

Development and application of  
atmospheric transport models for assessing  
radioactively contaminated sites:  
experience of IMMSP

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# Division of Environmental Modelling (DEM) - IMMSP

has been established in May, 1986, following Chernobyl Accident.

First team lead – Dr Mark Zheleznyak, since Nov 2013 – Professor of Institute of Environmental Radioactivity Fukushima University

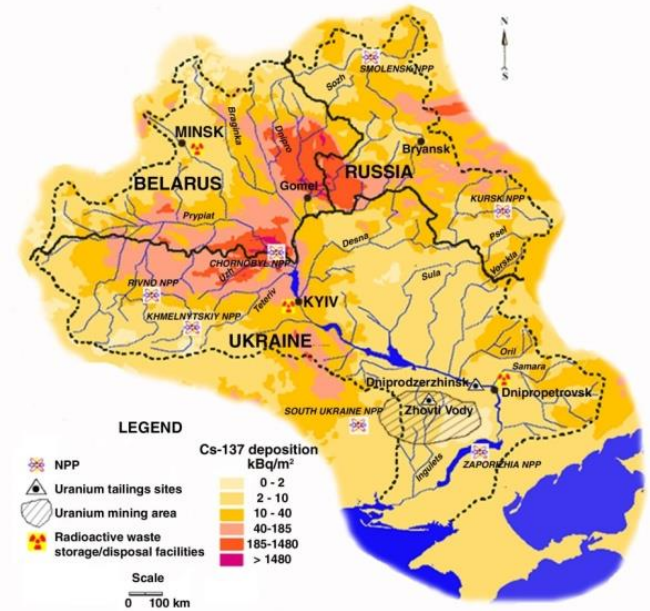
Present Head: Dr. Igor Brovchenko, Corresponding Member of NASU

Research provided by **two** Departments headed by

Dr. Ivan Kovalets (*Dep. of Environmental Informatics and Atmospheric Modeling*),

Prof. **Vladimir Maderich** (*Dep. of Marine and River Systems Modeling*)

as also by the spinoff company of IMMSP- Ukrainian Center of Environmental and Water Projects (**UCEWP**) [www.ucewp.kiev.ua](http://www.ucewp.kiev.ua)



# Motivation

- Several unique radioactive sites in Ukraine, such as the Chernobyl Exclusion Zone, the territory of the former uranium production Pridneprovsky Chemical Plant and others
- Environmental impact assessment for management and remediation of radioactively contaminated sites requires adequate models

# Pridneprovsky Chemical Plant, Kamianske (former Dniprodzerzhinsk), Ukraine



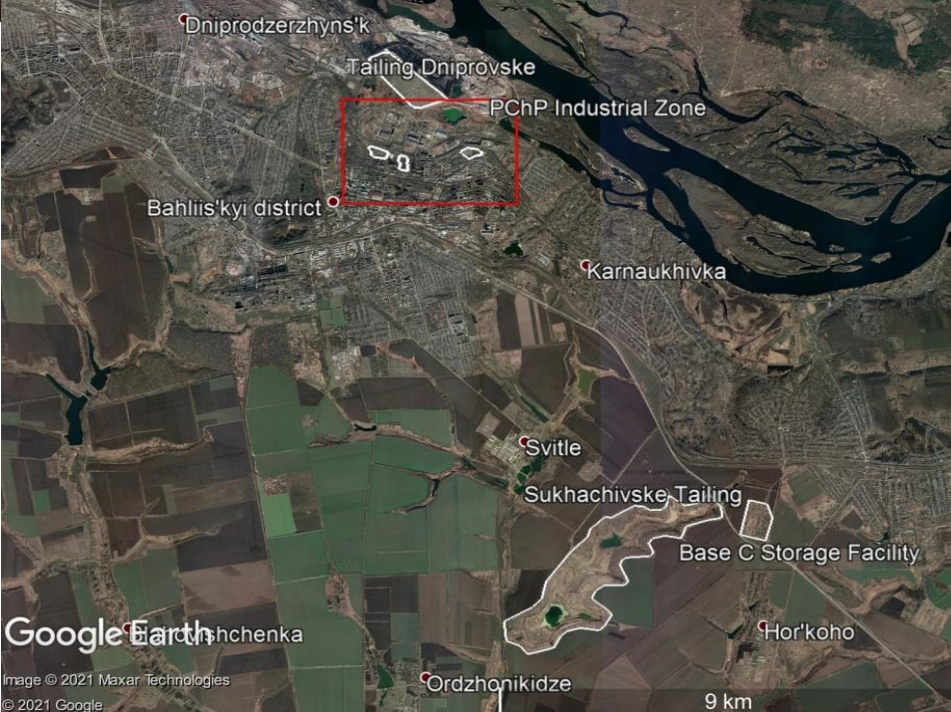
Picture courtesy: <https://archive.kyivpost.com/business/a-neglected-uranium-ore-plant-poses-threat-to-environment-in-kamianske.html>

