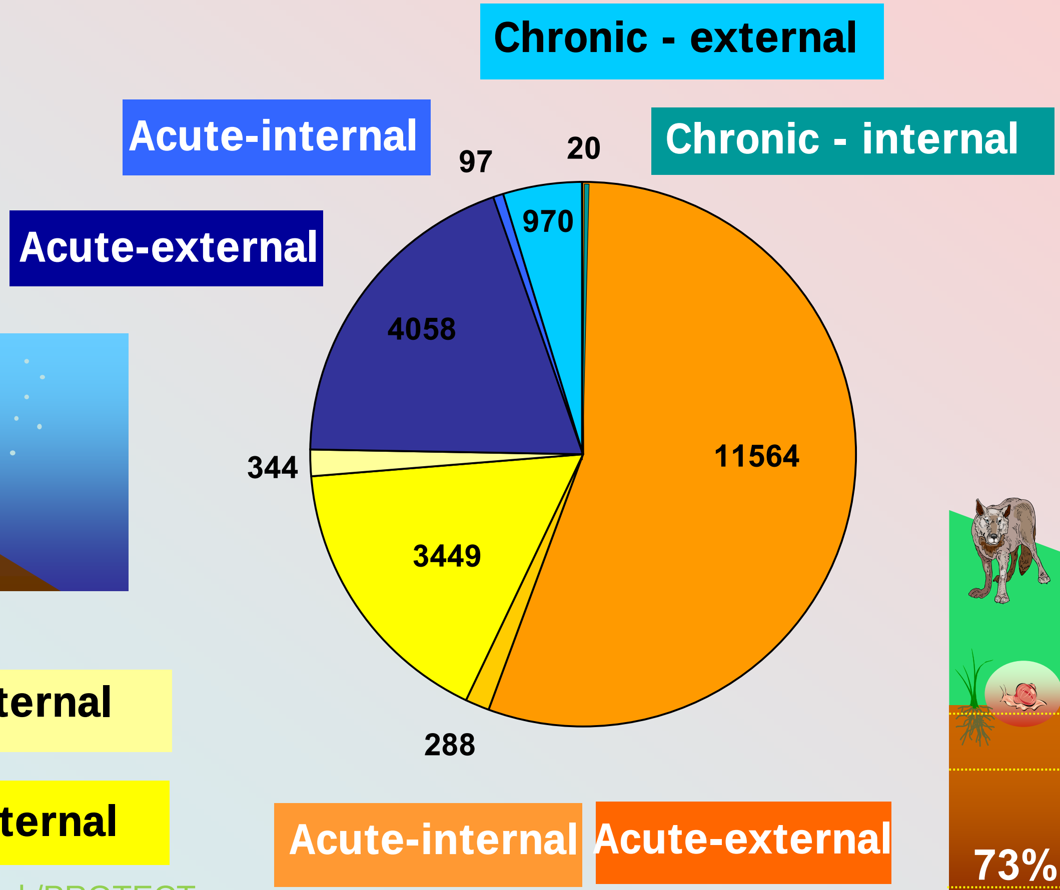
- laboratory exposures
- accidents (Kyshtym, 1957)
- areas of naturally high background
- nuclear weapons fallout
- large-scale field irradiators

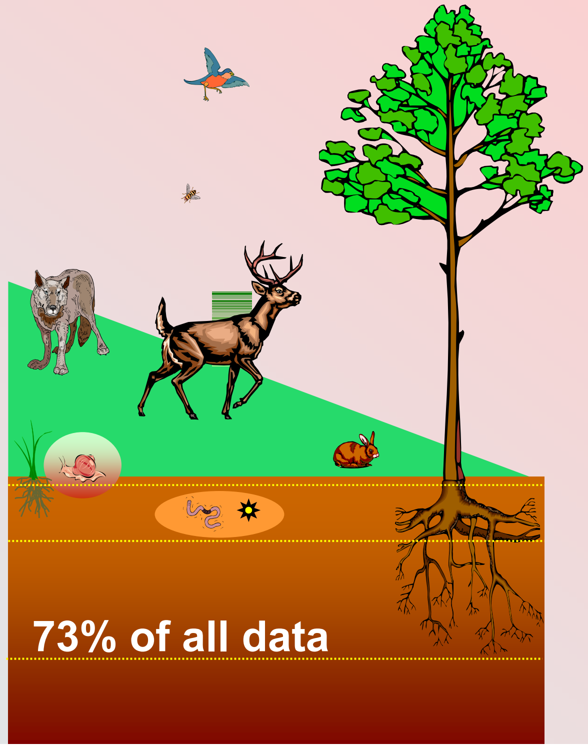
FREDERICA Database

effects data; per ecosystem
per exposure pathway (external or internal irradiation)
per duration (acute or chronic)









