Effects of non-human species in areas affected by the radiation accident: implications for radiation protection

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Implications for radiation protection

1. The data obtained in areas affected by the accidents are important source of information on effects of non–human species to assess acceptable dose levels for non-human species based on a variety of the end-points.
2. The data may improve understanding a need in protection of biota in general. Do we really need to address specifically protection of non-human species in the regulation and how?

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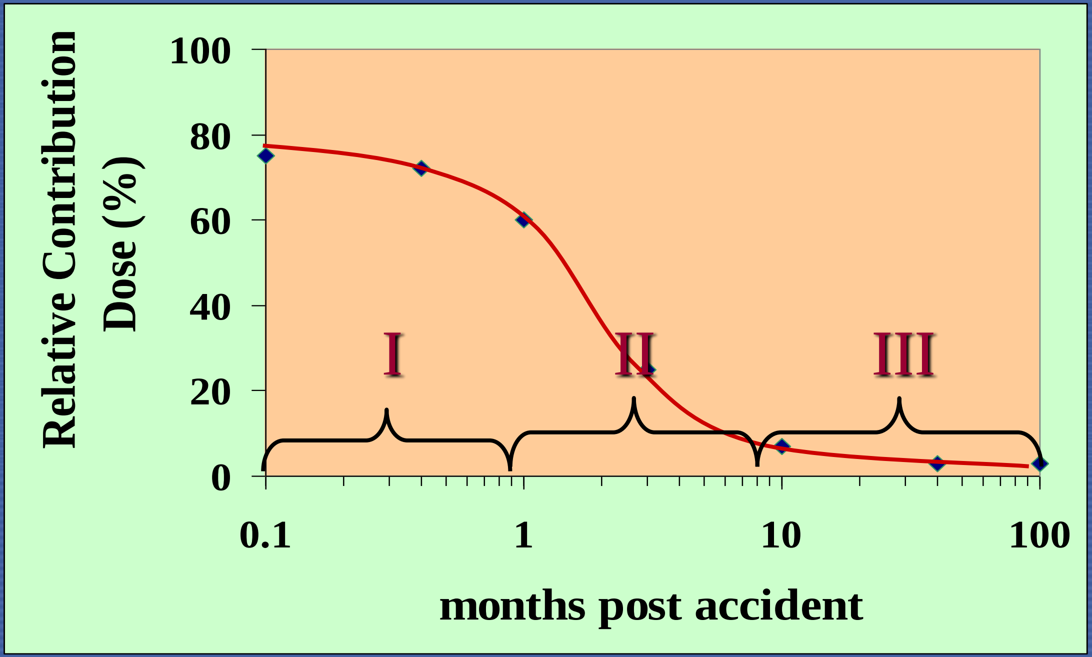
Features of the Chernobyl accident important for understanding data on biological effects (Chernobyl Forum: IAEA, 2006)

- Accident occurred at a period of high sensitivity for many biota species
- Environmental effects were specific to 3 distinct time periods



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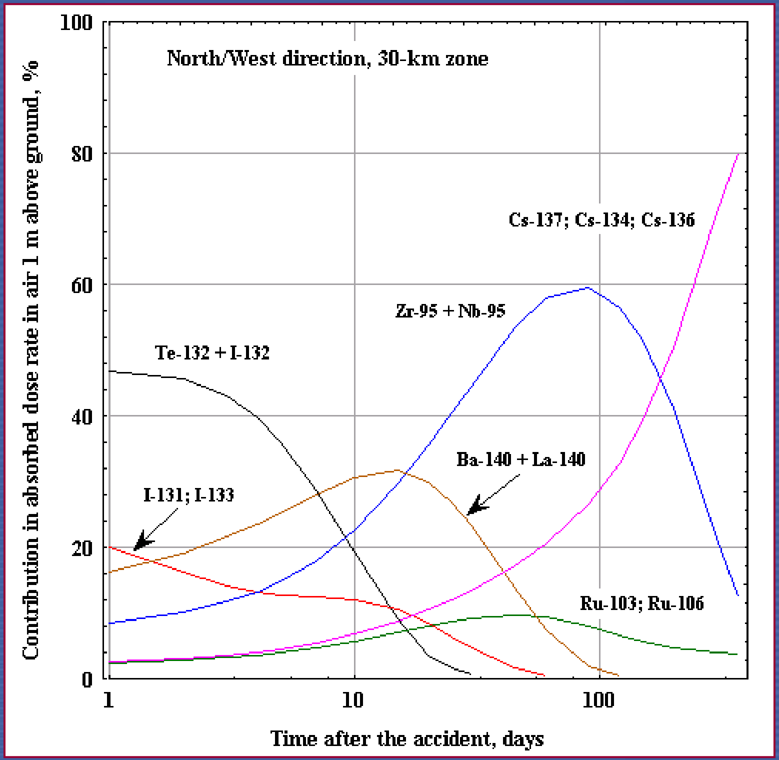
Features of the Chernobyl accident important for understanding data on biological effects

