Chernobyl, Environmental Effects, and the Dichotomy in Radioecology

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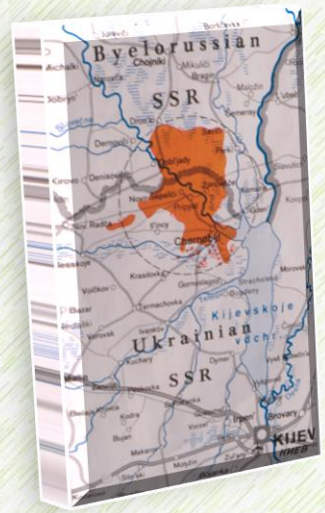
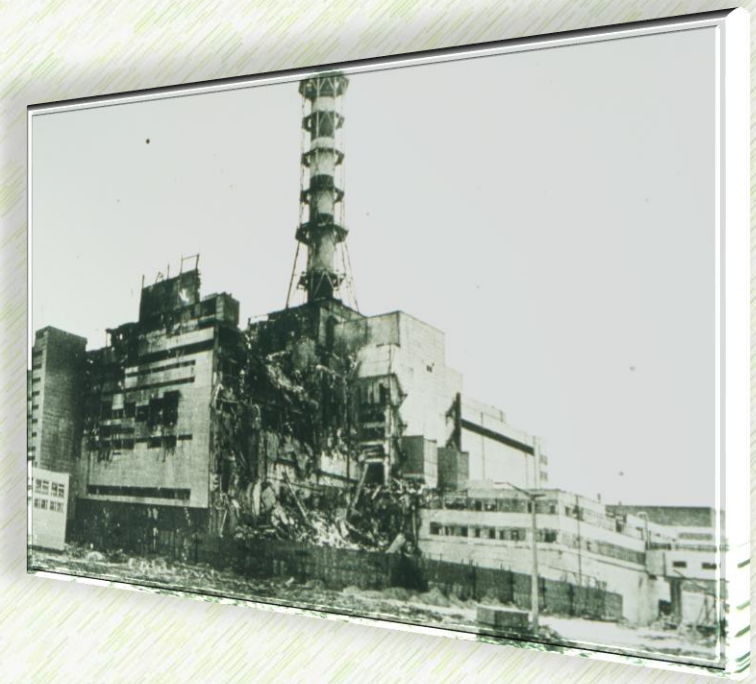
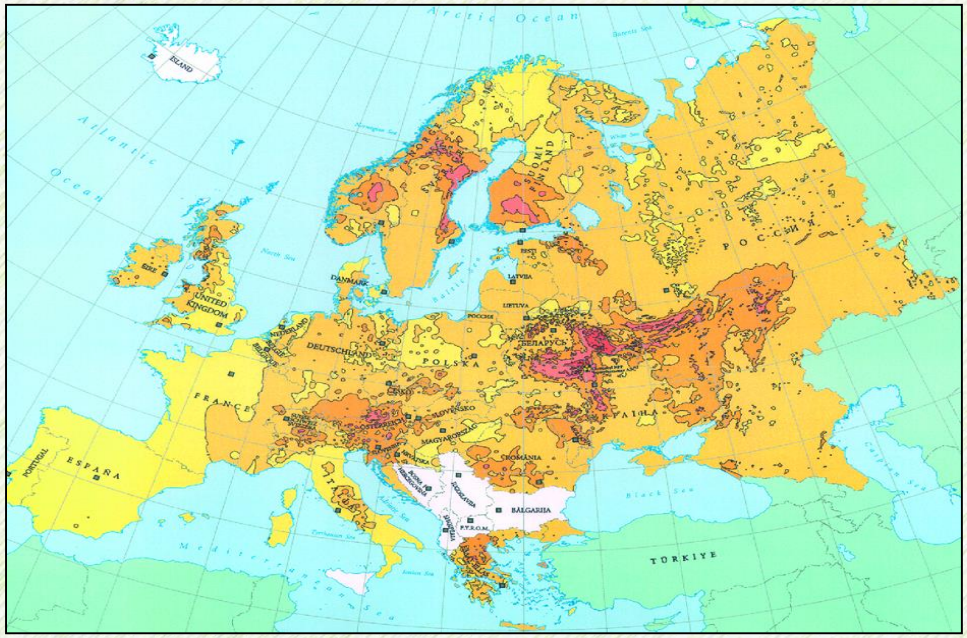
Fukushima University

CHERNOBYL



26 April 1986





Radioactive releases for 10 days

Contaminated 200,000 km^2

350,000 people relocated

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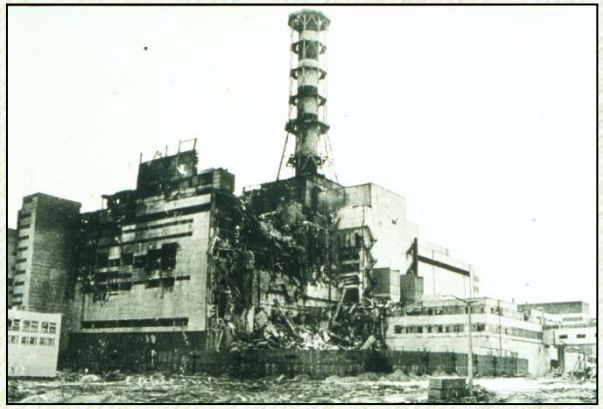
A hallmark of information about Chernobyl (and now Fukushima) has been CONTROVERSY….

Quantity Initially Released ?

Public evacuation ?



Long term effects ?

Costs ?

Ecological Effects ?

Remediation ?

Mutation rates ?

Psychological problems ?

Childhood thyroid cancers ?

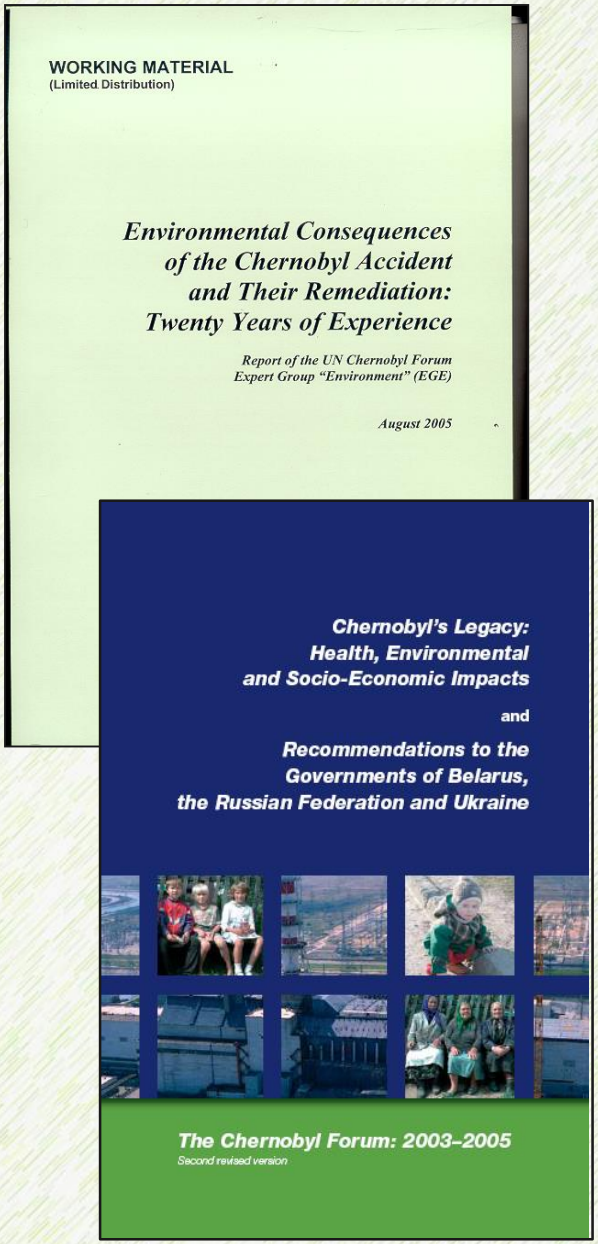
Human mortality ?

Extent of contaminant dispersal ?

Fuel particle contribution ?