www.ceh.ac.uk/PROTECT

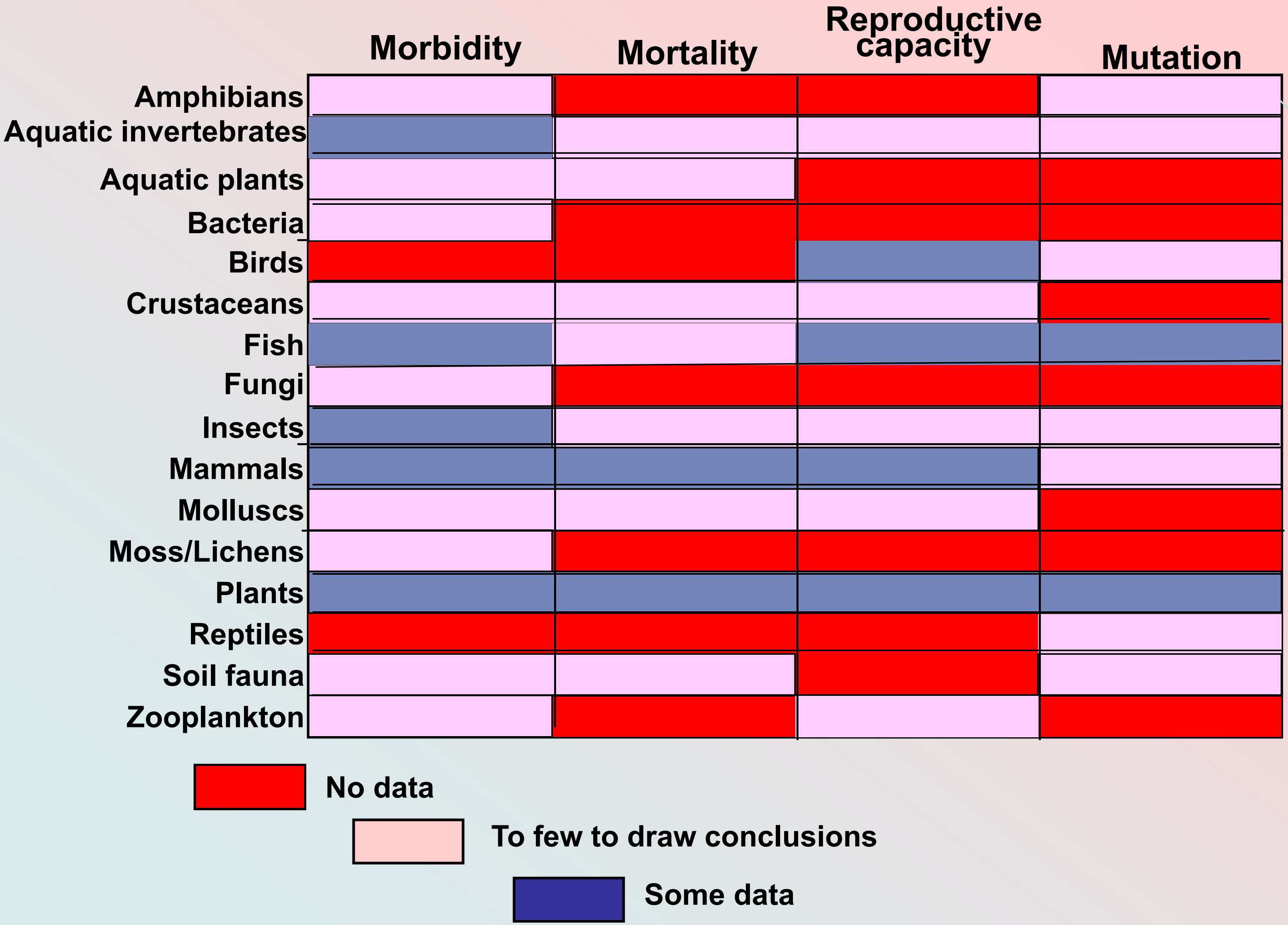
Data on radiation effects for non-human species

Chronic effects and γ external irradiation

	Morbidity	Mortality	Reproductive capacity	Mutation
Amphibians				
Aquatic invertebrates				
Aquatic plants				
Bacteria				
Birds				
Crustaceans				
Fish				
Fungi				
Insects				
Mammals				
Molluscs				
Moss/Lichens				
Plants				
Reptiles				
Soil fauna				
Zooplankton				

Data on radiation effects for non-human species

Chronic effects and γ external irradiation



Most Contaminant Research Is Not Directly Relevant to Responses in Nature

Data Exists but Least Relevant	Data Scarce but Most Relevant
Individual response	Population response
Mortality	Reproduction
Acute exposure	Chronic exposure
External gamma	Multiple exposure route
Laboratory	Field
Short-term	Long-term
Direct effects	Indirect effects

Four reasons why we DO need more data

Controversy and data gaps

Confusion over endpoints

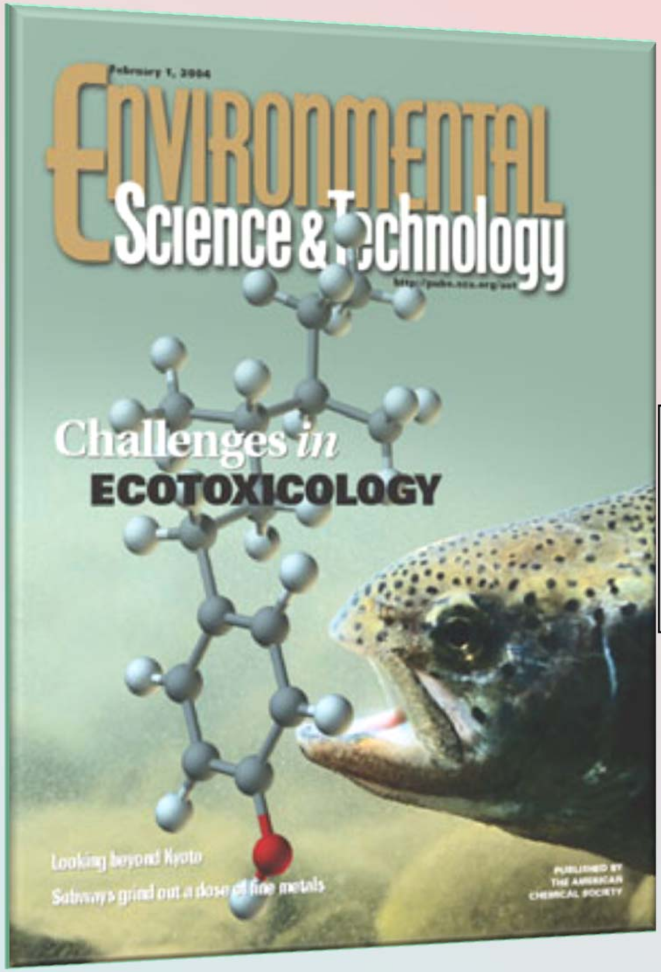
Fundamental Differences In Human and Ecological Risk Analyses

Type	Unit of Observation	Endpoint	Dose-Response
Human	individual	lifetime cancer risk	relationships established
Ecological	varies	varies	not established

population, community, ecosystem

> mortality, < fecundity, sublethal effects

for chronic, low level exposure to radiation, alone, or mixed with other contaminants



Which Endpoint?