- Biota species exposed to different radionuclides with different physical and chemical properties.
- High heterogeneity in contamination levels resulted in high heterogeneity in doses to non-human species.
- Diversity of the location also resulted in high heterogeneity in doses to non-human species.
- Not adequate dosimetry and documentation of the environmental parameters in many research.
- As a result high uncertainty in dose assessments and problems in interpretation of the biological effects.

First month following the accident (IAEA, 2006; Hinton et al., 2006)

- Gamma exposure dose rates were > 20 Gy/d at many locations
- High contributions of short-lived isotopes ^{99}Mo; $^{132}Te/I$; ^{133}Xe; ^{131}I; $^{140}Ba/La$
- Severe effects to biota, first of all to relatively radiosensitive species which were directly contaminated, such as forest trees or soil invertebrates.
- Effects to mammals was often because of high dose to thyroids from iodine



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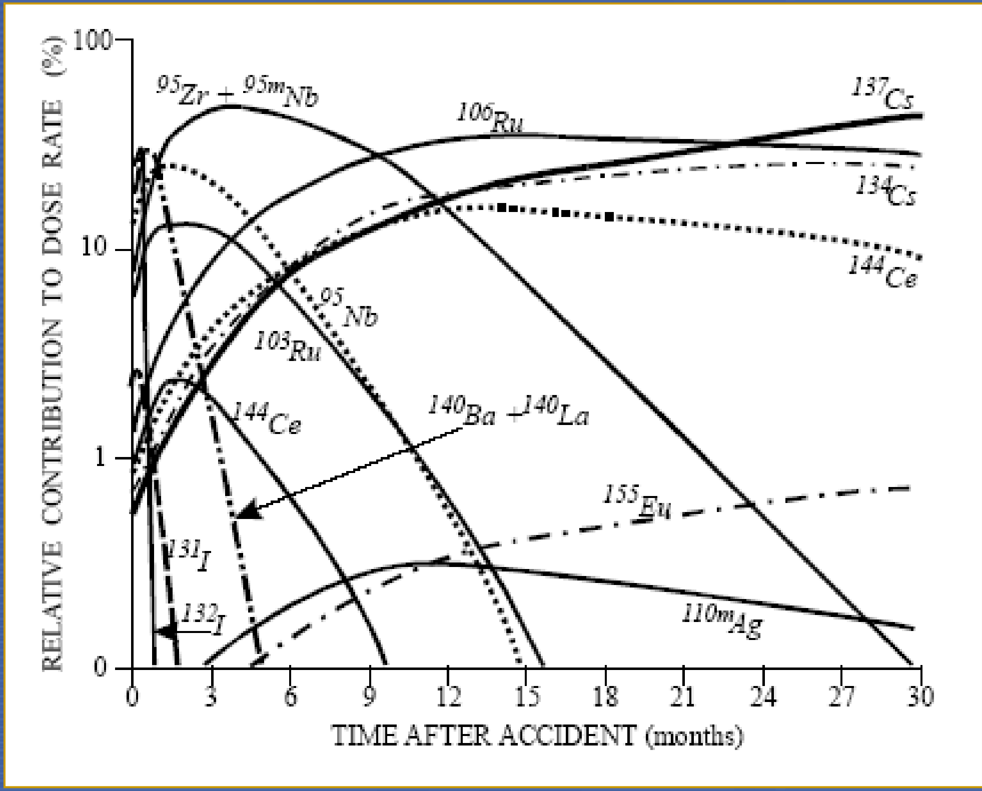
Second Phase (IAEA, 2006; Hinton et al, 2006)