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

Belarus

Russian Federation

Ukraine

plus an additional 80 experts from 12 countries

- Before Chernobyl

- Chernobyl overview
  - temporal aspects
  - general effects to major classes of organisms
  - indirect effects – confounding variables

- Possible reasons for controversy

Pre-Chernobyl…

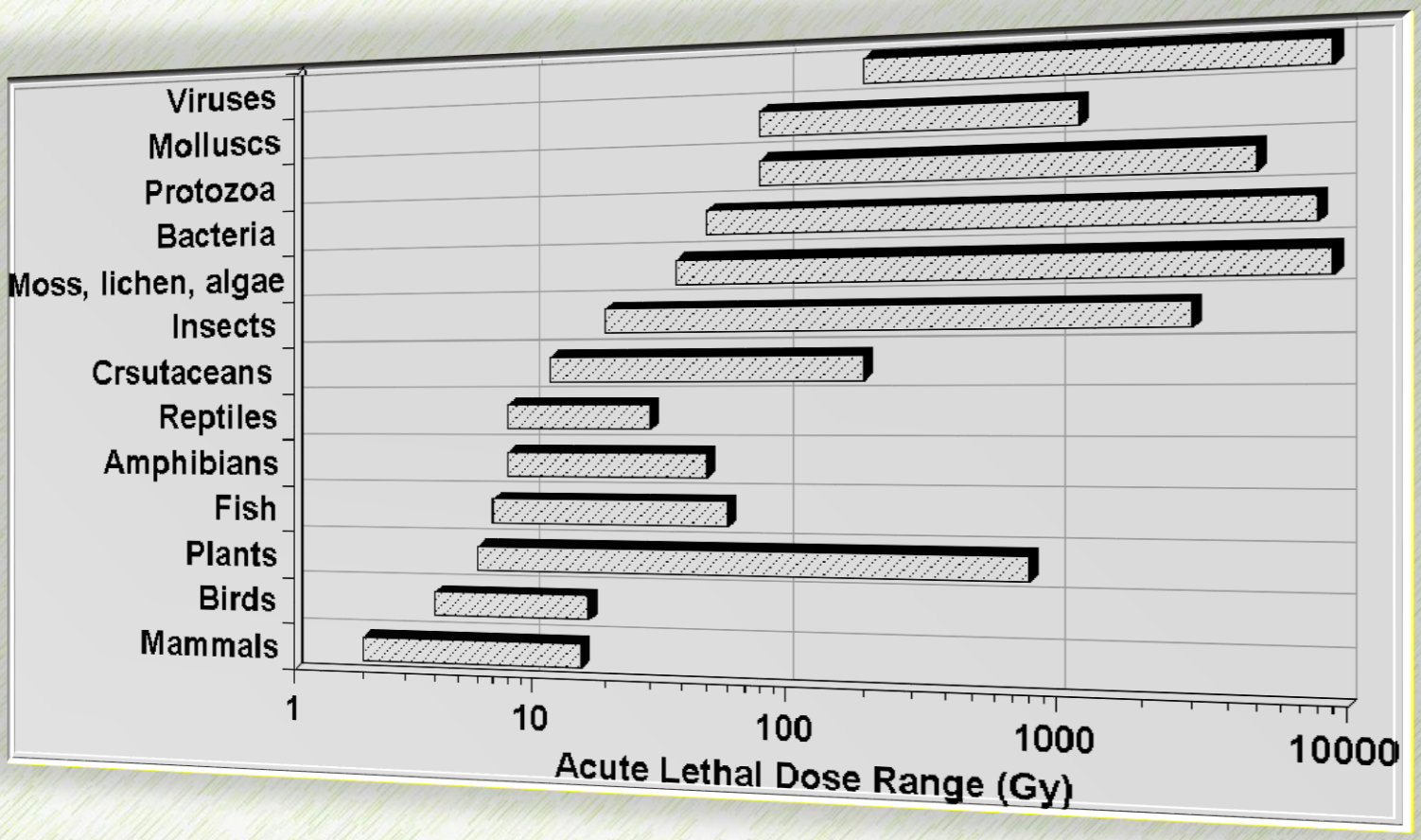
- wealth of data about the biological effects of radiation on plants and animals

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

Pre-Chernobyl…

Lethal Acute Dose Ranges

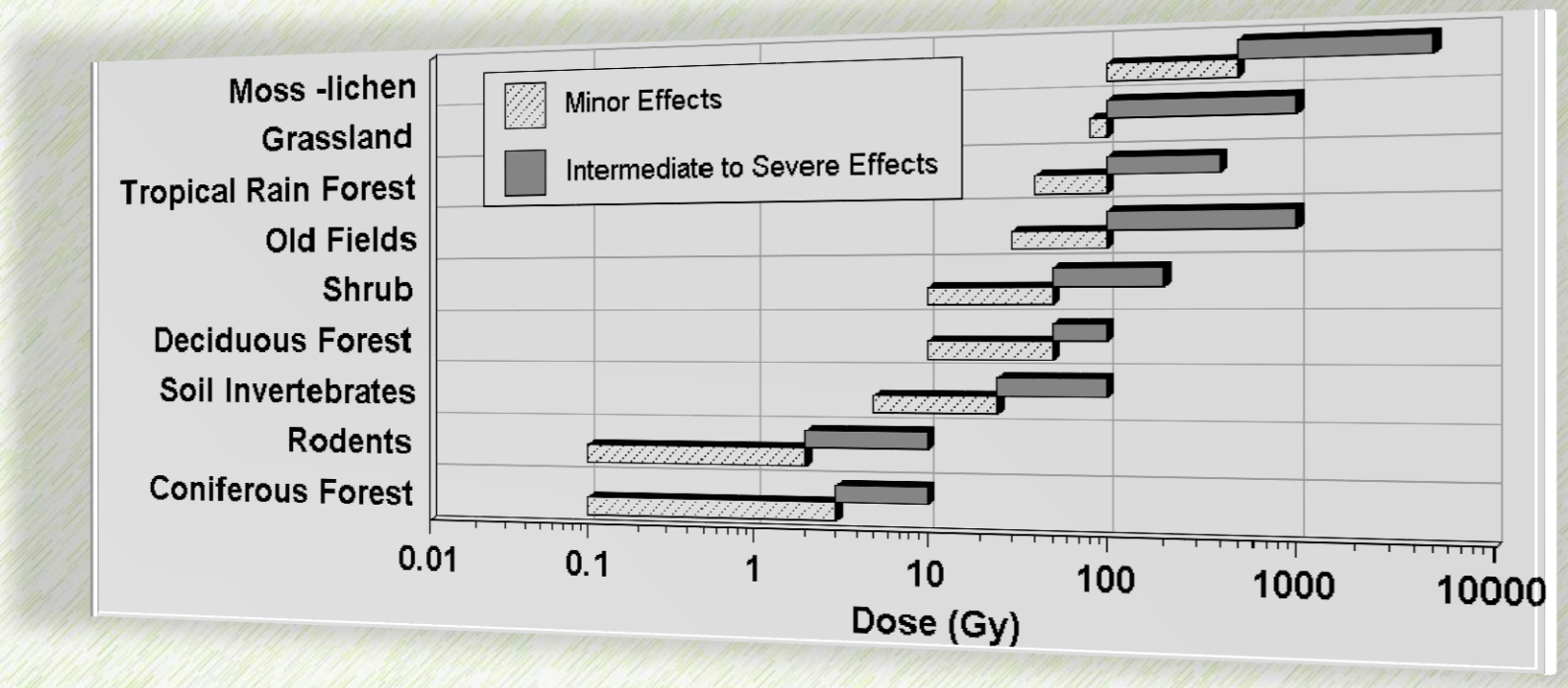
(Whicker and Schultz, 1982)



Pre-Chernobyl…

Effects from Short Term Exposures (5 to 60 d)

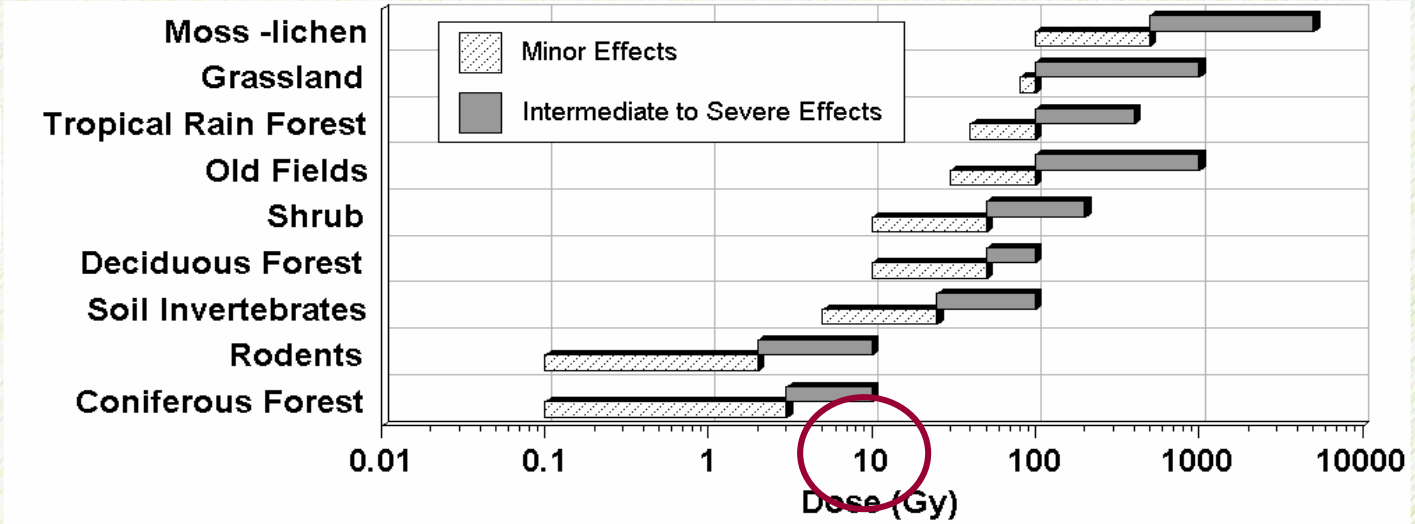
- minor effects (chromosomal damage; changes in reproduction and physiology)
- intermediate effects (selective mortality of individuals within a population)