41 studies that included 28 species and 44 toxicants

(Forbes & Calow, 1999)

Population Growth Rate

52% — Time to reach sexual maturity

31% — Reduction in number of offspring

Mortality of juveniles — No correlation

Mortality of adults — No correlation

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Scarcity of long-term multigenerational studies

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KYSHTYM accident; September 1957; **chronic 90Sr** (Sazykina & Kryshev, 2006; EPIC)			
Species	**mGy/d**	**Gy**	**Effect**
Microtus (vole; fenced study in early 1960s)	60	12 -20	Overwintering mortality increased Exposed: 60.9 % Control: 17.6 % Altered aged structure of population; Exposed: 98% young; 2% old Control: 50% young; 50% old Ilyenko
Apodemus (wood mouse; 20th generation field caught and kept in vivarium; 1981)	0.6 to bones	0.2	Longevity reduced in exposed animals Exposed: 344 ± 53 d Control: 433 ± 134 d (+ 20 %) Krapivko
Apodemus (wood mouse; 1990s)	11	4.3	5 to 10 % reduction in the reproductive period of exposed animals, compared to controls Spirin et al.

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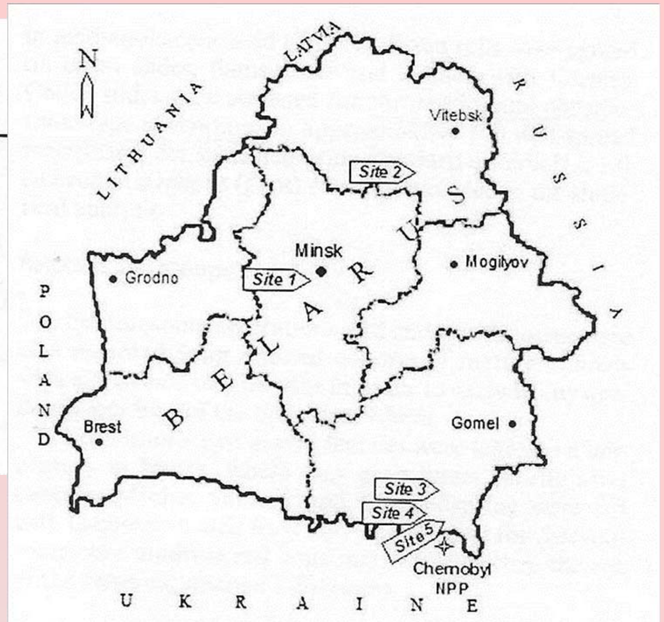
Radiat Environ Biophys (2006) 45: 167–177
DOI 10.1007/s00411-006-0054-3

ORIGINAL PAPER

Nadezhda I. Ryabokon · R. I. Goncharova

Transgenerational accumulation of radiation damage in small mammals chronically exposed to Chernobyl fallout

Institute of Genetics and Cytology
National Academy of Sciences of Belarus



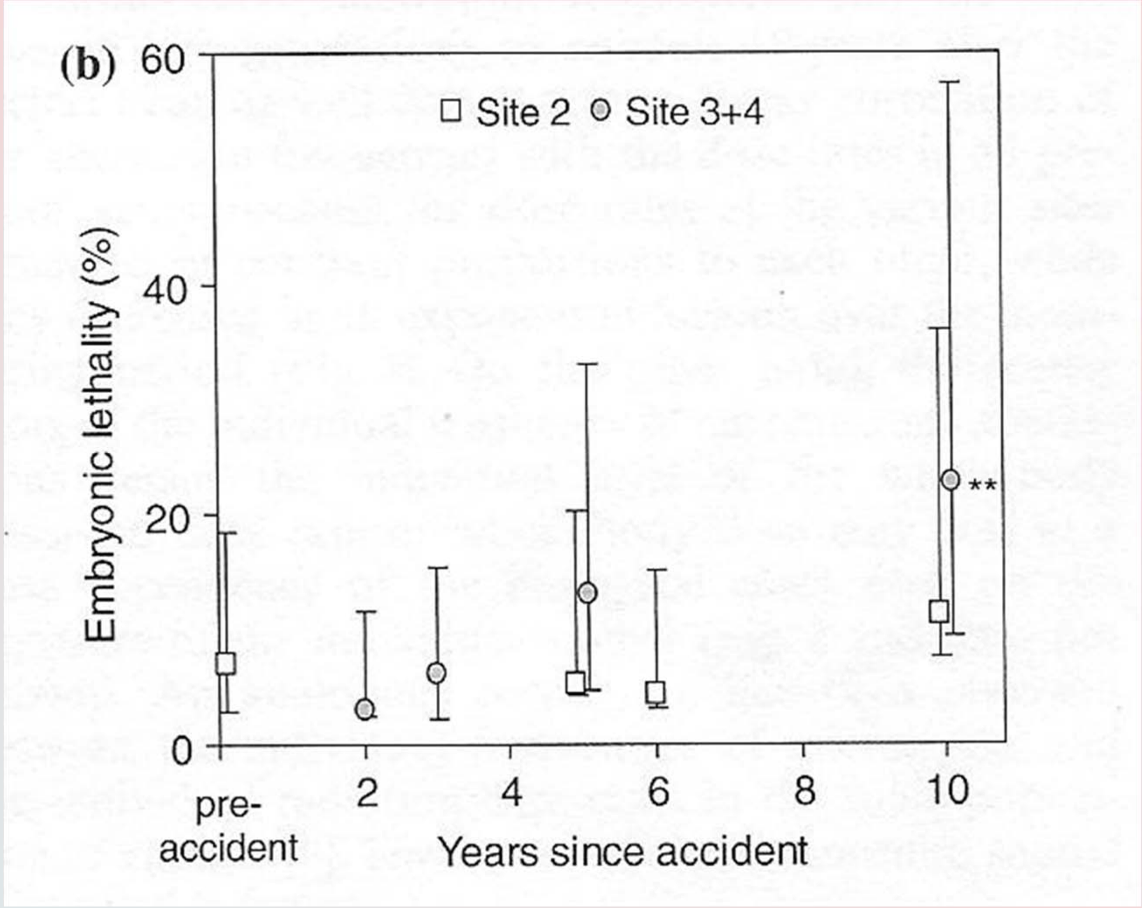
Biological damage in bank voles (*Clethrionomys spp*.) over 22 generations (1986 to 1996).