Redistribution of radionuclide within ecosystems:

From 60 to 90% of initial contamination captured by plant canopies. Majority washed off to soil and litter within several weeks

Doses were much lower because of the decay of short-lived isotopes

Ratio β to δ varied 6:1 - 30:1 with > 90 % of dose from β



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Later stage (IAEA, 2006)

1. Dose rates are getting chronic, < 1% of initial
2. Beta to gamma contributions more comparable, depending on accumulation of Cs
3. ^{137}Cs and ^{90}Sr dominate dose
4. Indirect effects dominate
5. Genetic effects persisted:
    - During years 2 & 3, frequency of cellular mutations in plants increased, even though radiation doses were decreasing.
    - In 2002, barn swallows from Chernobyl still had a higher frequency of abnormal sperm than did controls

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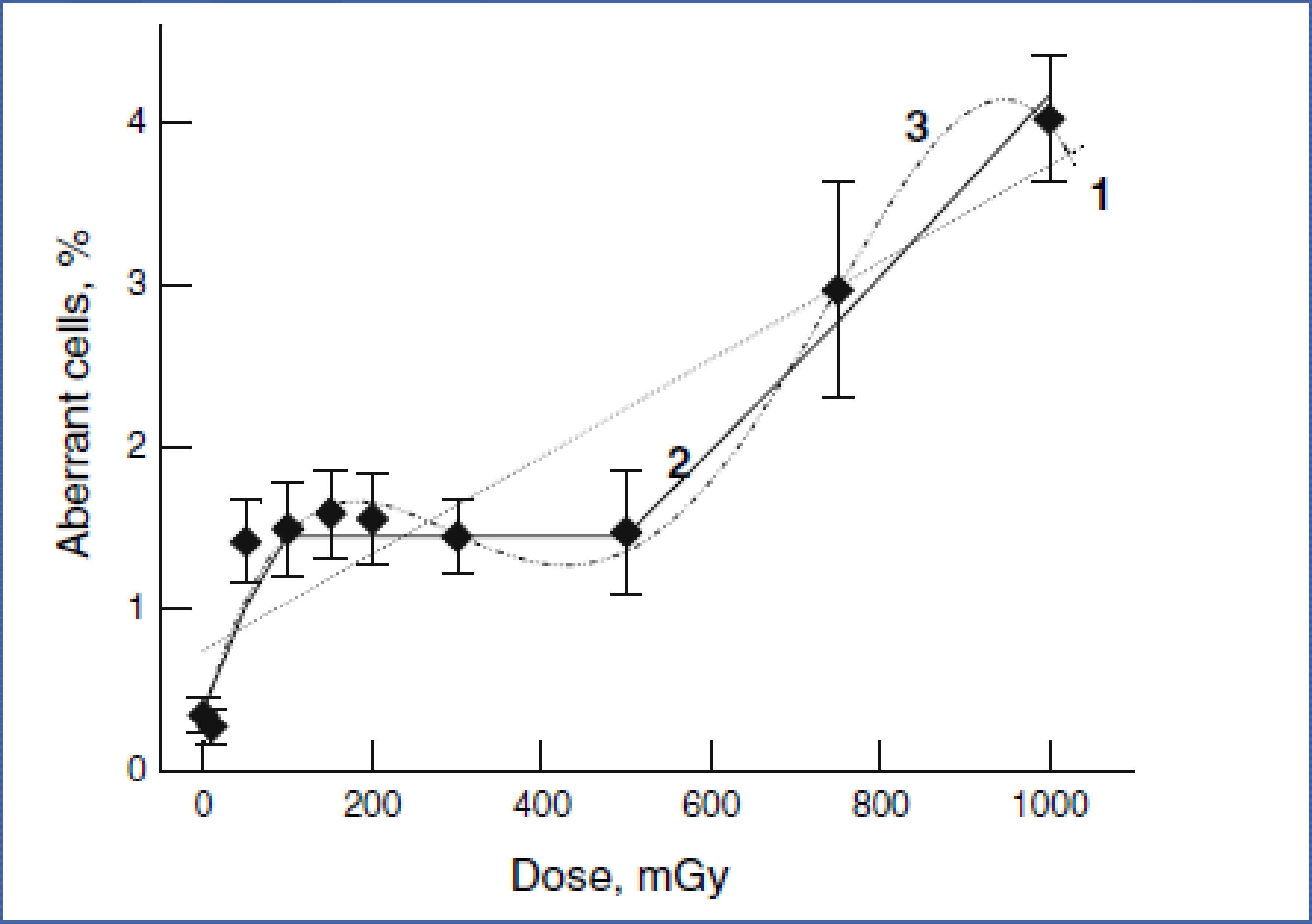
Nonlinearity of the observed effects: frequency of aberrant cells in barley seedlings (mean ± SE) (Geras'kin et al., 2003)



