



Wildfires risk reduction from forests contaminated by radionuclides: A case study of the Chernobyl Nuclear Power Plant exclusion zone

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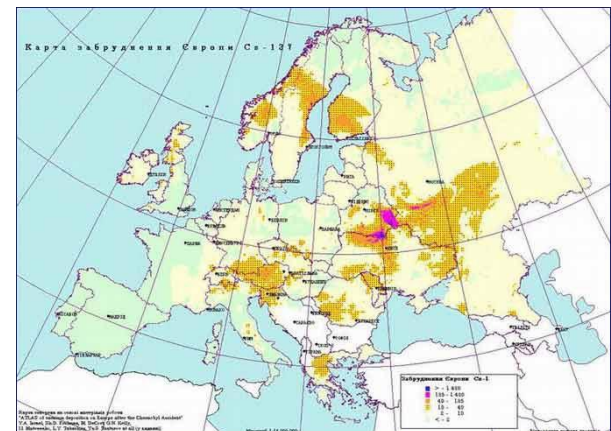
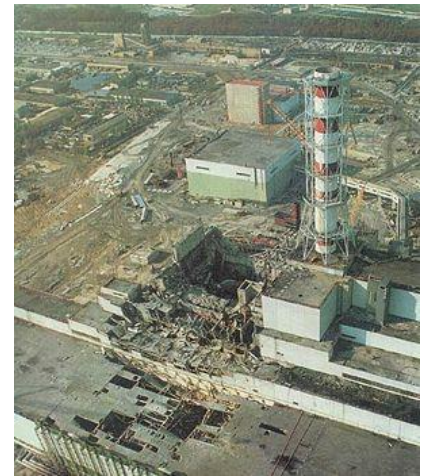
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Outline

- Disaster on Chernobyl NPP and radioactive contamination
- Forestry and forests in the Chernobyl exclusion zone (CEZ)
- Fuel loading, Fire history, regional level threats
- Doses for firefighters
- Regional Health risk assesment
- Modeling of fire risks
- Conclusions and recommendations

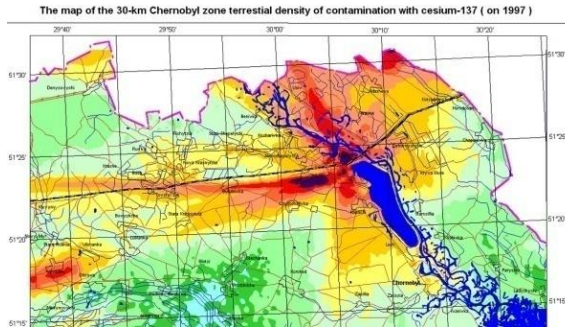
Disaster on Chernobyl NPP, 26 Apr 1986

- An area of more than 200 000 km² in Europe was contaminated above 0.04 MBq of ¹³⁷Cs/m² (IAEA,06);
- Most contaminated is Chernobyl exclusion zone (CEZ) with area 2600 km² : ⁹⁰Sr, ¹³⁷Cs, ¹⁵⁴Eu, ²³⁸Pu, ^{239,240}Pu, and ²⁴¹Am;
- Total amount of radionuclides that eventually could be mobilized by a catastrophic wildfire is - 2.1×10^{14} Bq (Hohl et.al);

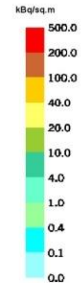
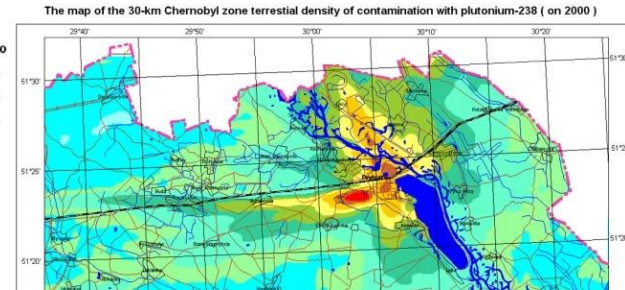


Radioactive contamination of CEZ

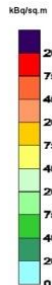
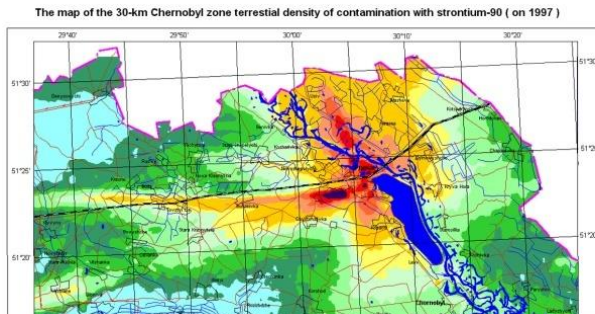
^{137}Cs



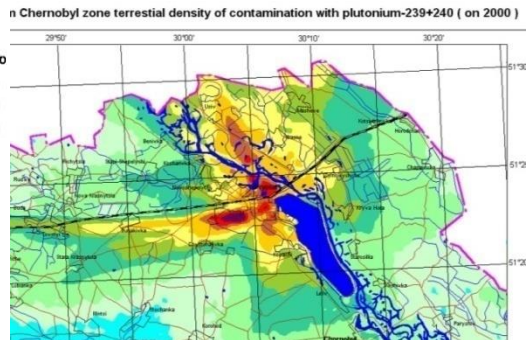
^{238}Pu



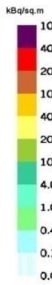
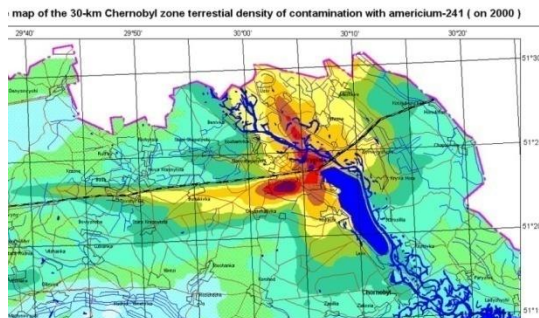
^{90}Sr



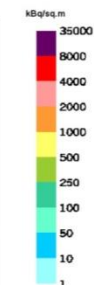
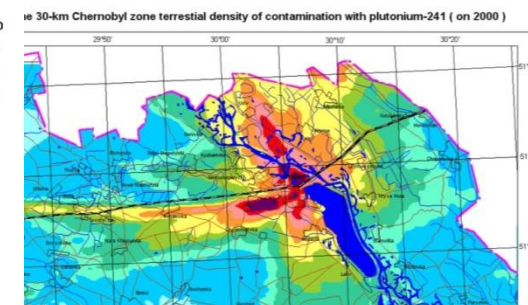
$^{239-240}\text{Pu}$