Dose decreased exponentially from highest in 1986 (73 mGy) (corresponding half-time of 2.5 – 3 years)

Chromosome aberrations (CA) in bone marrow were dose dependent and 3 to 15 times more abundant than controls

CA remained fairly constant with each generation, even as the dose decreased

Percent mortality of embryos ***increased*** with time



Barn Swallows at Chernobyl

Moller & Mousseau

- carotenoids used for plumage coloration
- carotenoids also used for free-radical scavenging…rather than plumage coloration
- partial albinism observed in barn swallows
- partial albinism correlated to reduced mating success
- clutch size, brood size and hatching success reduced

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Birds prefer to breed in sites with low radioactivity in chernobyl. *Proceedings of the Royal Society B: Biological Sciences* 2007

Bird population declines due to radiation exposure at chernobyl are stronger in species with pheomelanin-based coloration. *Oecologia* , 2010

Elevated frequency of abnormalities in barn swallows from chernobyl. *Biology Letters* 2007

Historical mutation rates predict susceptibility to radiation in chernobyl birds. *Journal of Evolutionary Biology, 2010*

Determinants of interspecific variation in population declines of birds after exposure to radiation at chernobyl. *Journal of Applied Ecology* 2007

Reduced abundance of raptors in radioactively contaminated areas near chernobyl. *Journal of Ornithology* 2009

Reduced abundance of insects and spiders linked to radiation at chernobyl 20 years after the accident. *Biology Letters, 2009*

Chernobyl
‘Shows Insect Decline'

By Victoria Gill,
Science Reporter, BBC NEWS

18 March 2009

“Two decades after the explosion at the Chernobyl nuclear power plant, radiation is still causing a reduction in the numbers of insects and spiders”.

A. Moller and T. Mousseau

biology
letters

Reduced abundance of insects and spiders linked to radiation at Chernobyl 20 years after the accident

Anders Pape Møller and Timothy A Mousseau

Biol. Lett. published online 18 March 2009
doi: 10.1098/rsbl.2008.0778

Four reasons why we DO need more data

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Acute Lethal Dose Ranges

(Whicker and Schultz, 1982)