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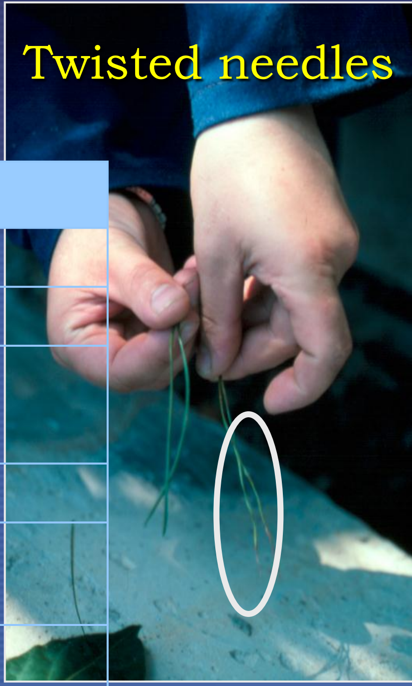
Effects to Plants (Geras'kin et al., 2008)



Effects	Dose
Forest trees	
Mass mortality of pine trees (600 ha)	60.0-100.0 Gy
Necrosis of meristems and young shoots death of tree tops (3800 ha)	30.0-40.0 Gy
Death of weakened trees	8.0-12.0 Gy
Suppression of growth, abscission of needles, damaged reproductive buds(11900)	5.0-6.0 Gy
Increased number of hollow seeds, morphological changes one year after the acc.	0.5-1.0 Gy
Cytogenetic effects	0.1-0.5 Gy
Herbaceous plants	
Sterility of seeds	10-40 Gy
Reduced biodiversity	17 – 730 mGy/d*
Morphological changes	4.2.-6.3 mGy/d
Reduced growth and developmental problems	Up to 10Gy
Inhibition of photosynthesis, transpiration	1-5 Gy
Chromosome aberrations in meristem cells	1-5 mGy/d
Short term sterility	0.4 mGy

*Dose rates are give on 15th day following the accident

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Effects to Ruminants (IAEA, 2006)

1. Ruminants received particularly high doses from ^{131}I & ^{133}I
2. Transfer of radioiodine to thyroids was 2 - 3 higher, than could be expected, due to endemic deficiency of stable I in local soils.
3. No apparent symptoms of acute radiation sickness were observed

Effects	Dose
Thyroid effects Reduction in function Destruction	50 Gy >200 Gy (Dose to thyroid)
Chronic radiation syndrome (reduced body mass and fat reserves; increase mass of lymph nodes, liver & spleen; thickening of lower gastrointestinal lining	>2 Gy
Reproductive failure; impaired immune response; offspring had reduced mass	>1 Gy