^{241}Am



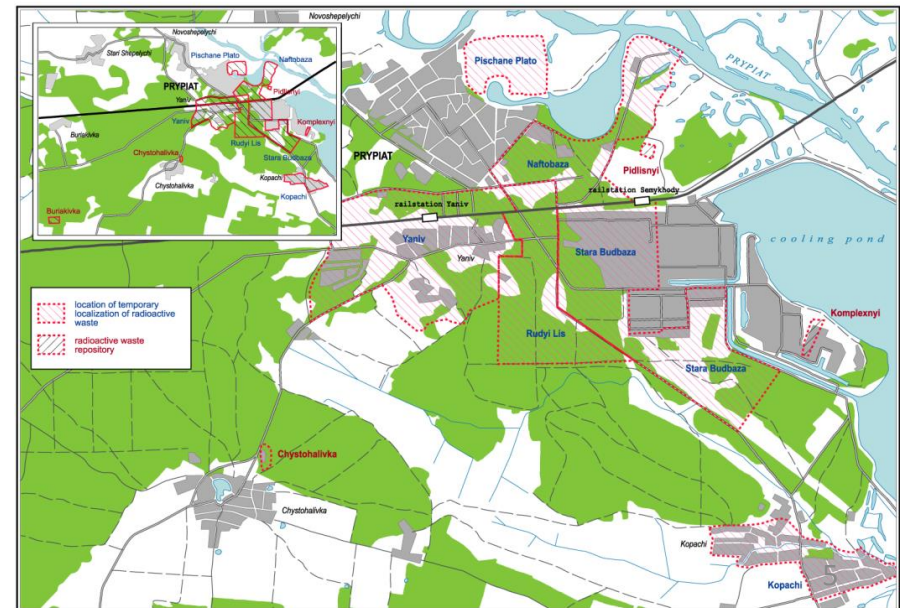
^{241}Pu



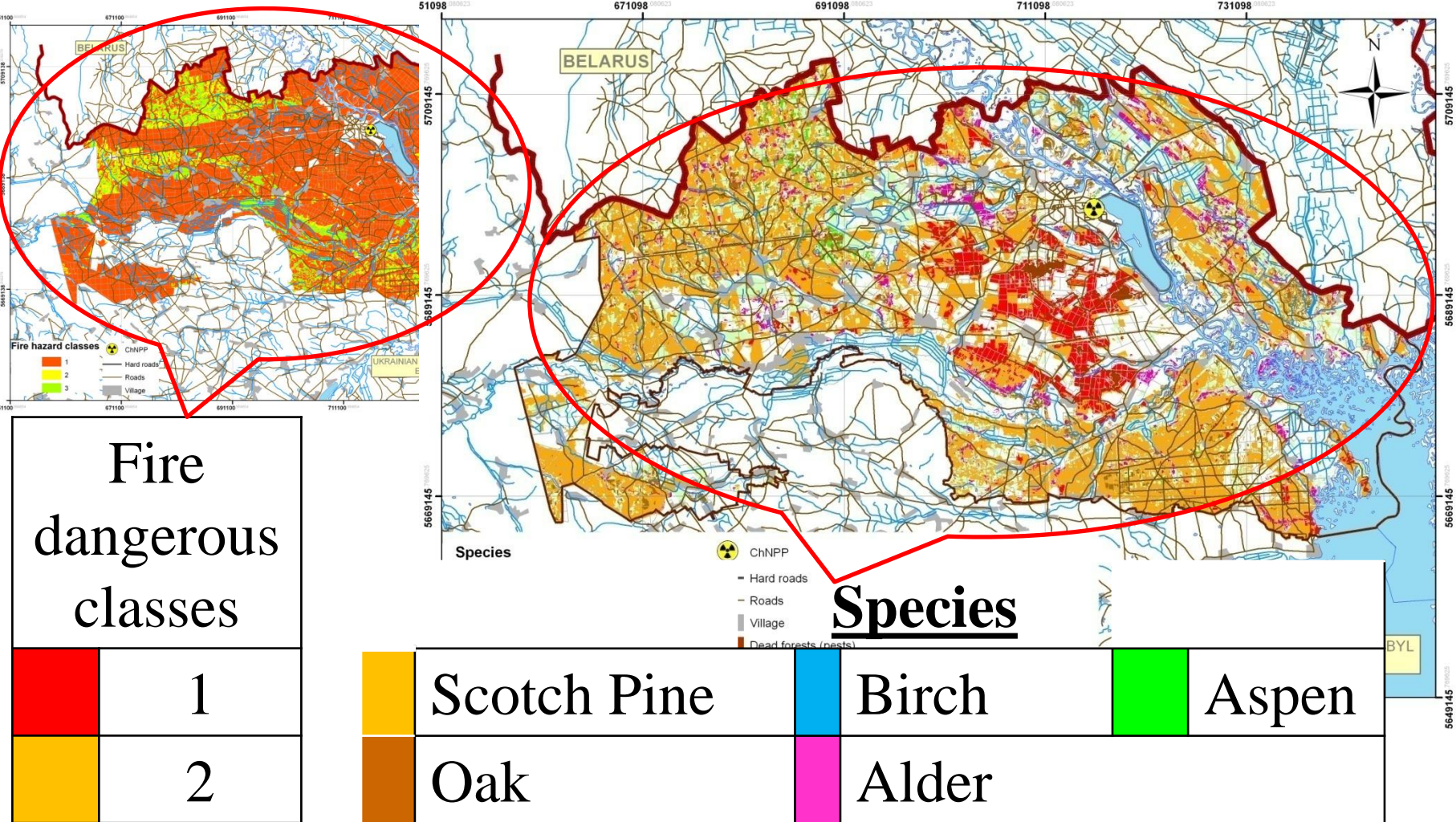
Radioactive waste in the CEZ as a potential threat during wildfires



RADWASTE REPOSITORIES IN THE EXCLUSION ZONE



Tree species distribution in CEZ and fire dangerous classes



Forests and forest management in the Chernobyl Exclusion zone

Total area of CEZ— 260 000 ha
Total area of forests 150 000 ha
Scotch Pine forests 89 000 ha
Total growing stock 30 mln m³
Total stock of died trees ~ 2 mln m³



Age structure:

≤ 40 years old - 23%,
40-60 years old - 67%

Plan for thinning in CEZ (2006)

8600 ha (407 thou m³)

Executed thinning:

680 ha (24 thou m³)