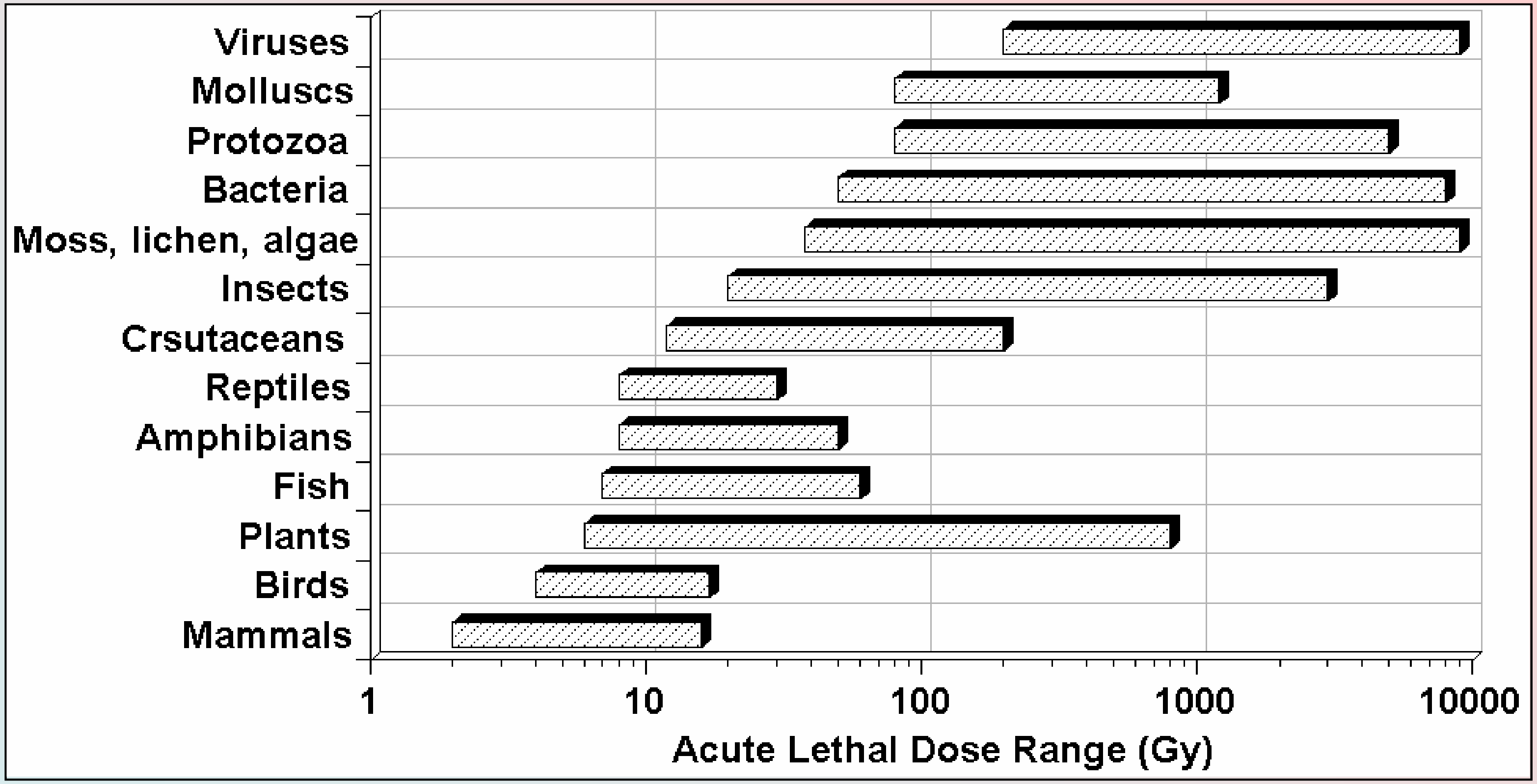


Table 6. Proposed organism group and generic ecosystems HDR_5 values ($\mu Gy\ h^{-1}$) estimated using SSD.

	Number of species	Lowest EDR_{10}	Most sensitive wildlife group (*species*)	SSD_HDR_5* (µGy/h)	r^2	Protect SSD_HDR5** (µGy/h)
plants	9	514	Plant (*Solanum tuberosum*)	192 (79-721)	0.924	n/a
invertebrates	10	35.8	Annelid (*Ophryotrocha diadema*)	43.0 (5.53-744)	0.960	505 (55-4447)
vertebrates	11	2.87	Mammal (*Capra hircus*)	1.4 (0.25-13)	0.951	2.1 (0.3-62)
Generic ecosystems	30	2.87	Mammal (*Capra hircus*)	9.55 (2.00 - 47.2)	0.976	17 (2-211)

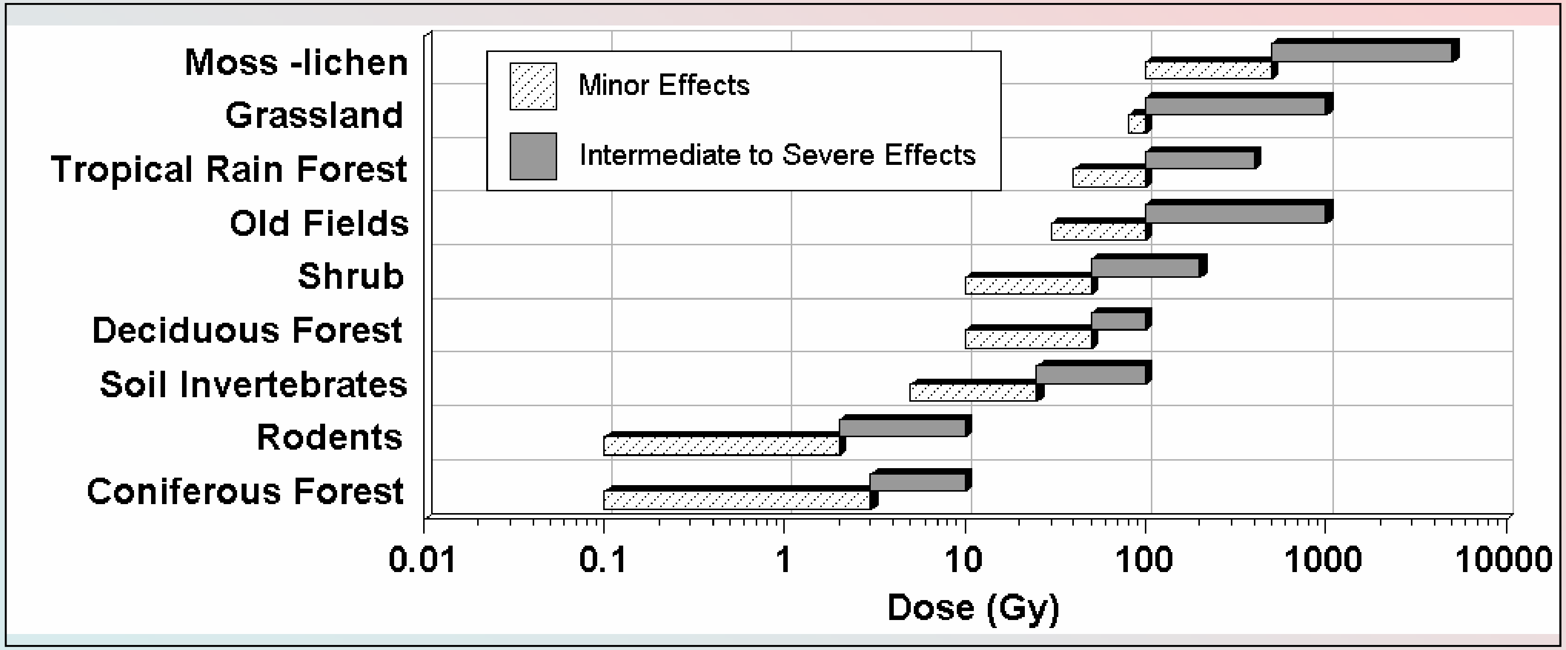
*HDR_5 estimated using SSD : best estimate and associated 95 % confidence limits (in parenthesis)

***see Garnier-Laplace et al., 2010 for details

Pre-Chernobyl…

Effects from Short Term Exposures (5 to 60 d)

- minor effects (chromosomal damage; changes in reproduction and physiology)
- intermediate effects (individual mortality, but population remains viable)