Was one of the largest enterprises in the former Soviet Union that carried out uranium processing from 1948.

The radioactive materials originating from uranium treatment are stored in 9 tailings, their total radioactivity is estimated as  $3.2E15$  Bq and some of the tailings are not properly covered.

Some buildings and parts of territories at the industrial site of PChP are highly contaminated, while the closest distance from the PChP to living zone is less than 1 km. The working enterprises still exist at the former territory.

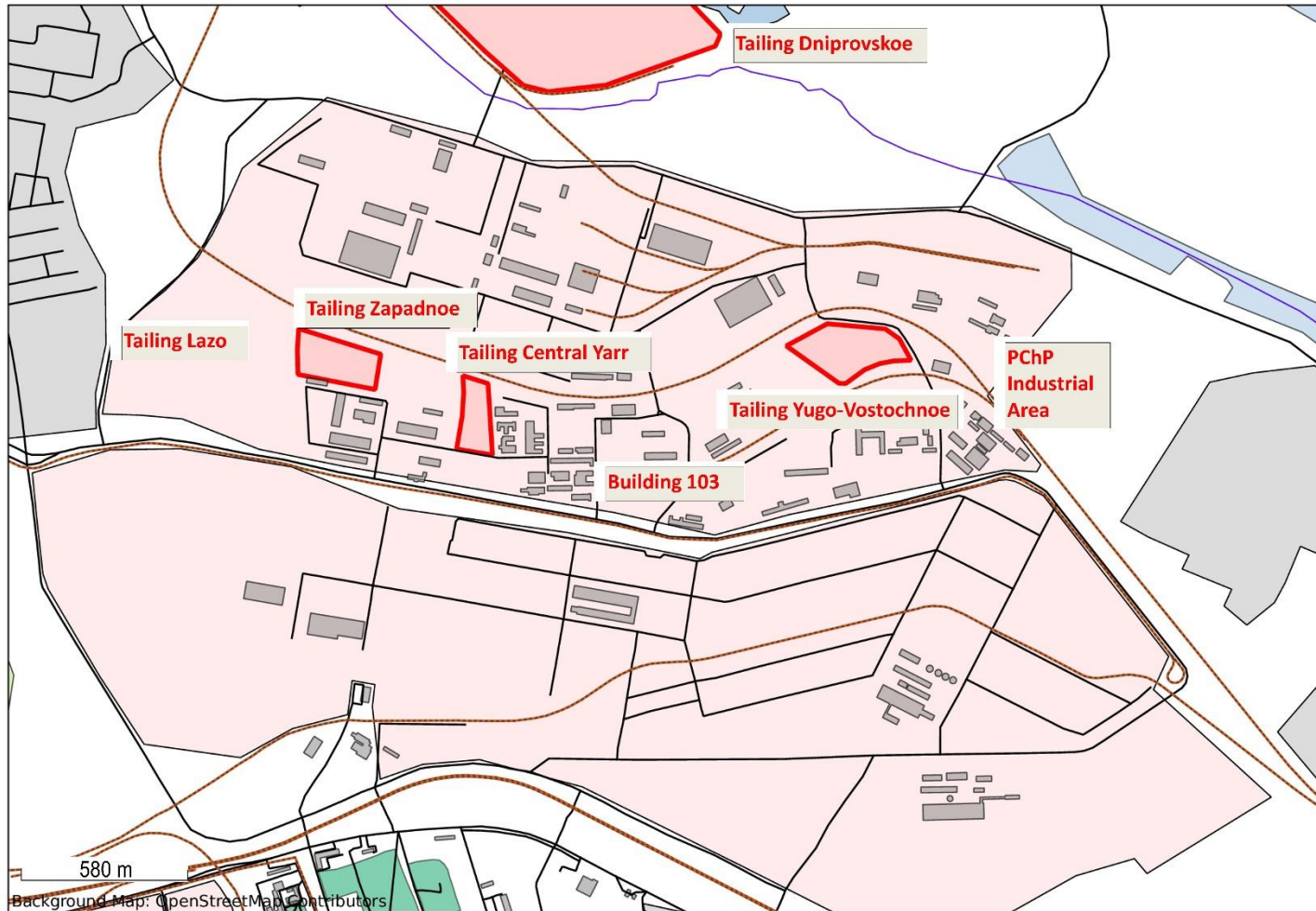
Appropriate decommissioning procedures were not taken upon closure of the PChP.