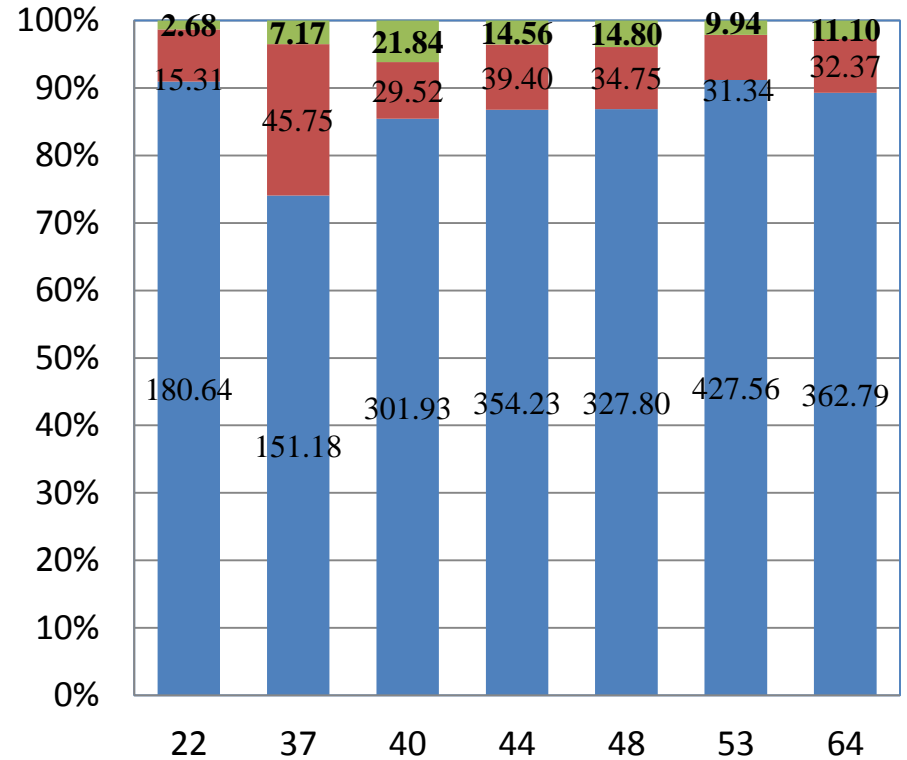
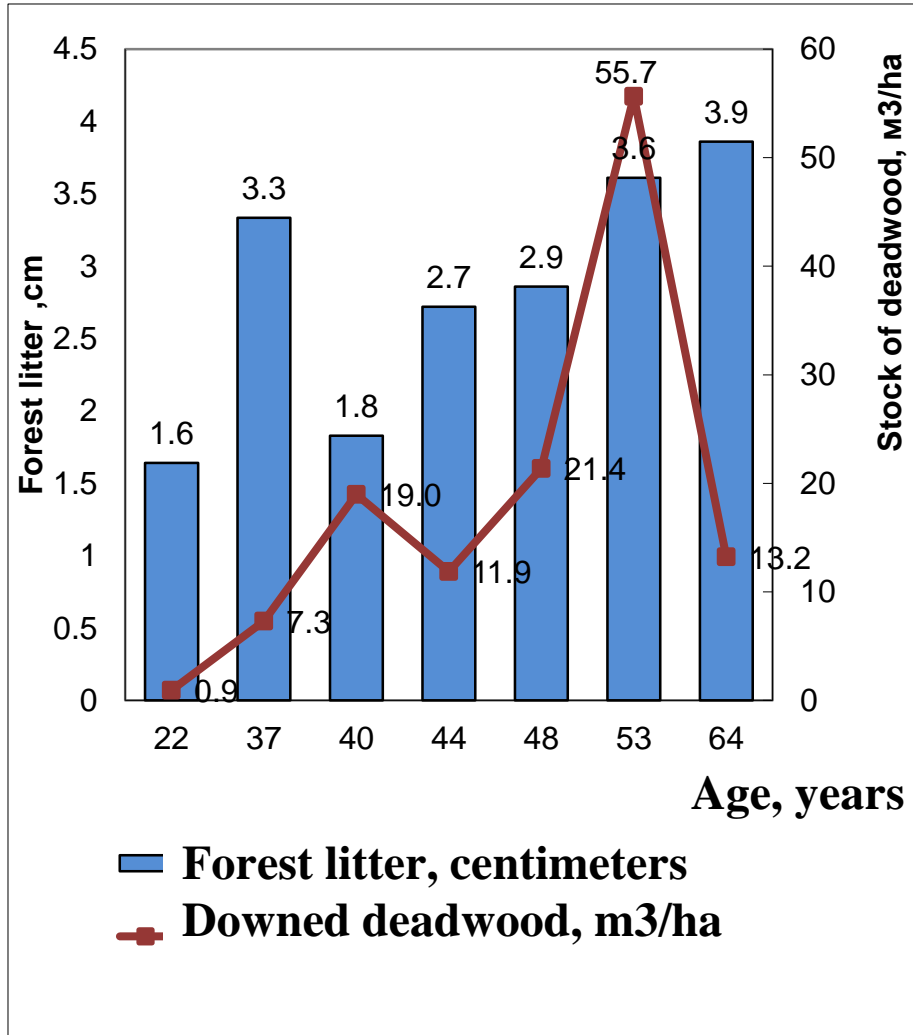


Lack of management and impact of diseases, insects and fires as a result





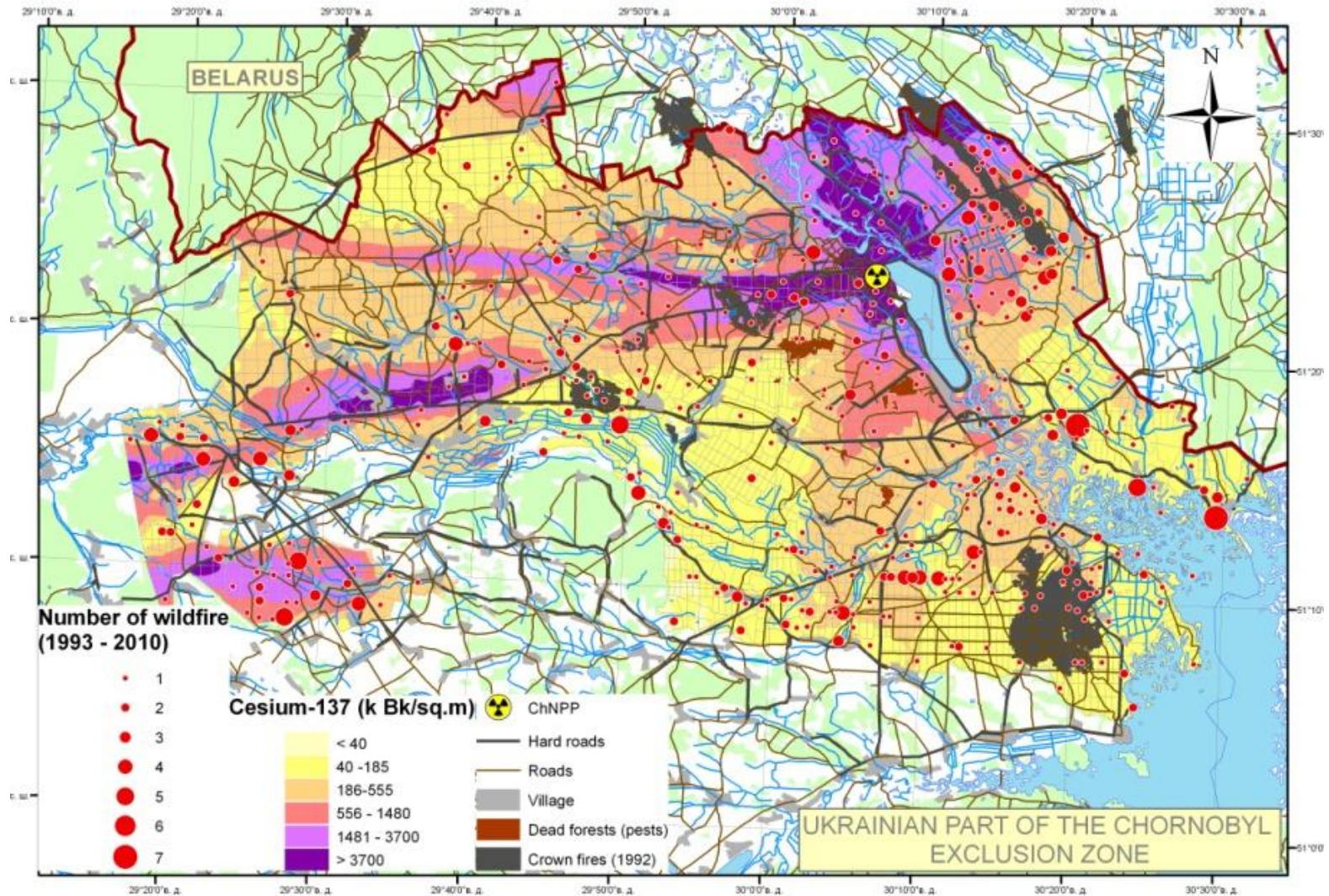
Fuel loading in Scotch Pine forests in CEZ