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Effects to Rodents (Geras'kin et al., 2008)

Observations:

- Dose-rate dependent increase in reciprocal translocations
- Numbers of mice recovered within 3 years (immigration), but cytogenetic effects persisted

Effect	Dose
During 1986, the rodents population decreased 2 - 10-fold	3- 30 Gy (during first year)
Inhibition of reproductive capacity	3-4 Gy (during first month)
Pathologic changes in hemopoietic system, liver, adrenals and thyroid	1-5 Gy per (during first year)
Chromosome aberrations in bone marrow cells, embryonic losses and genome mutations	6-600 $\mu Gy\ d^{-1}$

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Effects to Soil Invertebrates (IAEA, 2006)

- Time of the accident was reproduction and molting period for most soil invertebrates, corresponding to pick radiosensitivity.
- Highly affected at a distance of 3-7 km
- Populations of soil invertebrates reduced up 20-30-fold on the sites with the dose on the soil surface of 8-30 Gy.
- Reproduction strongly impacted.

Composition of species was substantially changed.

Diversity index was much lower at the highly affected sites.

Dose and effects to invertebrates in forest litter were 3- to 10-fold higher than those in agricultural soils.

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Genetic Effects (IAEA, 2006; Geras'kin et al., 2008)

- Studies were started in May 1986. A significant excess of aberrations was registered from an absorbed dose of 3.1 Gy, inhibition of mitotic activity from 1.3 Gy, germination from 12 Gy.
- The relationships between both cytogenetic disturbances frequency and the mutation rate of enzyme loci and contamination densities were found to be supra linear.
- 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)
- Some genetic effects are still apparent: In 2000 -2002, increased frequency of abnormal sperm, partial albinism, and decreased level of antioxidants in blood and liver were observed in barn swallows from Chernobyl

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With the removal of humans, wildlife around Chernobyl are flourishing (Hinton, et al., 2006)

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

Prejevalsky Horses

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Dose levels (CDVs) at which no effects are still expected, (Fesenko et al., 2005)

Non-human species	CDV (Gy)	Literature data
Terrestrial ecosystems		
Coniferous trees (pine)	0.40	0.4- 3.65
Herbaceous plants	3.00	0.4- 3.65
Cattle	0.60 (50*)	0.4-0.90
Mouse-like rodents	0.40	0.05- 1.0
Soil invertebrates	0.90	0.4- 2.0
Aquatic ecosystems		
Phytoplankton	3.00	0.88-1.0
Zooplankton	2.50	0.88- 1.0
Zoobenthos	0.90	0.6-2.0
Fish	0.60	0.1- 3.65