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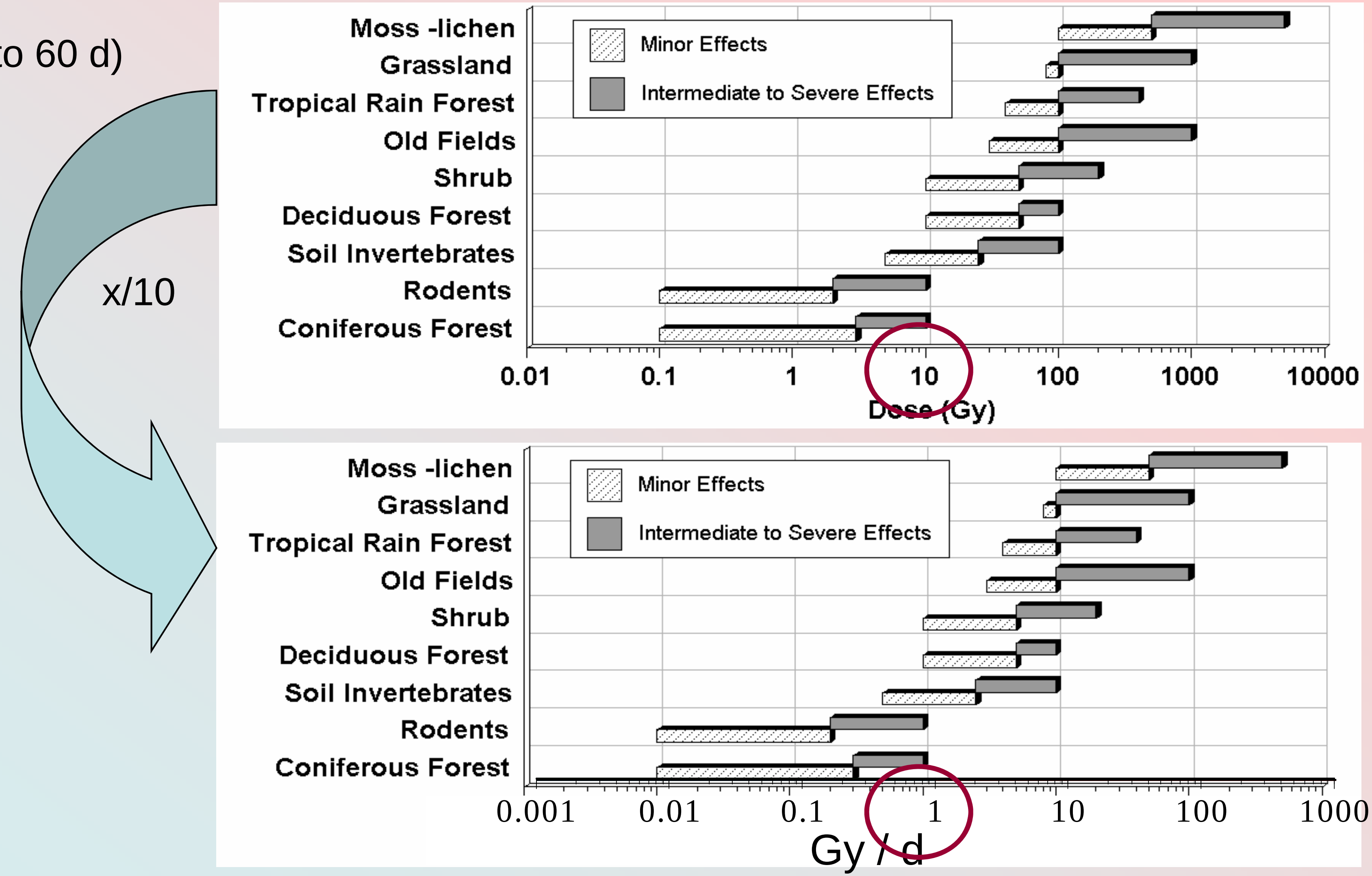
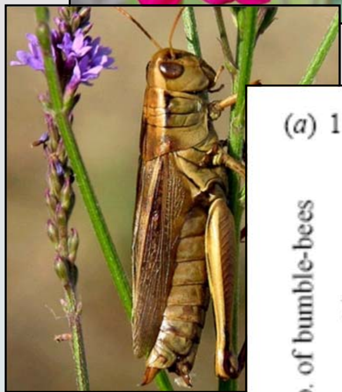
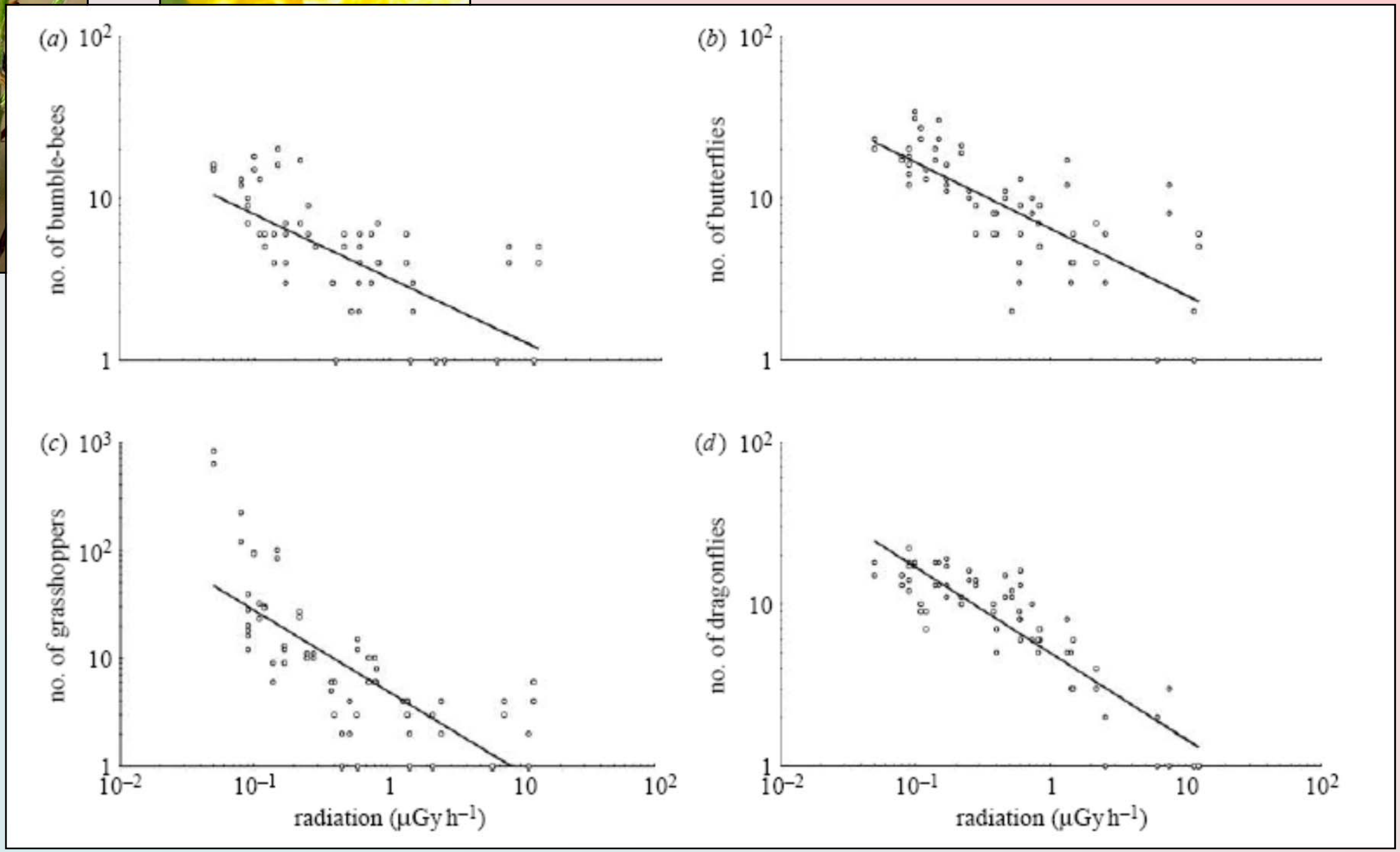
DOSE (Gy) to DOSE RATE (Gy / d) CONVERSION