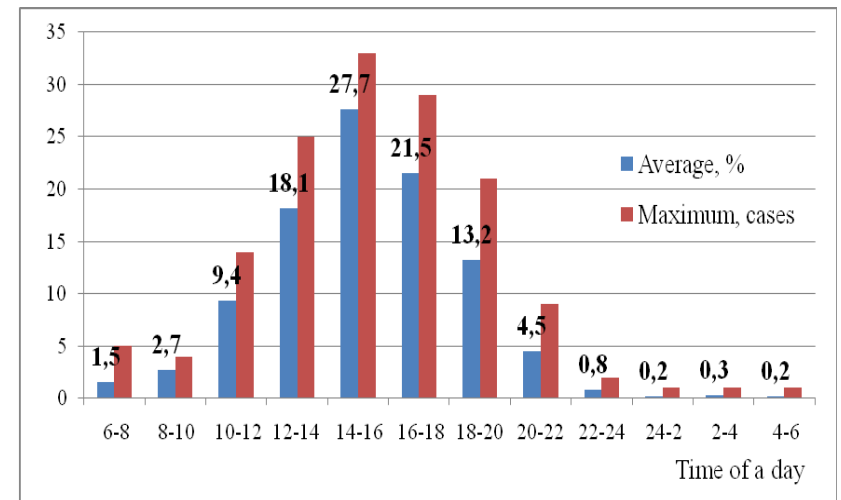
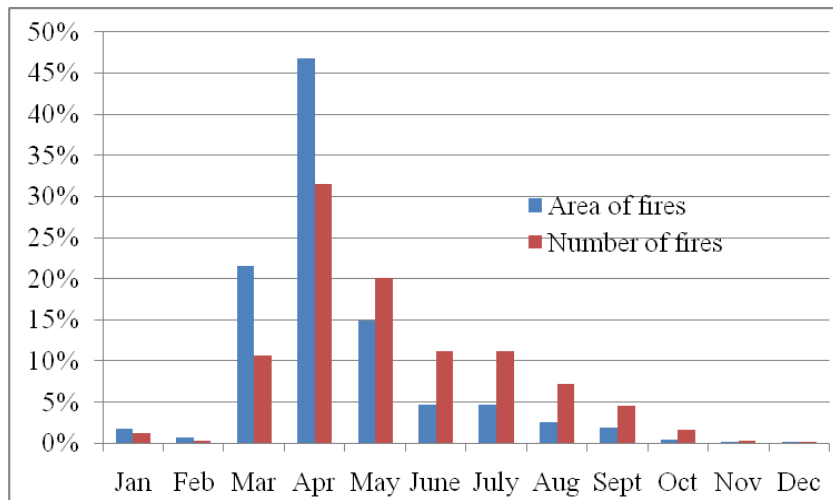
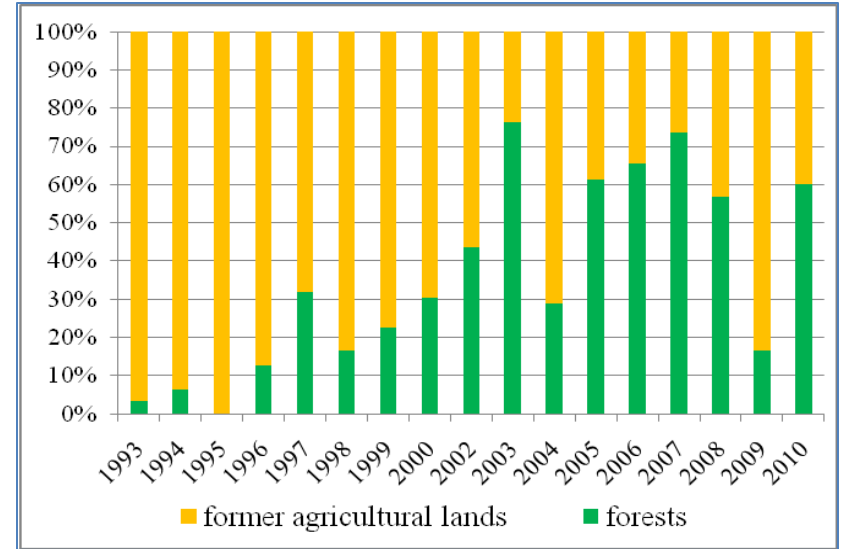
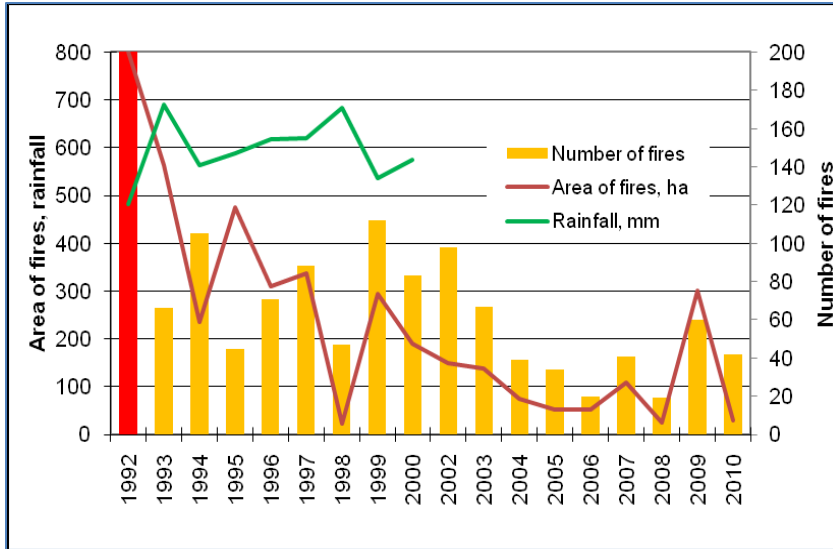
■ Health trees
■ Declined trees
■ Dead trees

Growing stock of declined trees and deadwood, m³/ha

Mapped wildfires, burned forests and forests damaged by insects in CEZ (92-10)