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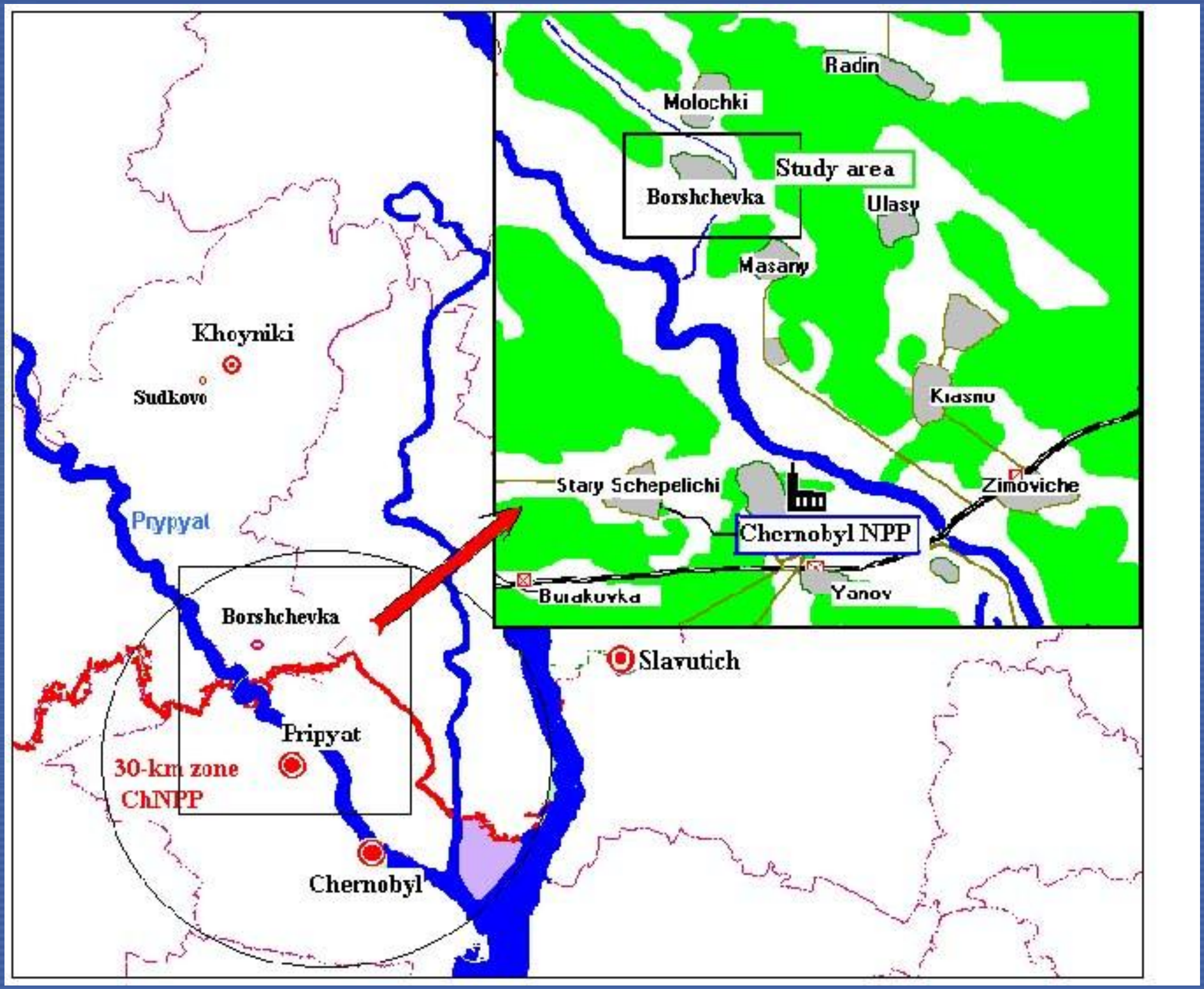
Case study: test site Borschevka

Located at the distance of10-16 km north-west of the ChNPP.

Mean contamination density with ^{137}Cs was 5000 kBq m^{-2}



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Doses and Impacts at the test site (Fesenko et al., 2005)

Biota species	Doses, Gy		Ratio dose to CDV, uniless	
	1986	1991	1986	1991
Forest trees (pine)	3.1	0.02	**7.85**	0.05
Soil invertebrates	7.9	0.06	**8.78**	0.06
Mouse-like rodents	0.6	0.03	1.50	0.08
Cattle	1.6	0.03	2.58	0.05
Herbaceous plants	10	0.02	3.33	0.007
Cereals	6	0.014	2.00	0.005
Phytoplankton	0.06	$3.4\ 10^{-4}$	0.02	0.0001
Zooplankton	0.18	$6.3\ 10^{-4}$	0.07	0.0003
Zoobenthos	0.8	0.08	0.89	0.09
Fish	0.4	0.05	0.40	0.05

Soil invertebrates and coniferous trees should be regarded as most affected species

Summary (Chernobyl Forum - IAEA, 2006)

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

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Major features of the Kyshtym accident

- Accident occurred at a period of low sensitivity for many biota species
- β-emitters dominated in the depositions; dose from γ-emitters lower 10%.
- Dose rates values at the time of deposition were not so important as following the Chernobyl accident.
- Environmental effects were specific to 2 distinct time periods 1957-1958 (acute stage) and from 1958 (recovery stage)
- High heterogeneity in contamination levels resulted in high heterogeneity in doses to non-human species
- Location effects: Protected and unprotected locations.