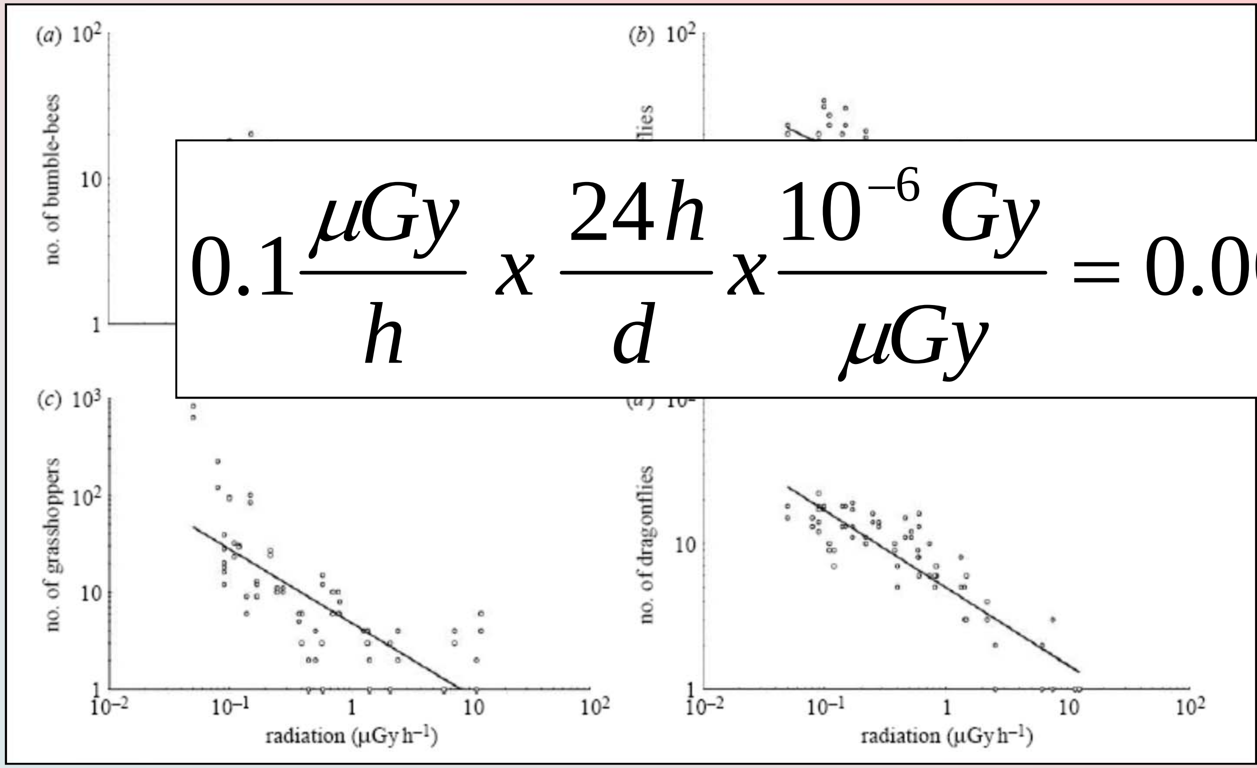
(5 to 60 d)