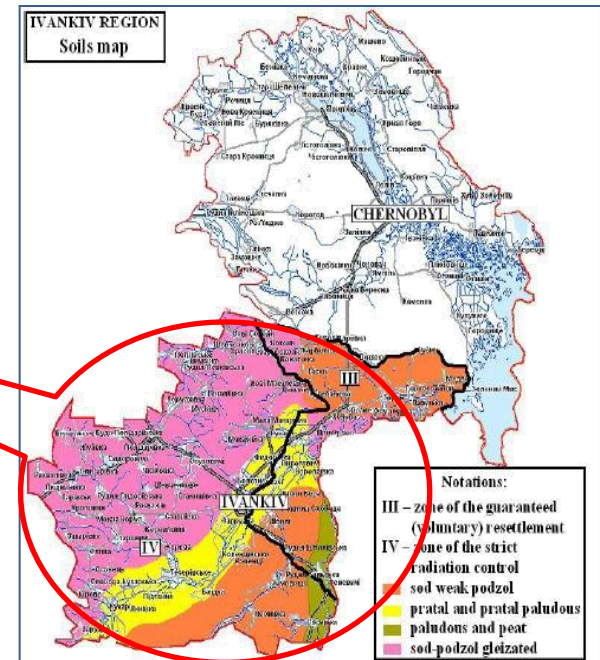
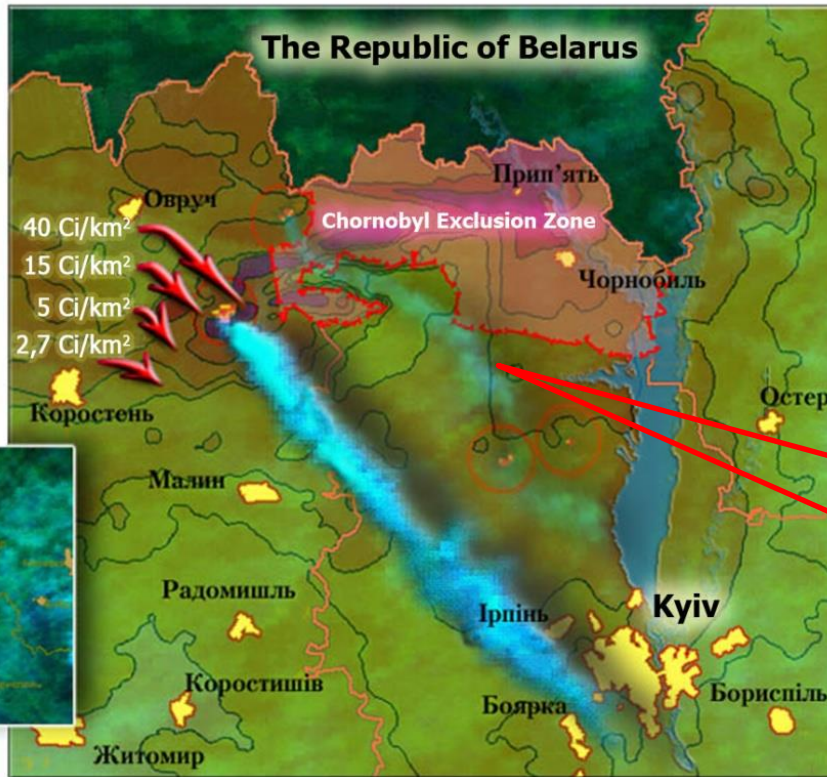
Fire history in CEZ



Distribution of wildfires in CEZ during fire season and day¹¹

Regional impact of wildfires from contaminated zones

Picture - courtesy of Ukrainian Land Resources Management Centre, image from 8 of May 2003



Populated area on South vicinity of the CEZ (Ivankiv rayon)

Prevention measures in CEZ



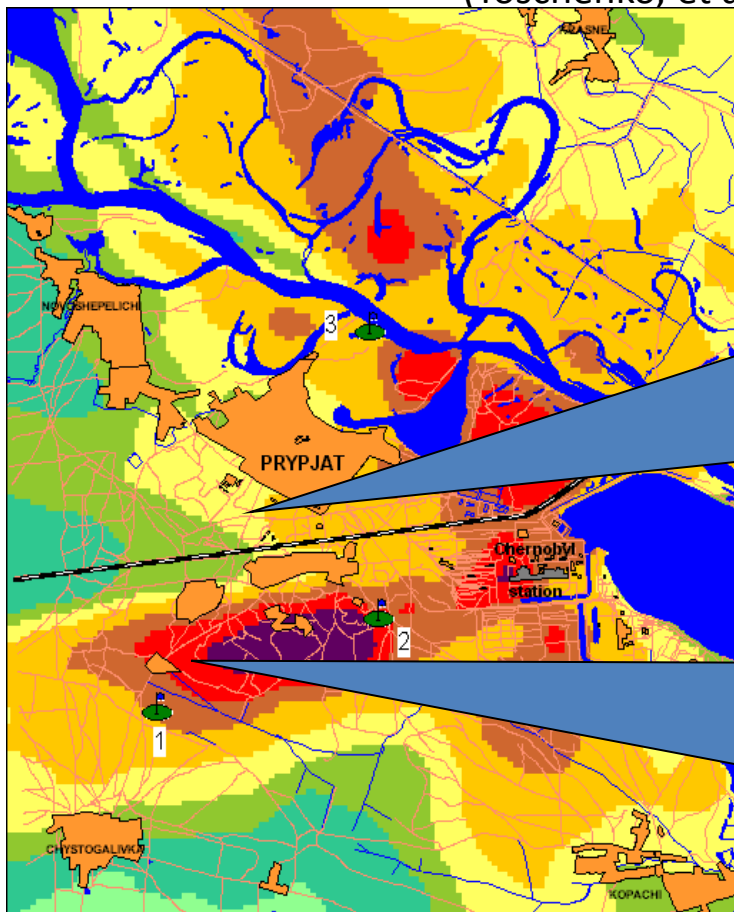
Fire forces and fire fighting





Experimental assessment of doses for firefighters from wildfires in CEZ

(Yoschenko, et al, UIAR, Project #1992 ICTU)



Density of contamination with $^{39+240}\text{Pu}$, kBq/m²



0,4 1 4 10 20 40 100 400 1000

Experimental assessment of doses for firefighters from ground and grass fires in CEZ

(1 hour exposition) (Yoschenko, et al, UIAR, Project #1992 ICTU)



	Maximum airborne concentration, Bq m ⁻³ , in the site			Dose type	Dose, μSv, in the site		
	#1	#2	#3		#1	#2	#3
¹³⁷ Cs	5	1	0.27	External from the cloud	6.9·10 ⁻⁴	1.4·10 ⁻⁴	3.7·10 ⁻⁵
				Inhalation	6·10 ⁻²	1.2·10 ⁻²	3.2·10 ⁻³
⁹⁰ Sr	3	0.5	0.33	External from the cloud	10 ⁻⁴	1.7·10 ⁻⁵	1.1·10 ⁻⁵
				Inhalation	0.24	4.1·10 ⁻²	2.6·10 ⁻²
²³⁸ Pu	3.4·10 ⁻³	2.5·10 ⁻⁴	4.6·10 ⁻⁴	Inhalation	7.1	0.53	1
²³⁹⁺²⁴⁰ Pu	6.7·10 ⁻³	5.1·10 ⁻⁴	1.1·10 ⁻³	Inhalation	17	1.3	2.8
External irradiation from soil and vegetation					16	10	4.2
Total dose					40	12	8