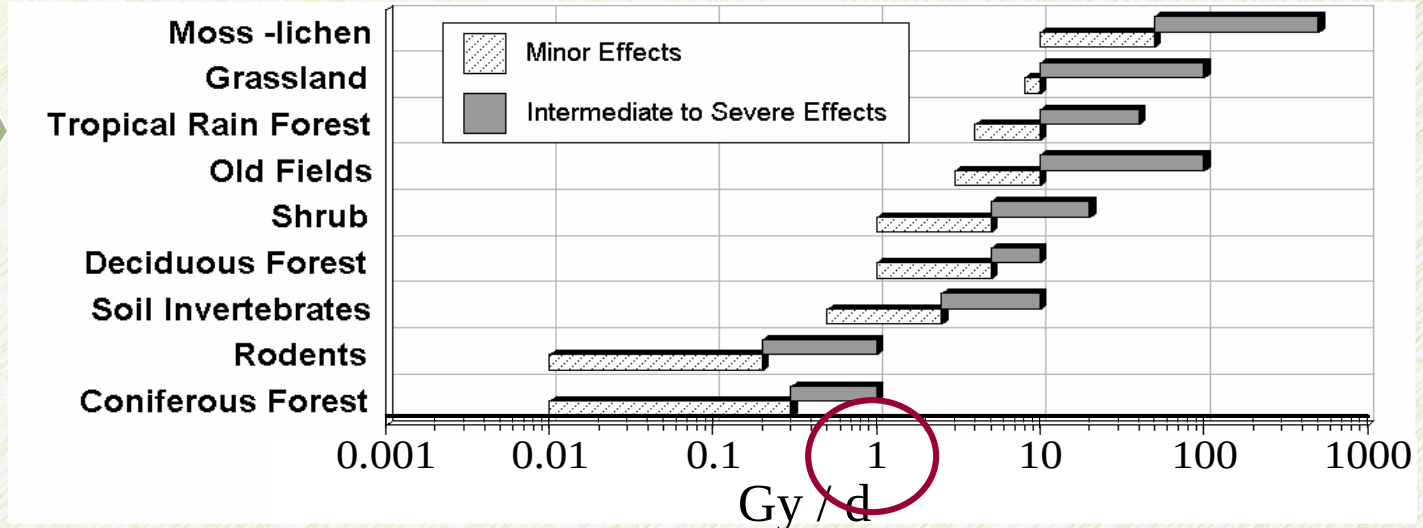


DOSE (Gy) to DOSE RATE (Gy / d) CONVERSION

(5 to 60 d)

x/10



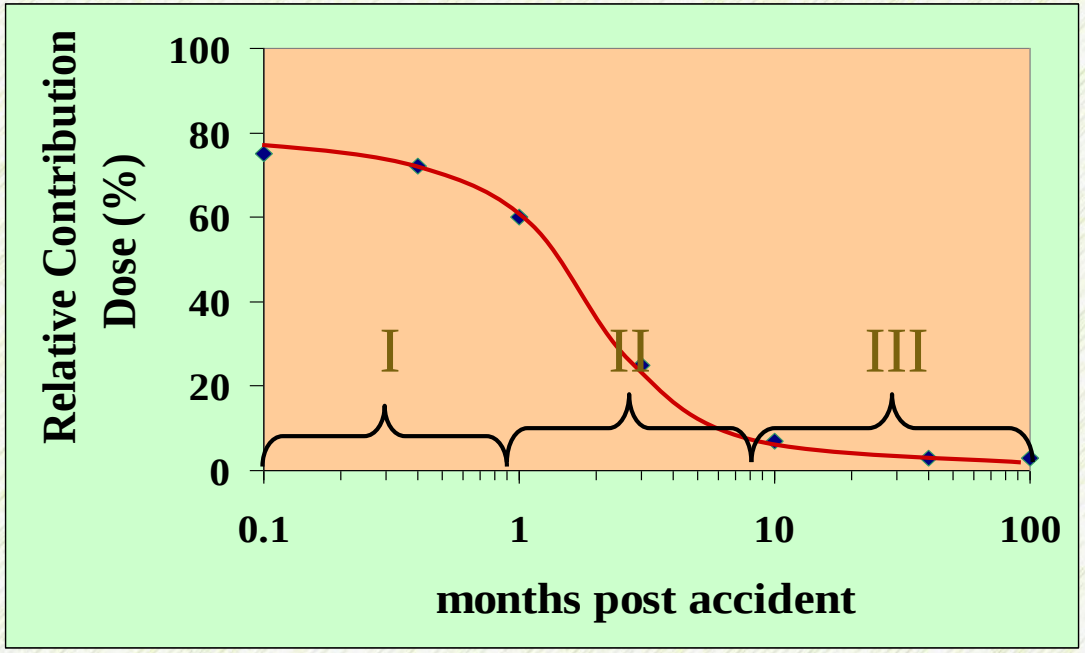


Effects of Radiation on the Environment: Findings of the UN Chernobyl Forum

R. Alexakhin (RIARAE, Obninsk)
M. Balonov (IAEA, Vienna)
N. Gentner (UNSCEAR, Vienna)
J. Hendry (IAEA, Vienna)
T. Hinton (University of Georgia)
B. Prister (Kiev University)
P. Strand (NRPA, Oslo)
D. Woodhead (Centre for Environment, Fishery and Aquaculture, UK)

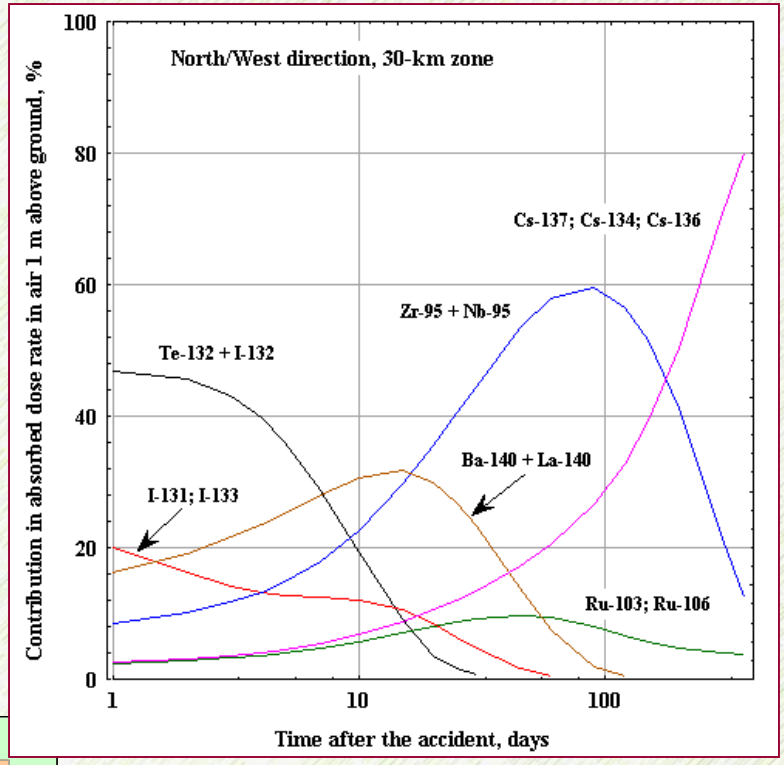
Within Chernobyl's 30-km zone

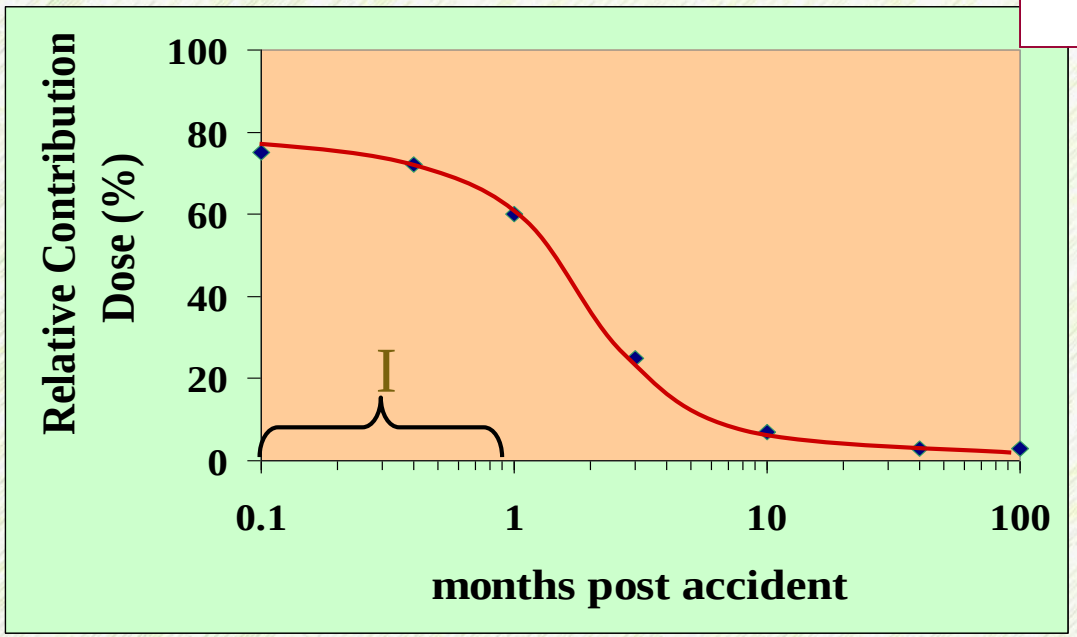
- Environmental effects were specific to 3 distinct time periods
- Biota were exposed to a diverse group of radioisotopes
- Tremendous heterogeneity and variability (in all parameters)
- Accident occurred at a period of peak sensitivity for many biota