# Application of atmospheric transport models

- Radiological safety assessment regarding Rn-222
- Radiological safety assessment regarding radioactive aerosols, resuspended by wind
- Environmental safety assessment regarding the most contaminated buildings

# Zapadnoe, Central Yarr, South-East and Lazo tailings considered in Rn-222 simulations



Picture courtesy: Kovalets et al. (2017) Journal of Environmental Radioactivity, Elsevier

# Measurements and model of radon emission from tailings' surface

2-layer model of radon emission from covered tailing fitted to measurements data

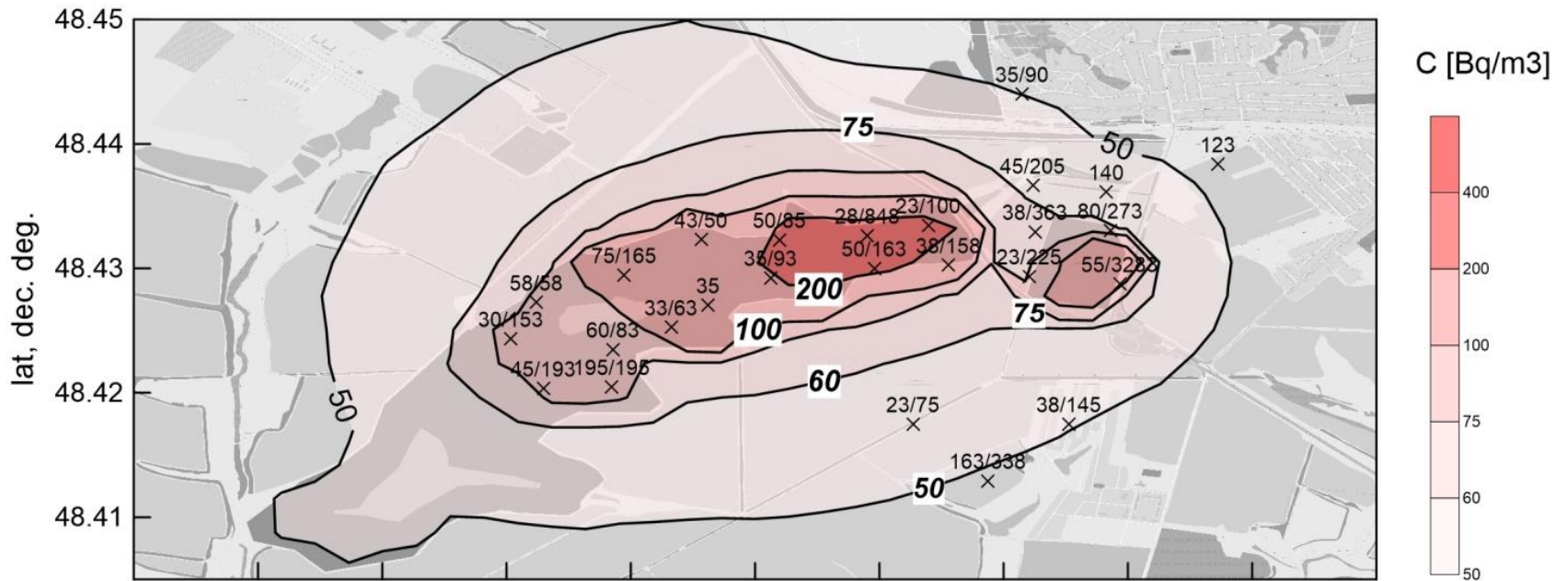


Measurements of radon emission [mBq/m<sup>2</sup>s] from the surface of West tailing. Figure Courtesy: Kovalets et al(2017) J.Env.Rad

# Setup of Calpuff model

- Simulations performed for year 2009
- Data of the nearest meteorological meteorostation and FNL data regarding atmospheric upper levels used to drive mode;
- 2 computational domains, covering PChP industrial site (9x9 km) and Sukhachivske site (20x20 km)
- Grid resolution of output results: 90 m