Summary: Features of the exclusion zone as a radioactive wildfire prone area

- Highly radioactive contamination territory
- Fire prone ecosystems
- Dangerous for firefighters
- Possible regional impact
- Lack of forest and fire management
- Lack of suppression capacity
- Absence of early warning

International efforts aimed in reduction of radioactive wildfires risk in the CEZ



**Global Fire Monitoring Center
(GFMC)**



Ministry of Emergencies of Ukraine

**Council of
Europe**



**National University of Life and
Environmental Sciences of Ukraine**

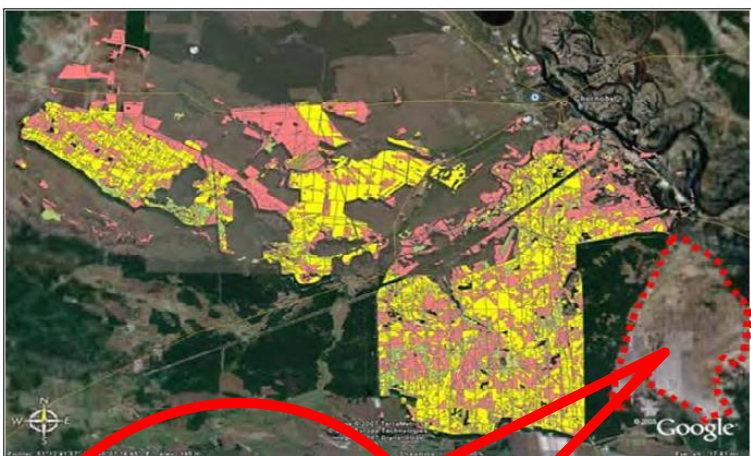
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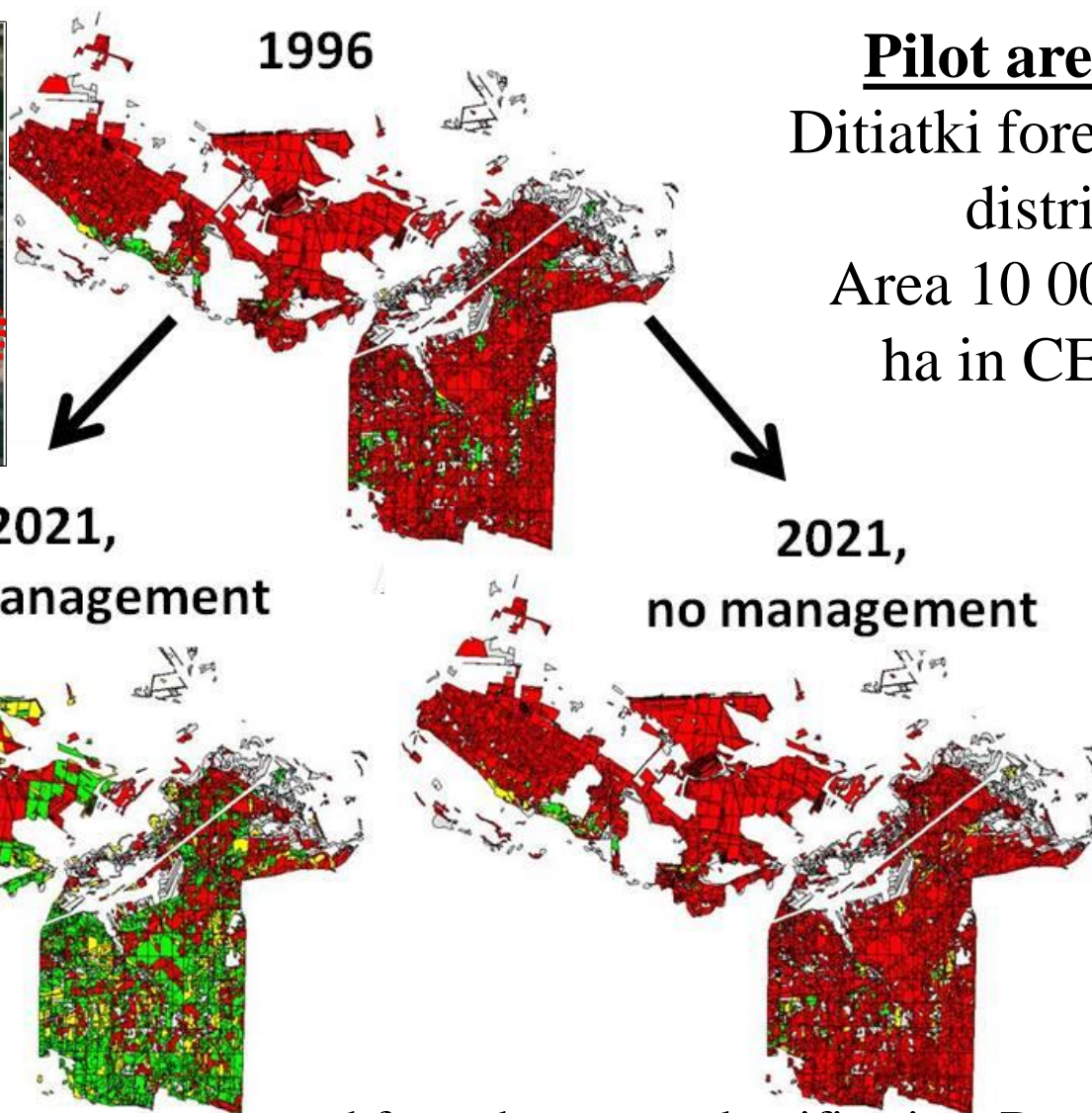
**Yale University
School of Forestry & Environmental Studies**