First 20 to 30 days

- Severe effects to biota
- Gamma exposure dose rates were > 20 Gy / d
- Dominated by short-lived isotopes ^{99}Mo; $^{132}Te/I$; ^{133}Xe; ^{131}I; $^{140}Ba/La$





- High dose to thyroids from iodine

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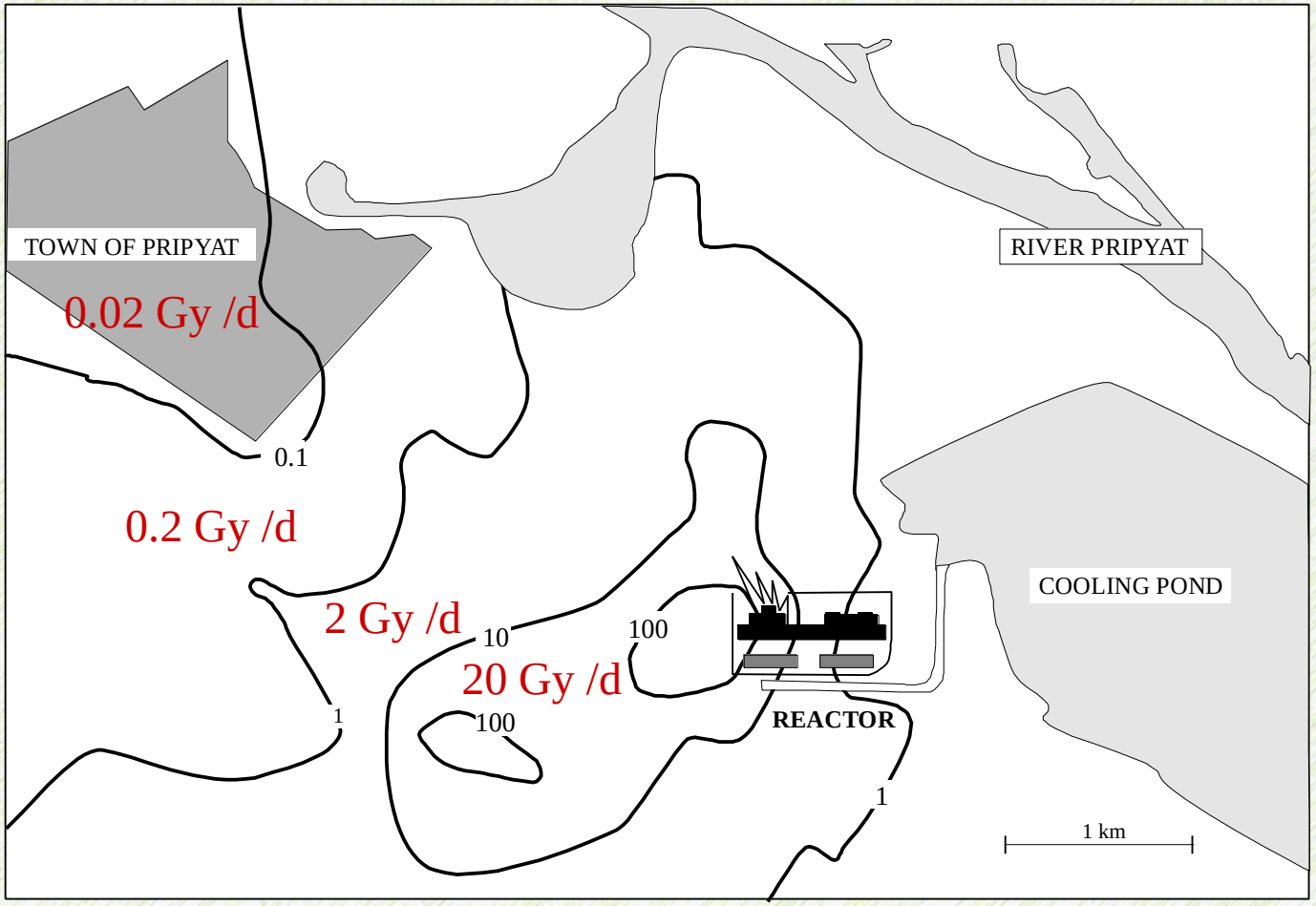
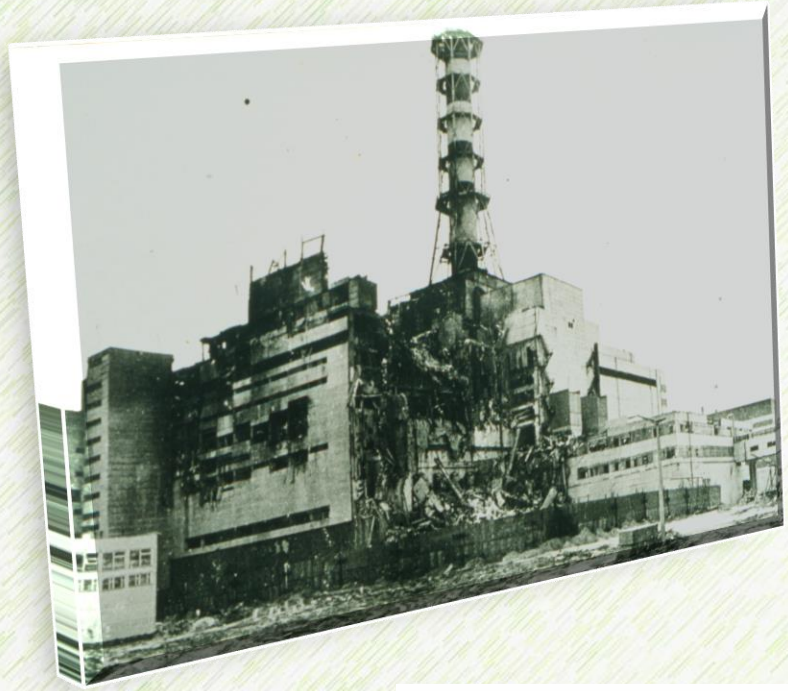
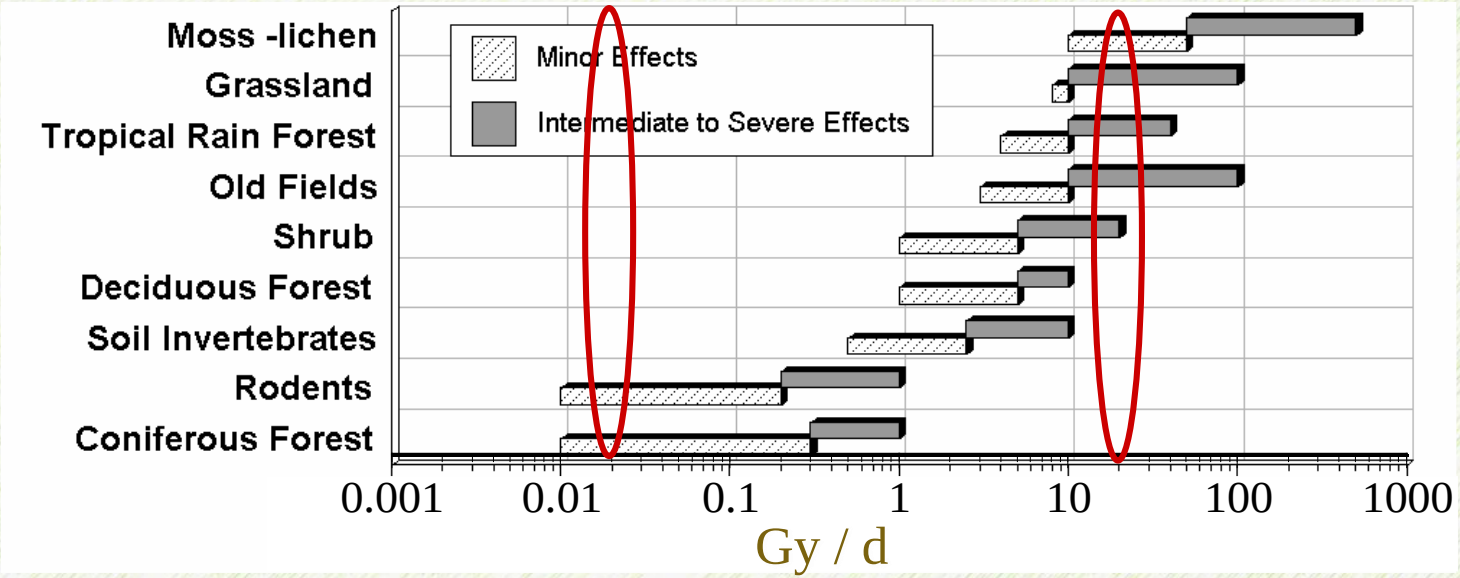
Air Exposure Rates on 26 April 1986



(1 R / h ~ 0.2 Gy / d; UNSCEAR 2000)