# Comparison with measurements of radon concentrations at Sukhachivke tailing



Kovalets et al. 2017. J.Env.Rad.

# Evaluation against yearly-averaged measurements at tailings' surfaces

Site	Measured	CALPUFF Emission Case I	CALPUFF Emission Case II
Zapadnoe	145	89	125
Central Yar	240	102	132
Yugo-Vostochnoe	180	57	90
Bld. N. 103	125	47	91
Sukhachivske	90	91	-
Base C	120	113	-

Case I: Evidence of undiscovered sources at PChP industrial site

Case II – radon flux of 1Bq/m<sup>2</sup>s added for the whole territory of PChP industrial site

Tailings appear to be NOT the main source of radon at PChP site!

# Estimation of aerosols resuspension at the PChP and Suhachivske sites

$$F = 3.6(u^*)^3$$

Dust (PM10) flux from bare soil in  $\mu\text{g}/\text{m}^2$   
 $u^*$  is friction velocity in m/s

$$F = 3.6(u^*)^3 (1 - CLF)(1 - CF)$$

Corrected PM10 flux for different land uses  
CF- correction factor for land use  
CLF – fraction of closing (territories from which resuspension do not happen)

$$F_q = F \cdot C_s$$

Radioactivity flux depending on soil contamination  $C_s$  (Bq/kg)