http://research.yale.edu/gisf/EDSC/Chernobyl/chernobyl_ftp.htm

Modeling of fire risks and scenarios



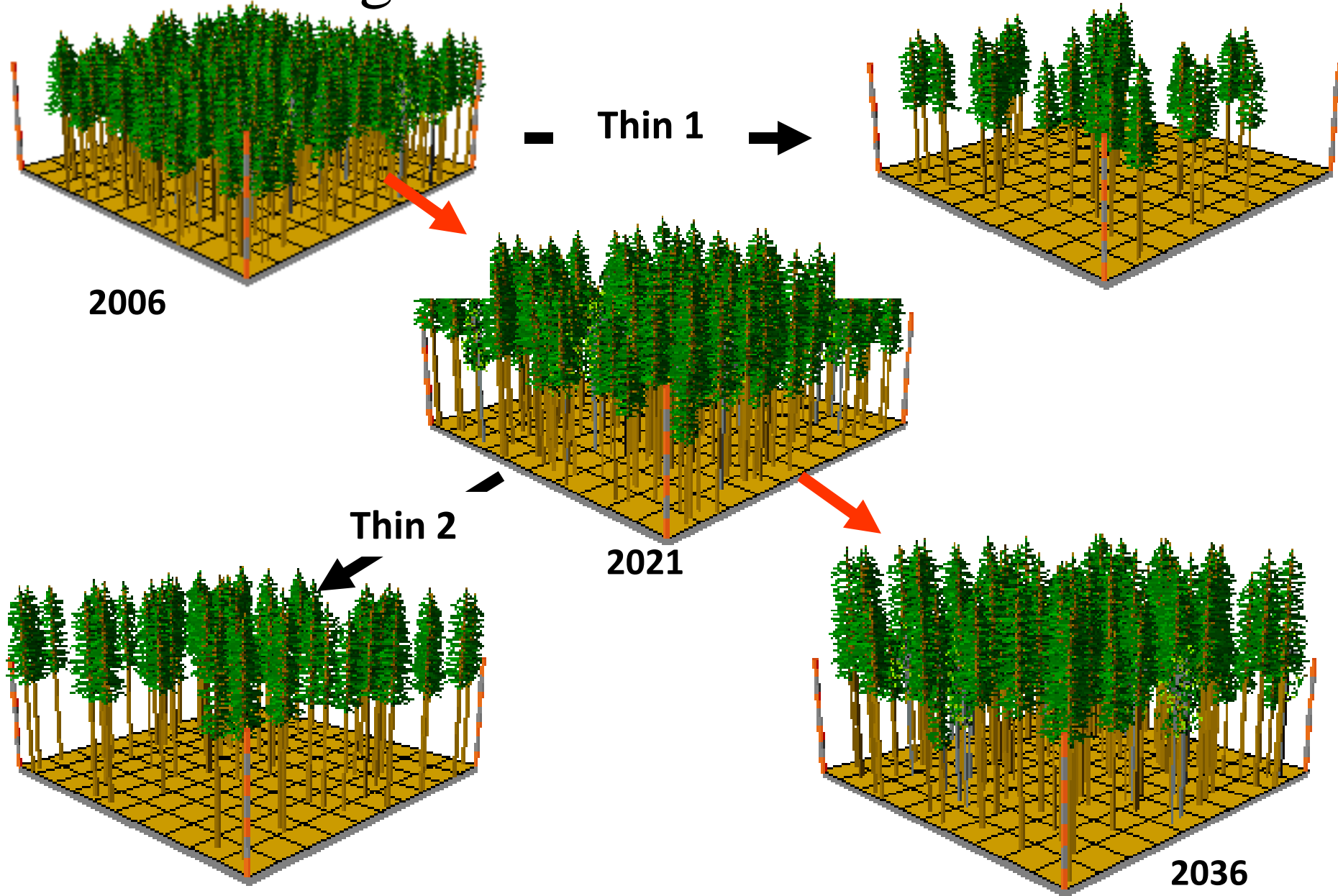
Burned forest
in 1992
(5 000 ha in
CEZ)



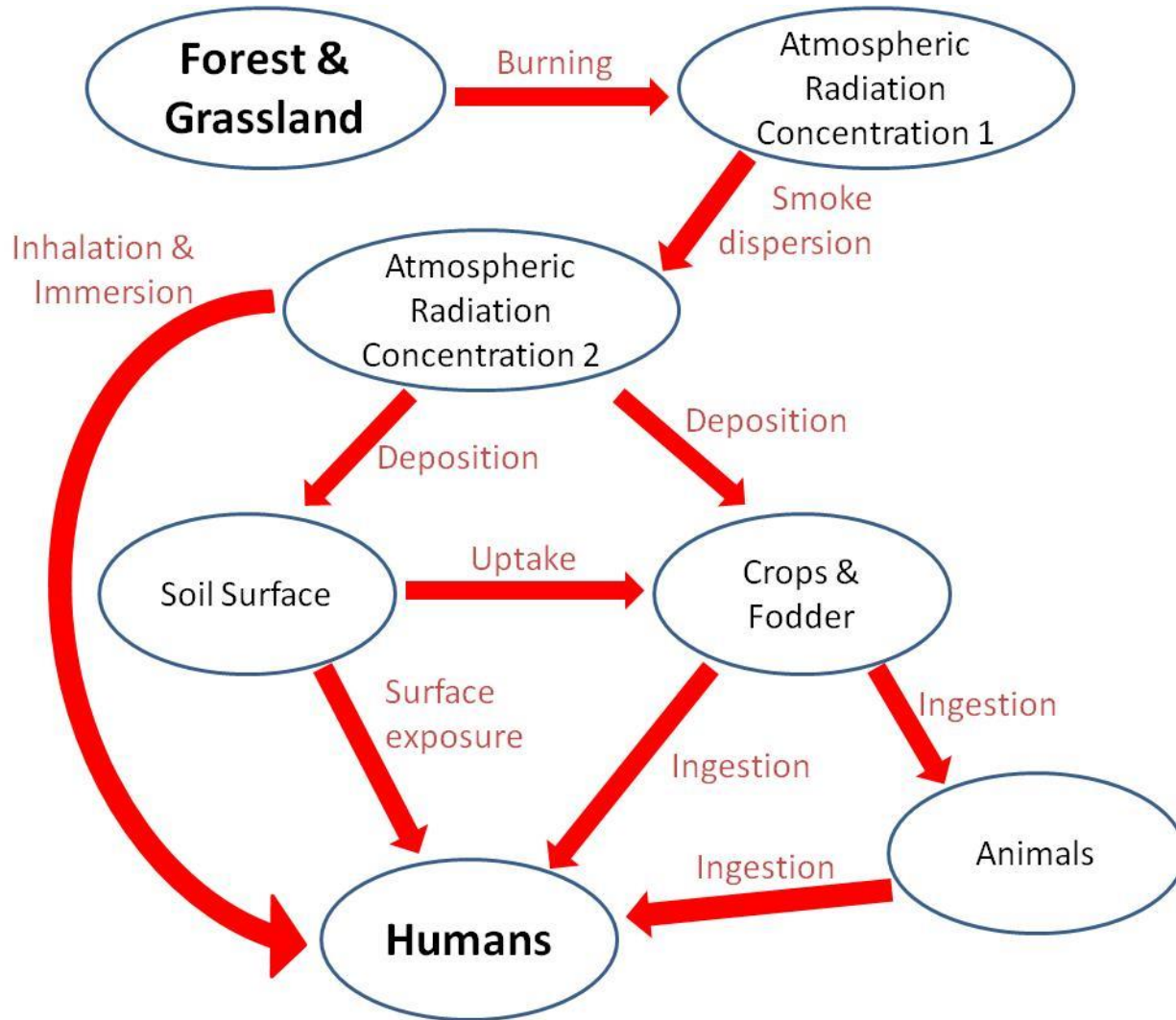
Pilot area:
Ditiatki forest
district
Area 10 000
ha in CEZ

Stand groups are named for a three part classification: B = broadleaf, C = conifer; Site class 1-4; Age class 1-3.