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Doses to biota species following the Kyshtym accident normalized on the deposition density of 1×10^6 Bq m^{-2} (Tikhomirov et al., 1994)

Species	Maximum dose rate, mGy d^{-1}	Dose, Gy	Dose at the site near the point of release, Gy
Pine			
Meristem of buds	30-50	3-5	100-800
Seeds in crowns	20-30	2-3	50-400
Seeds at the soil	10-20	0.5-1	20-200
Birch			
Meristem of buds	20-30	3-5	20-200
Seeds in crowns	10-20	2-3	10-100
Herbaceous			
Meristem of buds	0-100	0-10	0-2000
Seeds in crowns	20-100	2-10	70-2000

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Doses to biota species following the Kyshtym accident normalized on the deposition density of 1×10^6 Bq m^{-2} (Tikhomirov et al., 1994)

Species	Maximum dose rate, mGy d^{-1}	Dose, Gy	Dose at the site near the point of release, Gy
Soil invertebrates			
In forest litter	3-20	0.5-5.0	200-800
In soil at 1 cm	2	2-3	10-40
Mammals			
Large game	3-20	3	100-400
Rodents	3-5	1-2	10-100
Predators	10	3	30-100
Birds			
Non-migratory herbivorous	20-30	2-3	50-400
Non-migratory carnivore	10	1	30-100

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Effects to non-human species (Sokolov et al., 1994)

Effects	Dose
Forest trees	
Mortality of pine trees	30-40 Gy – needles 15-20 Gy – buds
Mortality of birch trees	150-200 Gy – meristem 100 Gy – buds
Suppression/delay of leaves development (7 d)	100-200 Gy
Death of weakened trees	8.0-12.0 Gy
Herbaceous plants	
Sterility of seeds	10-30 Gy
Mortality of some species and reduced biodiversity	200 Gy
Morphological changes	1-10 Gy
Reduced growth and developmental problems	1-10 Gy
Inhibition of photosynthesis, transpiration	3-8 Gy
Chromosome aberrations in meristem cells	6-12 Gy
Mortality of some species of invertebrates	70 Gy larvae *Tachinidae*

Effects to non-human species (Sokolov et al., 1994)

Effects	Dose
Substantial decrease of biodiversity of freshwater species	1.5-25 Gy
Mammals: Mortality, acute radiation syndrome	1-3 Gy (External) 4-23 Gy (intestine)
Mammals: Chronic radiation syndrome	0.1-1.3 Gy (External) 4-23 Gy (intestine
Up to the end of 1958, the rodents population decreased 2 - 10-fold	5-30
Up to the end of , the number of wintering birds decreased by around 10-fold	3-100

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Genetic Effects (Shevchenko et al., 1992; Alexakhin et al., 2001)

- Studies were started in 1962 - 5 years after the accident .
- A significant excess of chromosome aberrations was registered in areas close to the axis of the trail.
- Genomic instability (increase freq. of cellular damage in offspring, while contamination decreased).
- Radioadaptation effects.
- Genetic effects are still observed at some sites.

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Secondary effects (Alexakhin et al., 2001)

Irradiation of plants and animals (primary effects) resulted in many cases in the disruption of ecological relations between the components of ecosystems. That was because of:

(1) changes in microclimatic and edaphic conditions (in affected coniferous forests, because of improvement of both light and mineral nutrition condition, more radioresistant deciduous species actively develop);

(2) disturbances in the synchronism of seasonal phases in the development of ecologically connected groups of organisms;

(3) imbalance in food interrelations between consumers and producers (decrease in food resources as a result of irradiation);

(4) changes in biological pressure as a result of species differences in radioresistance;

(5) changes in affected communities open ecological niches for immigration of new species.