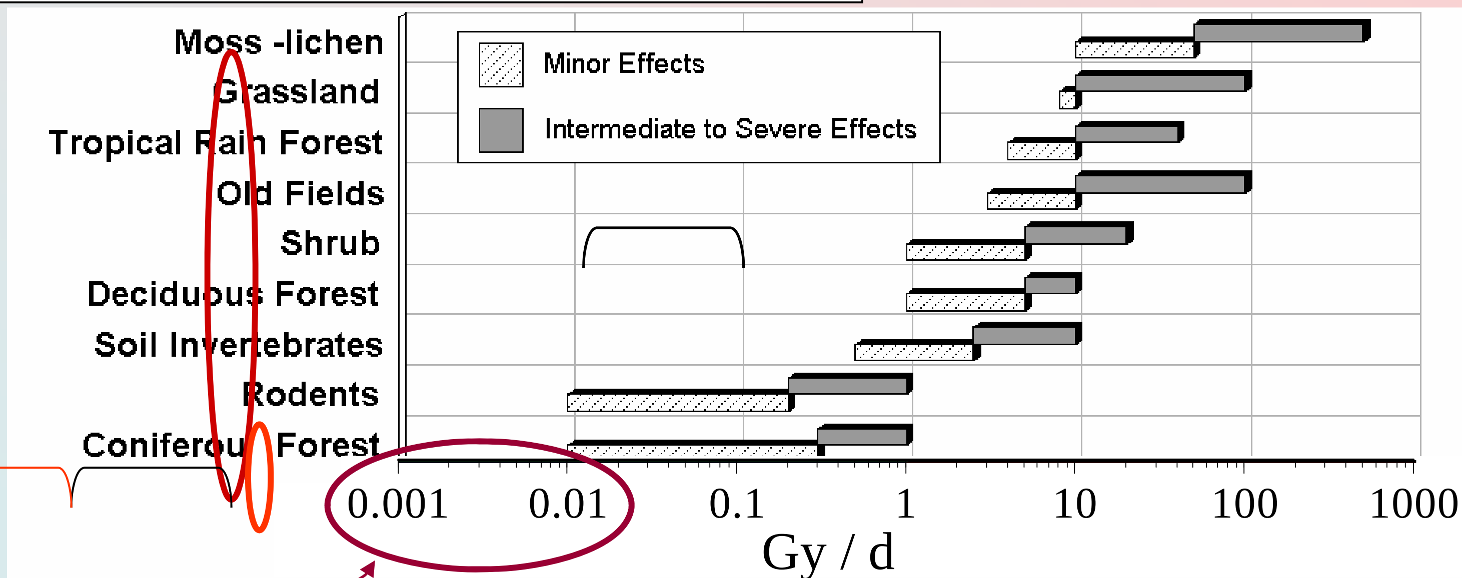
(a)
no. of bumble-bees
(b)
no. of butterflies
(c)
no. of grasshoppers
(d)
no. of dragonflies
radiation (μGy h−1)
radiation (μGy h−1)



$$0.1\frac{\mu Gy}{h} \ x \ \frac{24\,h}{d} \ x \ \frac{10^{-6}\,Gy}{\mu Gy} = 0.0000024\frac{Gy}{d}$$

IAEA
Guidelines
1 & 10 mGy / d

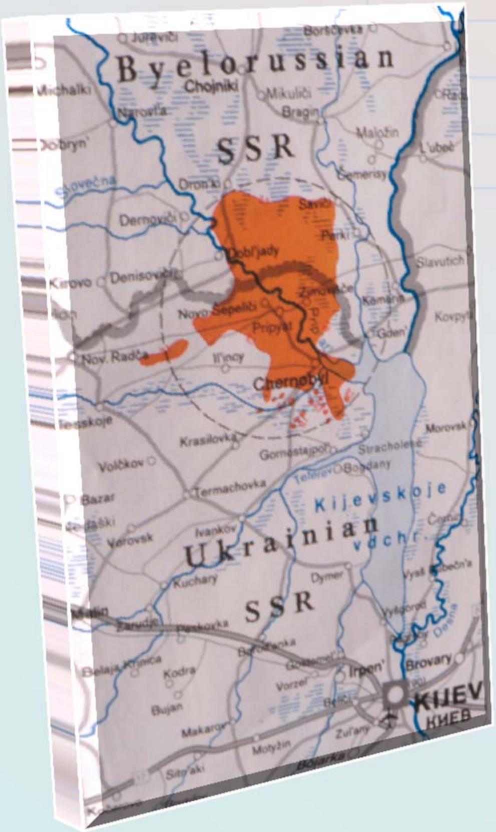
0.000001



CHERNOBYL

Moller and Mousseau

2010	11
2009	4
2008	5
2007	6
2006	2
2005	3
2004	0
2003	1
2002	0
2001	1
	33



JOURNAL	Impact Fact.
Nature	32.2
Science	31.4
Environmental Health Perspectives	6.2
Evolution	5.8
Journal of Applied Ecology	5.6
Ecological Applications	4.6
Journal of Animal Ecology	4.6
Heredity	4.2
Journal of Evolutionary Biology	4.0
Oecologia	3.9
Biology Letters	3.6
Behavioral Ecology	3.4
Microbial Ecology	3.4
Ecological Indicators	3.1
Journal of Ornithology	1.7
Cytology and Genetics	0.2

Controversy and data gaps

Confusion over endpoints

Scarcity of long-term multigenerational studies

Growing abundance of data counter to established paradigms

YES, we *<u>REALLY DO</u>* need more data!!

ELSEVIER
Review
TRENDS in Ecology and Evolution Vol.21 No.4 April 2006
Full text provided by www.sciencedirect.com
SCIENCE DIRECT

Biological consequences of Chernobyl: 20 years on

Anders Pape Møller[1] and Timothy A. Mousseau[2]

The disaster at the Chernobyl nuclear power plant in 1986 released 80 petabecquerel of radioactive caesium, strontium, plutonium and other radioactive isotopes into the atmosphere, polluting 200 000 km^2 of land in Europe. As we discuss here, several studies have since shown associations between high and low levels of radiation and the abundance, distribution, life history and mutation rates of plants and animals. However, this research is the consequence of investment by a few individuals rather than a concerted research effort by the international community, despite the fact that the effects of the disaster are continent-wide. A coordinated international research effort is therefore needed to further investigate the effects of the disaster, knowledge that could be beneficial if there are further nuclear accidents, including the threat of a 'dirty bomb'.

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