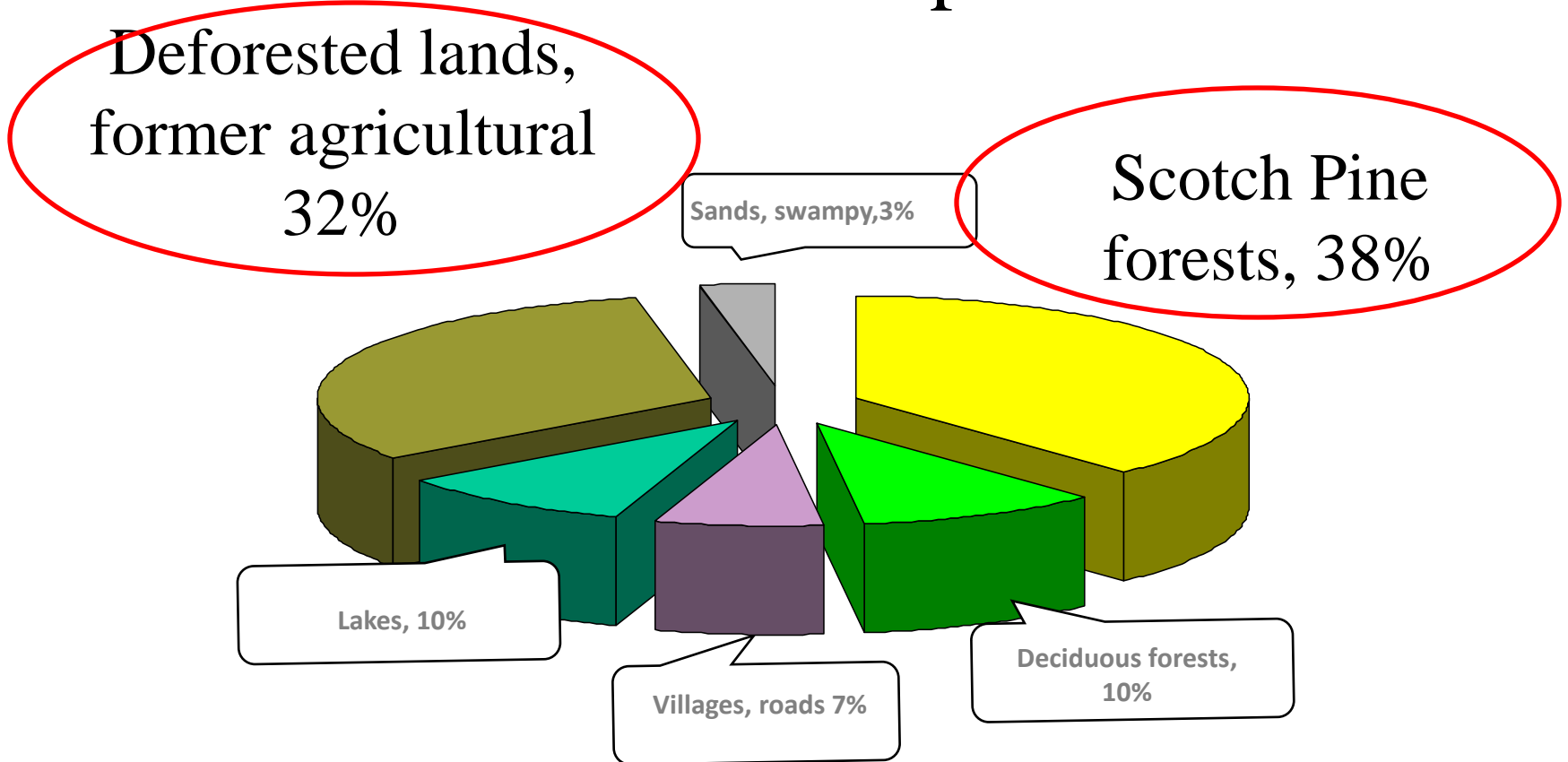
Modeling of fire risks and scenarios



Health Risk: Conceptual Model



Source Model: Fire prone lands



Distribution of lands in the Chernobyl Exclusion Zone according to 1996 inventory

Source Model: Radionuclide Distribution

Radionuclide	Radionuclide Inventory (Bq)			Ratio Combustible/Soil	
	Soil in 2000	Soil in 2010	Combustible in 2010	Forest	Grassland
⁹⁰ Sr	7.7E+14	6.1E+14	1.5E+14	0.351	0.023
¹³⁷ Cs	2.8E+15	2.2E+15	5.8E+13	0.101	0.037
¹⁵⁴ Eu	1.4E+13	6.4E+12	8.5E+10	0.031	0.005
²³⁸ Pu	7.2E+12	6.7E+12	8.4E+10	0.03	0.004
^{239,240} Pu	1.5E+13	1.5E+13	2.0E+11	0.031	0.005
²⁴¹ Am	1.8E+13	1.8E+13	4.7E+11	0.062	0.01

Transport Model: Resuspension & Ground concentration

Gaussian plume model

- Air concentration downwind depends on
 - Fraction of time per event that wind blows toward the target (assumed 90%)
 - Diffusion factor (assumed Pasquill-Gifford stability class D)
 - Wind speed (assumed 2 m/s)
- Ground concentration depends on
 - Deposition velocity (assumed 1000 m/d)

Exposure Model

- Total dose is sum of:
 - Inhalation
 - Cloud immersion
 - Ground exposure
 - Ingestion (for foodstuffs including milk, meat, and crops)

Exposure Model: Inhalation

$$E_{inh} = C_A R_{inh} D F_{inh}$$

E_{inh} is the periodic effective dose (Sv/a),

C_A is the radionuclide concentration in the air obtained from Equation [1] (Bq/m³),

R_{inh} is the inhalation rate during the wildfire event (m³/a),

$D F_{inh}$ is the inhalation dose coefficient (Table 2; Sv/Bq).

Results: Total exposure of Adults

Distance (km)	Immersion (mSv/a)	Ground.Exposure (mSv/a)	Inhalation (mSv/a) Adult	Ingestion (mSv/a) Adult	Total (mSv/a) Adult
25	1.8E-04	2.1	1.7	14	17
50	6.4E-05	7.2E-01	6.1E-01	4.8	6.2
100	2.2E-05	2.6E-01	2.2E-01	1.7	2.1
150	1.2E-05	1.4E-01	1.2E-01	9.1E-01	1.2

Estimated effective dose for the critical population after a catastrophic wildfire.

Conclusion

- Results suggest substantial risk of large wildfires.
- Wildfire would not, under Ukrainian law, require resettlement, evacuation, or limitation of time spent outdoors for populations living outside of CEZ.
- Limitations of consumption of foodstuffs might be required.
- A series of activities by Ukrainian and international scientists, global citizens, administrators, and policymakers is leading to a promising outcome: to the decision of the Ukrainian government to initiate measures to prevent them.

Conclusions and recommendations

- Urgent steps that should be taken in Chernobyl exclusion zone related with installation of advanced automated early warning system, implementation of individual protection means for fire fighters and fast response capacity increasing.
- Second package should include silvicultural measures aimed in long-term reduction of fire dangerous in forests, developing of DSS for prevention of catastrophic radioactive wildfires, modeling of risks and doses

Conclusions and recommendations

- International procedures for fire monitoring and fire fighting operation should be approved by Governments of Ukraine, Byelorussia and Russia for better co-ordination in emergencies situation
- Classification of others wildfire prone territories in the world with additional risks (radioactive, chemical contamination, explosive etc) should be developed. Special safe procedures for fire management should be implemented

Acknowledgements

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Thank you for attention!