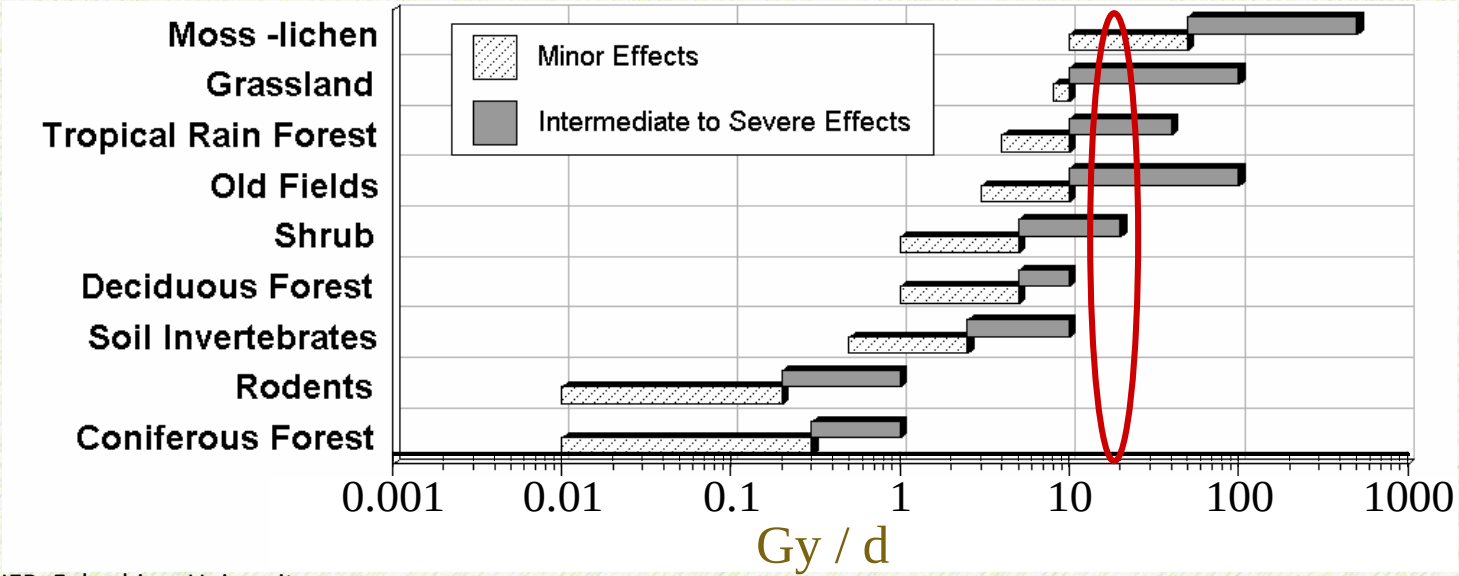


- Dose rates from gamma exposures ranged from 0.02 to 20 Gy / d



First Phase

- Acute adverse effects within 10-km zone
- Mortality to most sensitive plants and animals
- Reproductive impacts to many species of biota



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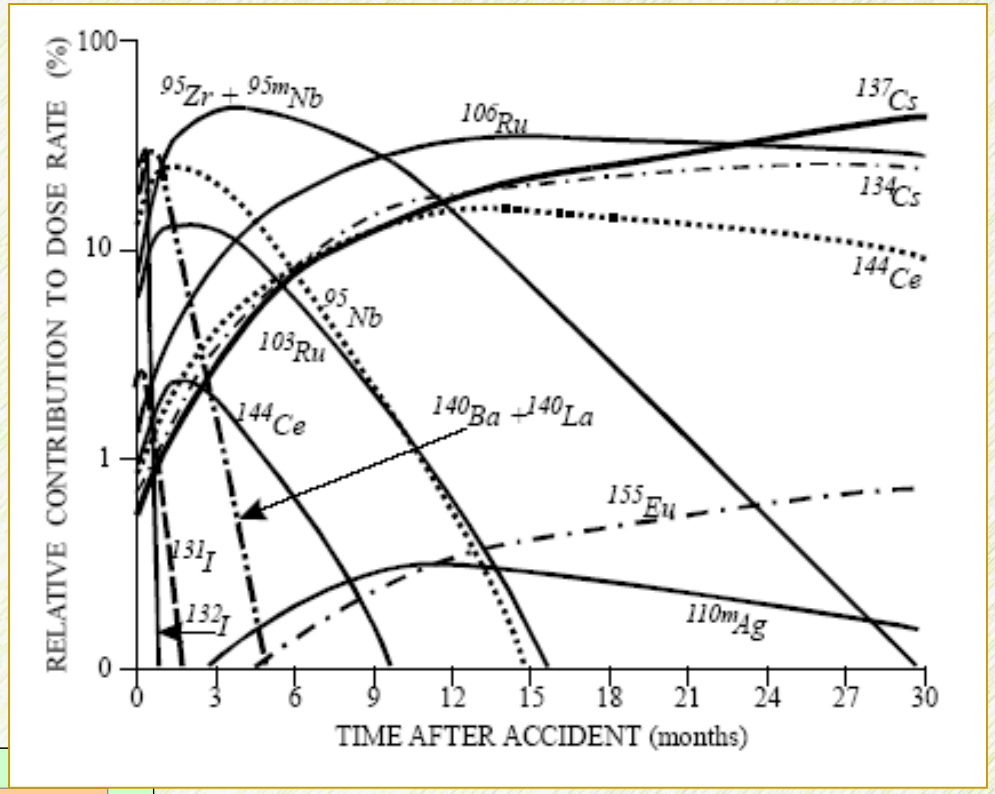
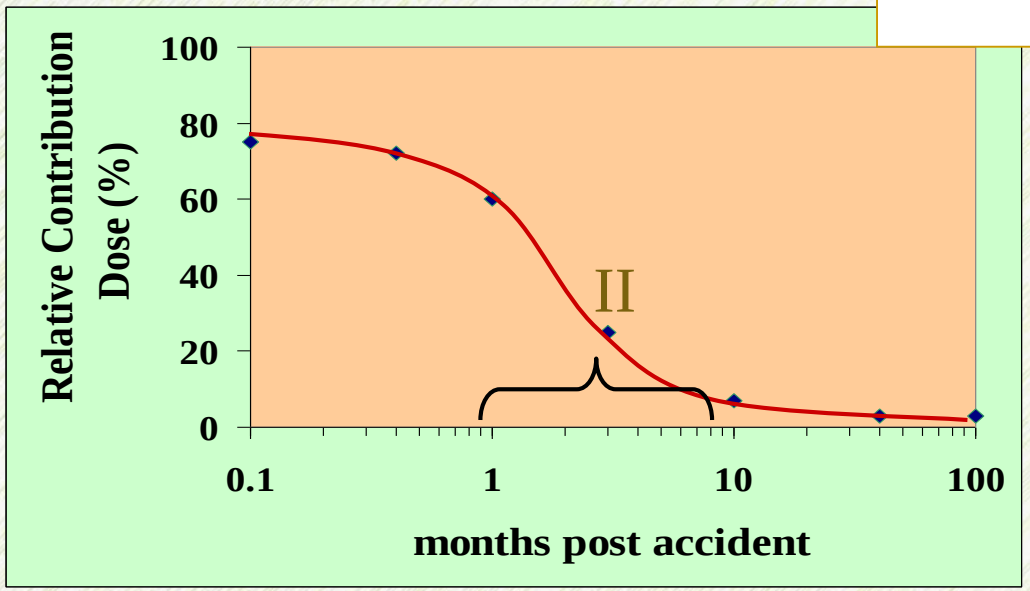
Second Phase

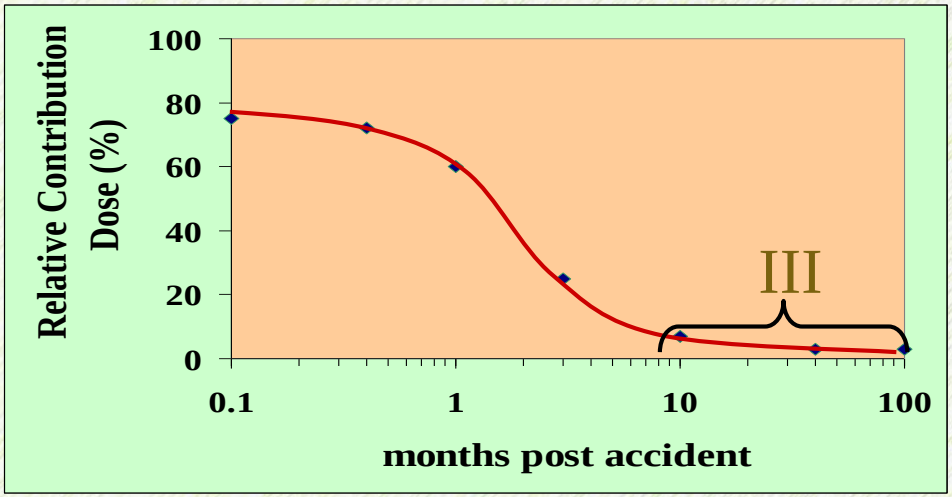
- Decay of short-lived isotopes
- Radionuclide migration
- β to δ ~ 6:1 to 30:1 with > 90 % of dose from β