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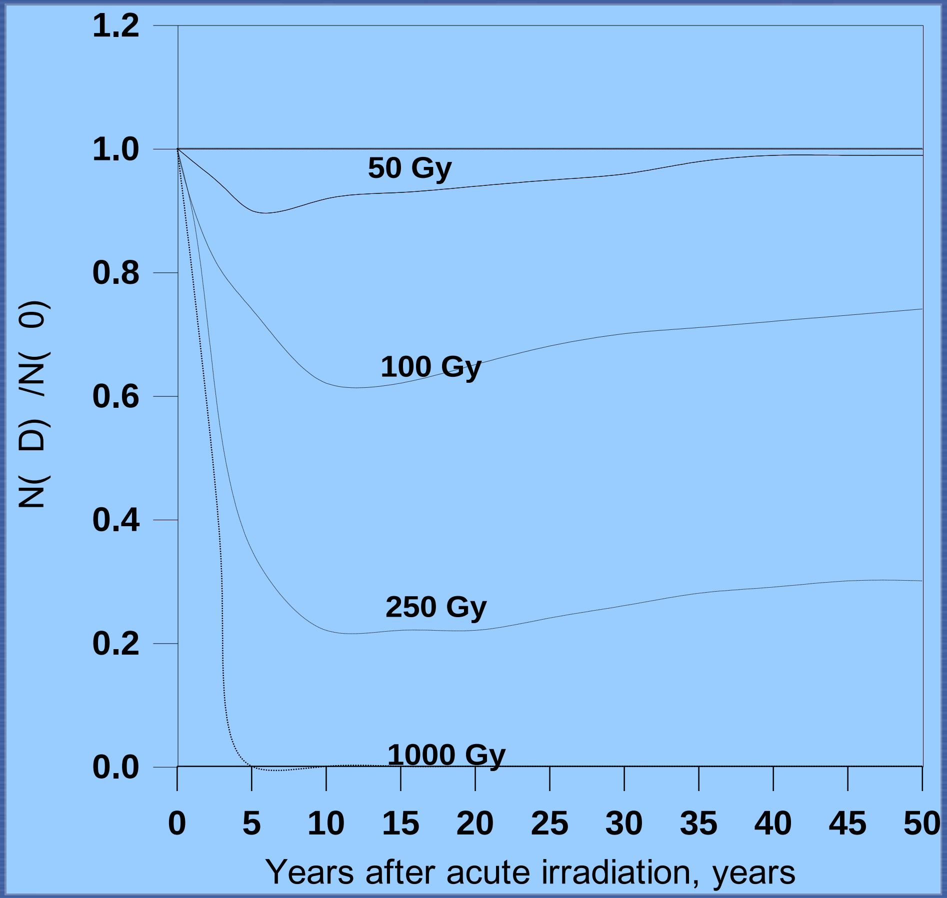
Radiation injury and post radiation recovery: Coniferous forest (Fesenko et al., 1996)



N(D) is the number of trees at the sites where the trees received dose of D (Gy)

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Summary

Period 1 (first year)

- Acute adverse effects
- Mortality of conifers; reproductive impacts to plants & animals
- Morphological effects
- Soil invertebrates highly impacted

Period 2 (> 1 year)

- Ongoing recovery
- Secondary effects
- Noticeable positive impacts
- Full long term genetic consequences are unknown

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Conclusions

- Even for severe radiation accidents, such as the Chernobyl and the Kyshtym, the severe effects of non-human species were observed on relatively small areas.
- Highly impacted populations of the biota species were recovered during 2-3 years after the accident, excepting coniferous trees.
- Some ecological consequences, such as the disruption of the of relations between the various species within the ecosystems persist and will persist for long time.
- Genetic effects are still also persisting in many areas subjected to high contamination and their consequences are not still fully understood.
- Such effects require further evaluation and special attention within identification of the management plan for the affected areas.
- Thus, evaluation of the effects of biota species in areas affected by the radiation accident do not show a need in introduction of new biota related options in the regulation for emergency preparedness and response. At the same time, the potential impact on biota should be carefully assessed and taken into account to provide a proper management on the affected areas.

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...Thank you for your attention!

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