Third and Continuing Phase

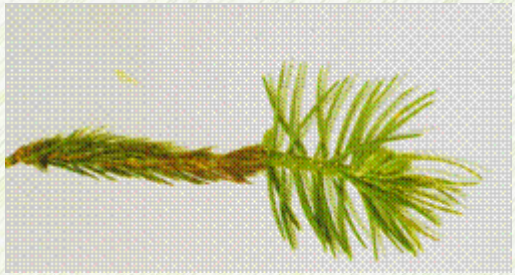
- Dose rates are chronic, < 1% of initial
- Beta to gamma contributions more comparable, depends on bioaccumulation of Cs
- ^{137}Cs and ^{90}Sr dominate dose
- Indirect effects dominate



- Genetic effects persist; although some results are controversial

General Effects to Plants

- Morphological mutations 1 to 15 Gy (e.g. leaf gigantism)



- Hardwoods more radioresistant
- Shift in ecosystem structure: Deceased pine stands were replaced by grasses, with a slow invasion of hardwoods
- Genetic effects extended in time 1993, pines of 5 to 15 Gy had 8 X greater cytogentic damage than controls

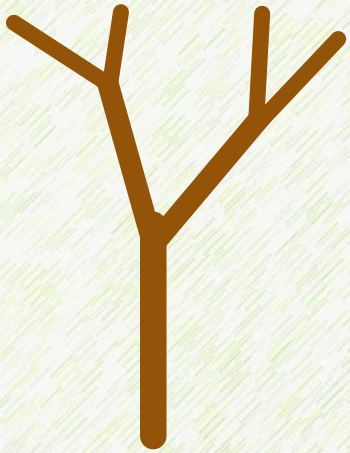
- Evidence of adaptive response

Most radiosensitive species in Chernobyl zone: Scots pine (*Pinus sylvestris* L.)

Typical morphological changes in Scots pine due to radiation: cancelling apical dominance (deletion of the main trunk)

Normal development

Cancelling apical dominance



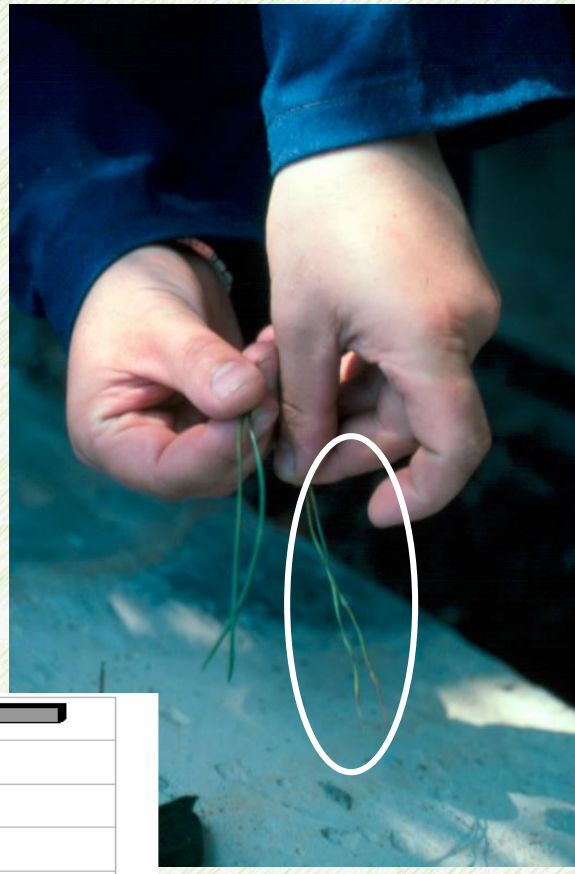
Most radiosensitive species in Chernobyl zone: Scots pine (*Pinus sylvestris* L.)

Typical morphological changes in Scots pine due to radiation: cancelling apical dominance (deletion of the main trunk)

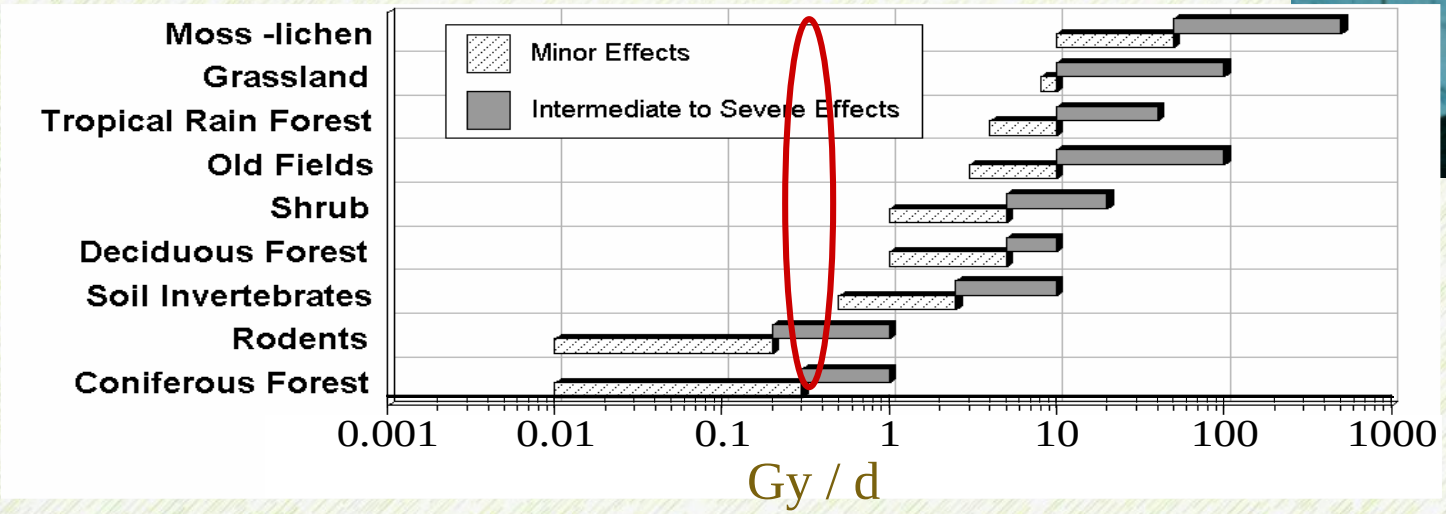
General Effects to Plants

0.3 Gy / d

- Growth and developmental problems
- Inhibition of photosynthesis, transpiration
- Chromosome aberrations in meristem cells
- Short term sterility
- High mutation rates in wheat due to non-targeted mechanisms



Twisted needles

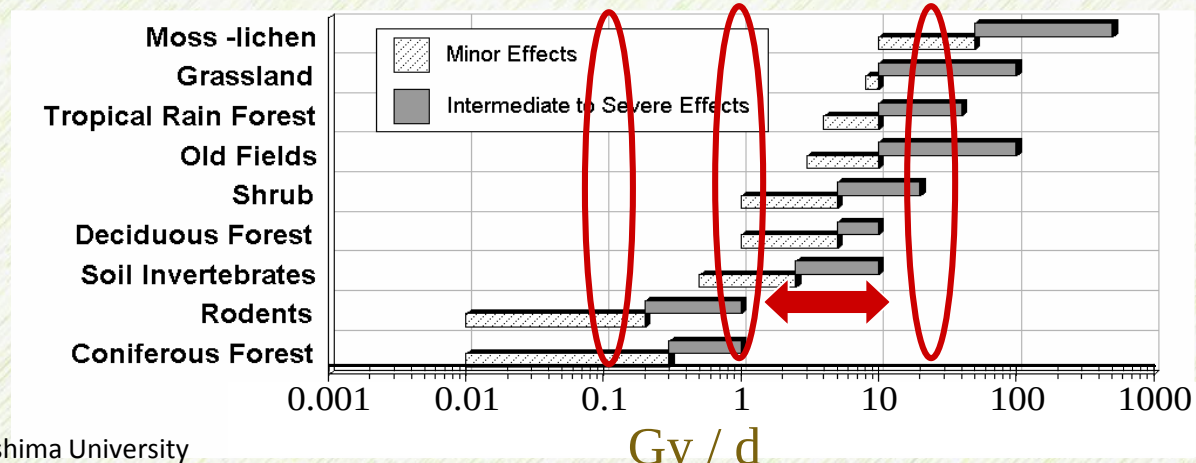


Arabidopsis

- research from 1987 to 1992 (Abramov, Shevchenko, et al).
- β contributed 82 to 96% of dose
- in 1992, mutations were still 4 to 8 times > than controls
- effect per unit dose was lower at high-dose rate; low dose chronic IR exerted a greater effect per unit dose

General Effects to Rodents

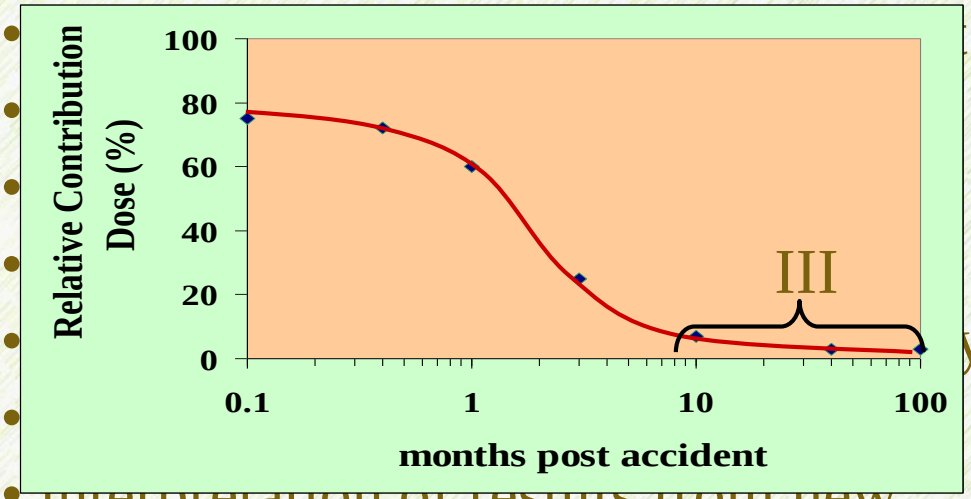
- During Fall 1986, rodents population < 2- to 10-fold, dose rates 1 to 30 Gy/d (δ & β)
- At ~ 0.1 Gy/d temporary infertility, reduced testes mass
- Increased mortality of embryos
- Dose-rate dependent increase in reciprocal translocations
- Numbers of mice recovered within 3 years (immigration), but cytogenetic effects persisted



Effects Data from Rodents Collected in Phase III Are Ambiguous and Controversial

From virtually no effect….

… to significantly elevated mutation rates



- Interpretation of results from new methods (microsatellites)

General Effects to Soil Invertebrates

- 60 to 90% of initial contamination captured by plant canopies
- Majority washed off to soil and litter within several weeks
- Populations of soil invertebrates reduced 30-fold, reproduction strongly impacted

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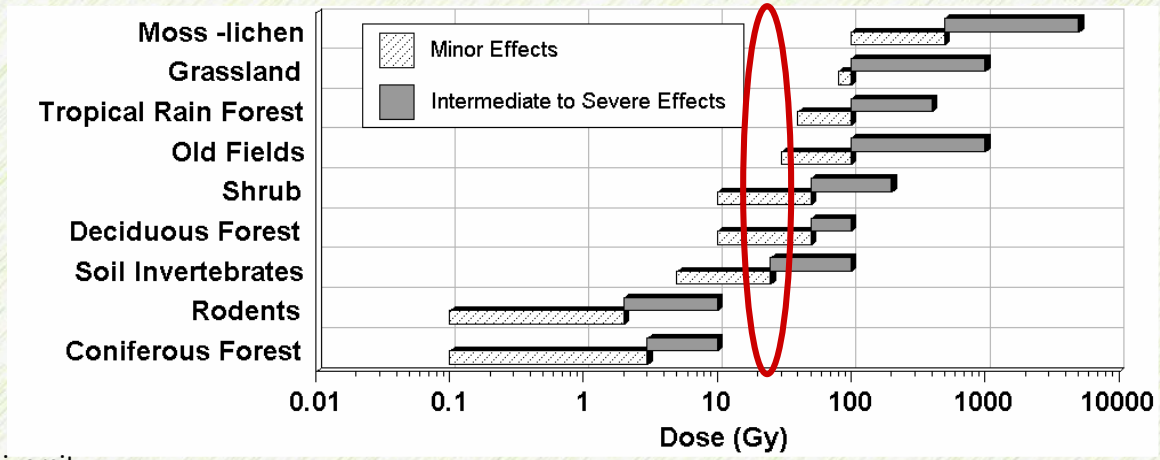
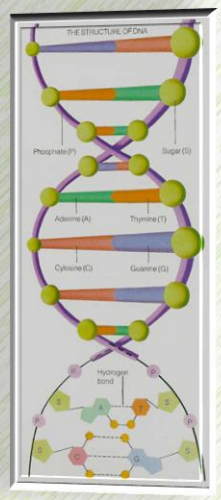
General Effects to Soil Invertebrates

- Dose and effects to invertebrates in forest litter were 3- to 10-fold higher than those in agricultural soils
- 30 Gy altered community structure (species diversity) for 2.5 years



General Cytogenetic Effects



- Decline in cytogenetic damage lagged behind the decline in radiation exposure
- Some suggestions of genomic instability (increase freq. of cellular damage in offspring, while contamination decreased)
- Evidence of DNA hypermethylation in plants: such epigenetic modification is thought to be a defense strategy to reduce genome instability
- Plant data suggest that chronic low-level irradiation might alter the genetic structure of populations, increasing the karyotypic variability in the offspring

Indirect Effects of Human Abandonment

Pripyat
Abandoned

4 km N of Reactor
50,000 people

135,000 people and 35,000 cattle evacuated

Dozens of towns and villages deserted.

With the removal of humans, wildlife around Chernobyl are flourishing

48 endangered species listed in the international Red Book of protected animals and plants are now thriving in the Chernobyl Exclusion Zone

Russian Boar

Wolves

Przewalski Horses

ZONE DWELLERS

Introduced: European bison, Przewalski's horse

Reappeared: Lynx, eagle owl, great white egret, nesting swans, and possibly a bear

Booming mammals: Badger, beaver, boar, deer, elk, fox, hare, otter, raccoon dog, wolf

Booming birds: Aquatic warbler, azure tit, black grouse, black stork, crane, white-tailed eagle

BROAD SUMMARY

Period 1 (first month)

Acute adverse effects within 30-km zone
Mortality of conifers; reproductive impacts to plants & animals

Period 2 (1 to 12 months)

Lowered dose rates
Morphological effects
Soil invertebrates impacted

Period 3 (> 1 year)

Ongoing recovery
Secondary effects due to human abandonment
Noticeable positive impacts
Long term genetic consequences are unknown

Main conclusions of the Chernobyl Forum

Radiation-induced effects on plants and animals

- Irradiation caused numerous acute adverse effects on the plants and animals living up to 10-30 kilometres from the release point.
- The following effects caused by radiation-induced cell death have been observed in biota:
  - Increased mortality of coniferous plants, soil invertebrates and mammals; and
  - Reproductive losses in plants and animals.
- A few years were needed for recovery from major radiation-induced adverse effects in populations of plants and animals.
- "Due to removal of human activities, the Exclusion Zone has paradoxically become a unique sanctuary for biodiversity."

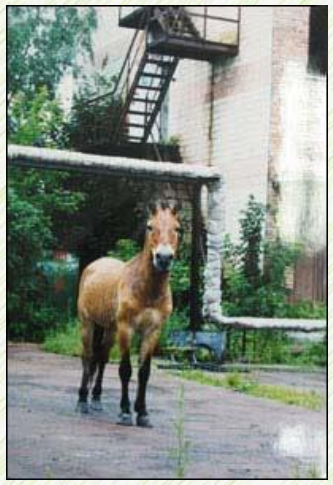
(Chernobyl Forum Report, 20066)

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. »

Dichotomy

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".

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

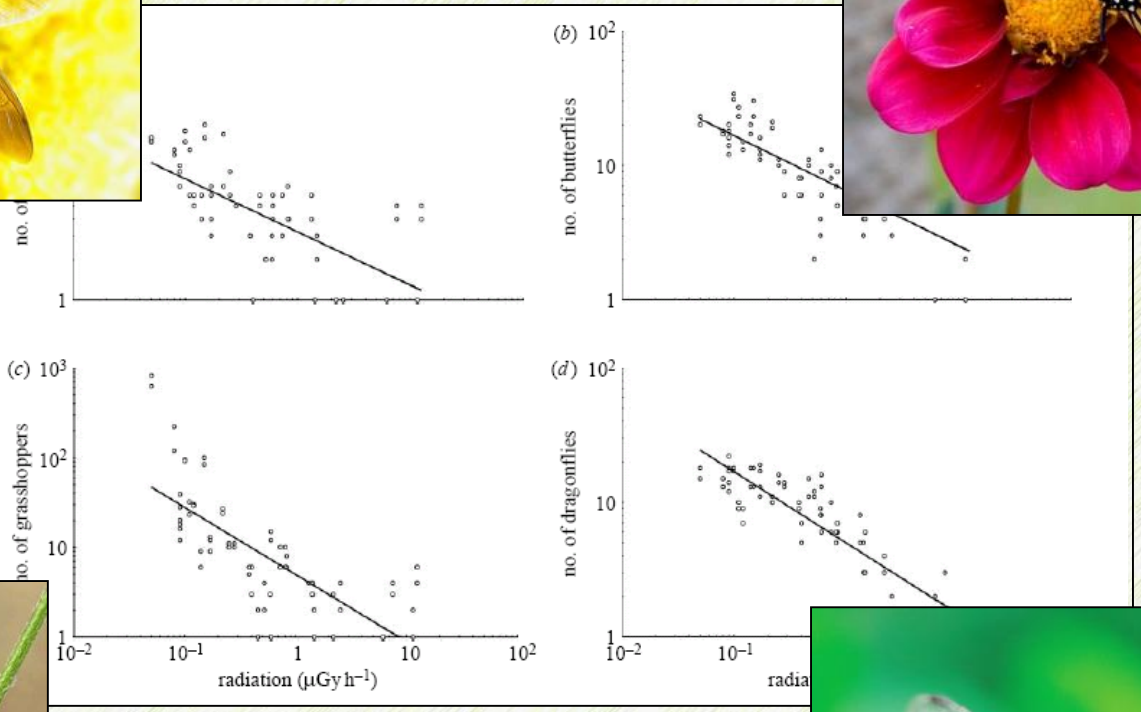
Chernobyl
‘Shows Insect Decline'

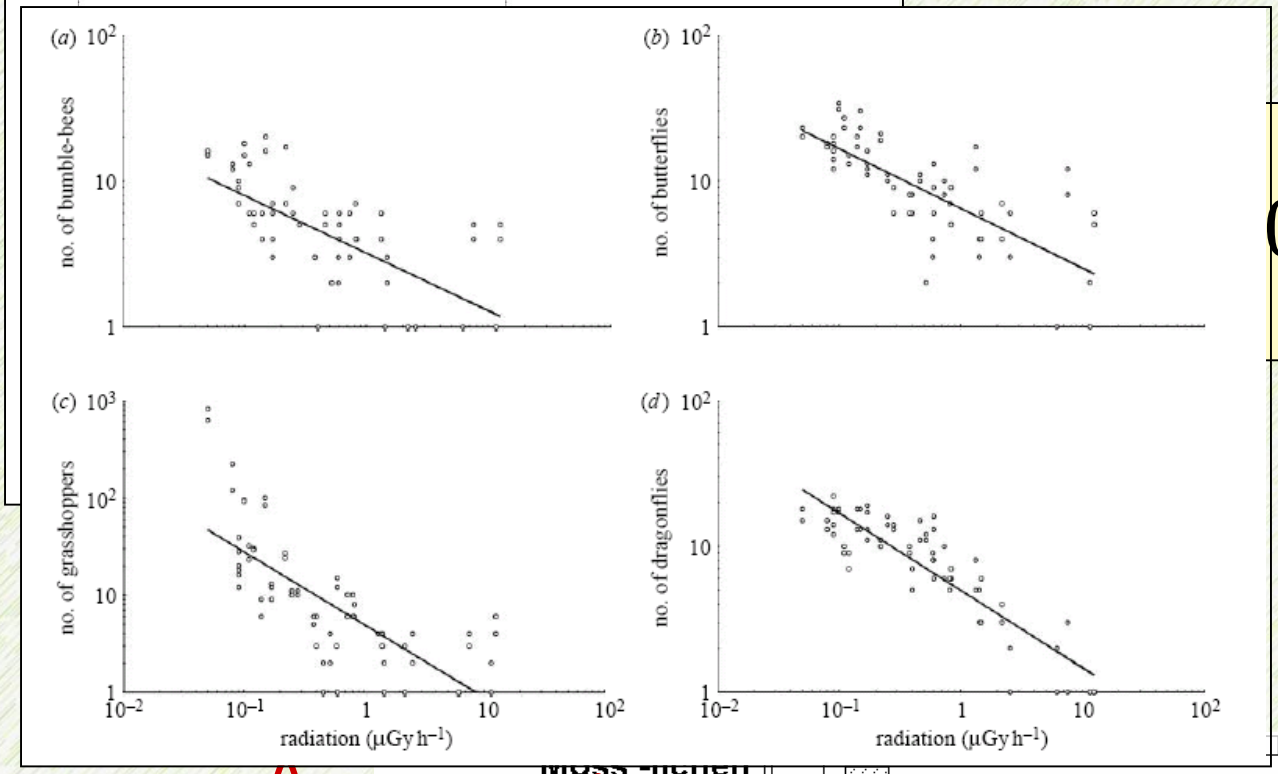
By Victoria Gill,
Science Reporter, BBC NEWS

18 March 2009

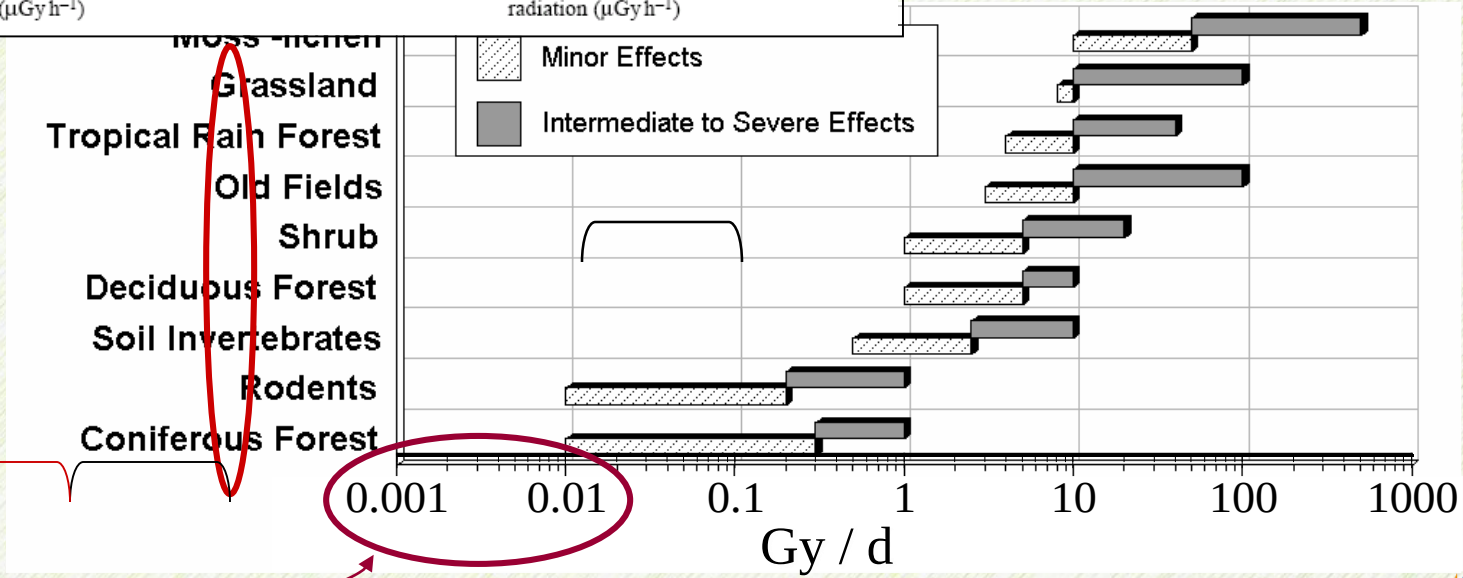
“Two decades after the explosion at the Chernobyl nuclear power plant, radiation is still causing a reduction in the numbers of insects and spiders”.

A. Moller and T. Mousseau


(b) 10^2
no. of butterflies
10
1
(c) 10^3
no. of grasshoppers
10^2
10
1
10^{-2}
10^{-1}
1
10
10^2
radiation (μGy h^{-1})
(d) 10^2
no. of dragonflies
10
1
10^{-2}
10^{-1}
radia



$$00024\ \frac{Gy}{d}$$



IAEA Guidelines 1 & 10 mGy / d

0.000001

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Link to a poorly done study on cataracts in rodents, published in a prestigious journal (be sure to read the comments section at the end of the manuscript to learn why this is poor science)

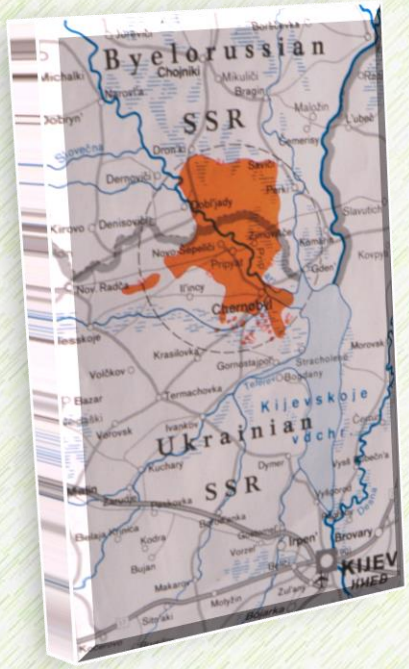
http://www.nature.com/articles/srep19974

The second link is an interesting write up by the BBC that describes the dichotomy that exists in radioecology concerning environmental effects and the role that Moller and Mousseau play in furthering it

http://www.bbc.com/earth/story/20160421-the-chernobyl-exclusion-zone-is-arguably-a-nature-reserve

Dichotomy is driven by the prolific publication of substandard data, generated by *Moller and Mousseau,* that are counter to established paradigms in RB and RE…

2015	15
2014	6
2013	9
2012	7
2011	8
2010	11
2009	4
2008	5
2007	6
	84



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

Potential Causes for Controversial Data

- Poor dosimetry can cause misinterpretation of data
- Spatial heterogeneity of exposure; free-ranging wildlife
- Confounding variables and indirect effects

- Lack of appropriate controls
- Questionable statistical analyses
- What constitutes a “significant effect”??
- Motives beyond science ??

Criticism of M&M is related to their:

- Poor experimental designs
- Questionable statistical analyses
- Bad methodologies
- Inadequate dosimetry
- Not accounting for confounding variables (e.g., humans)

The take home lessons relative to this dichotomy are:

Do not believe everything you read…..even if it is scientific material published in prestigious journals

Be critical of EVERYTHING you read….evaluate thoroughly!

Formulate your own conclusions,
based on your scientific training