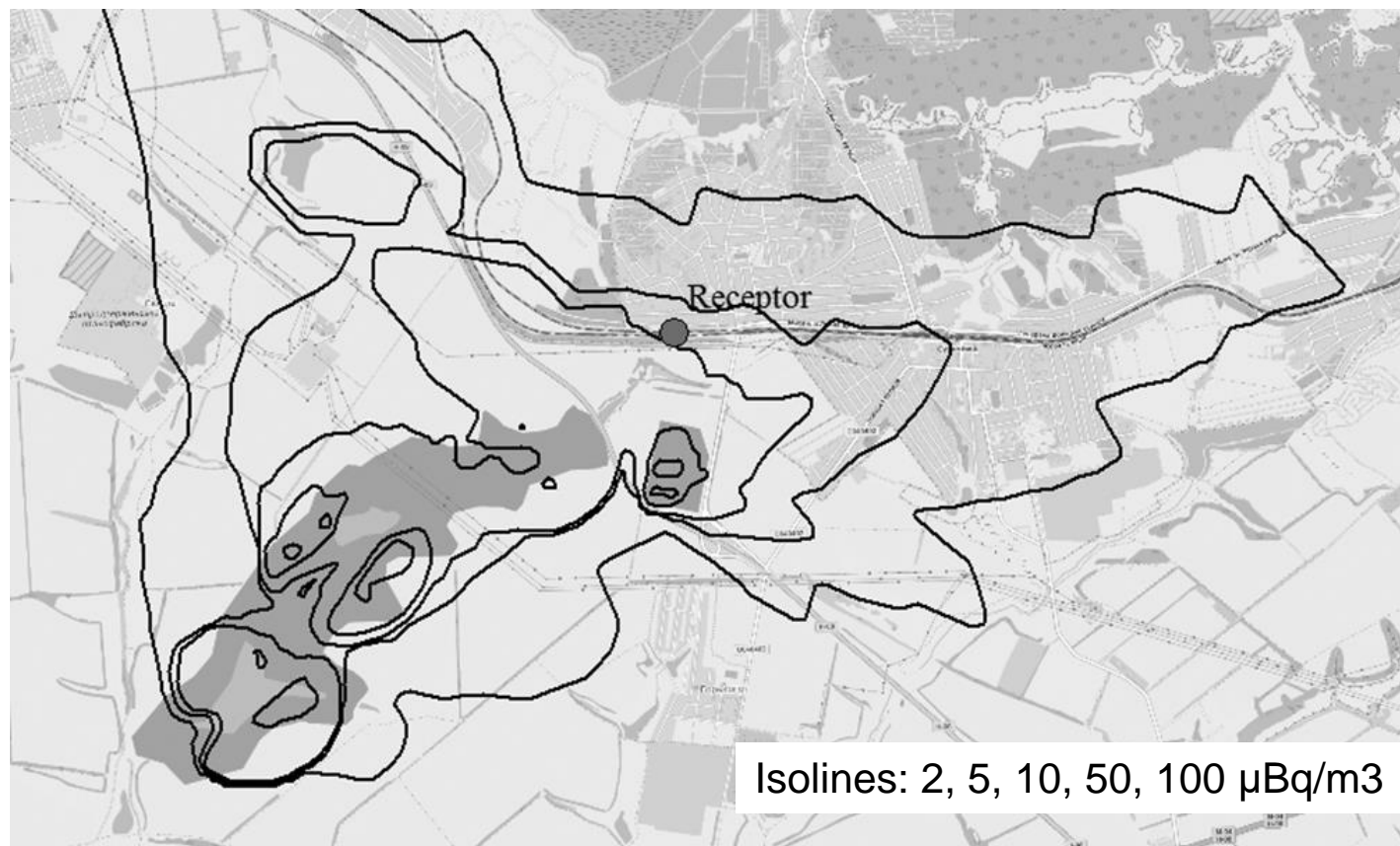
# Comparison of calculated and measured concentrations in 2011

Suhachivske tailing				
	U-238, $\mu\text{Bq}\cdot\text{m}^{-3}$		Ra-226, $\mu\text{Bq}\cdot\text{m}^{-3}$	
	Measured	Calpuff	Measured	Calpuff
15.08-02.09.11	48.0	Min = 0.3 Max = 22.1 Mean = 3.1	28.0	Min = 0.5 Max = 24 Mean = 5.8
02.09-03.10.11	4.0		2.0	
03.10.-31.10.11	4.0		5.0	
01.11-01.12.11	7.0		7.0	
01.12-14.12.11	3.0		5.0	

Reference: Khalchenkov et al.,2016. Probl. of Nucl. Power Plants Safety & Chornobyl

Maximum U238 concentration for 2011 in the nearest residential point 60 times less than regulatory value. For extreme winds such as dust storm maximum value could be higher

# Map of maximum simulated concentrations of Ra226 in the Fall of 2011

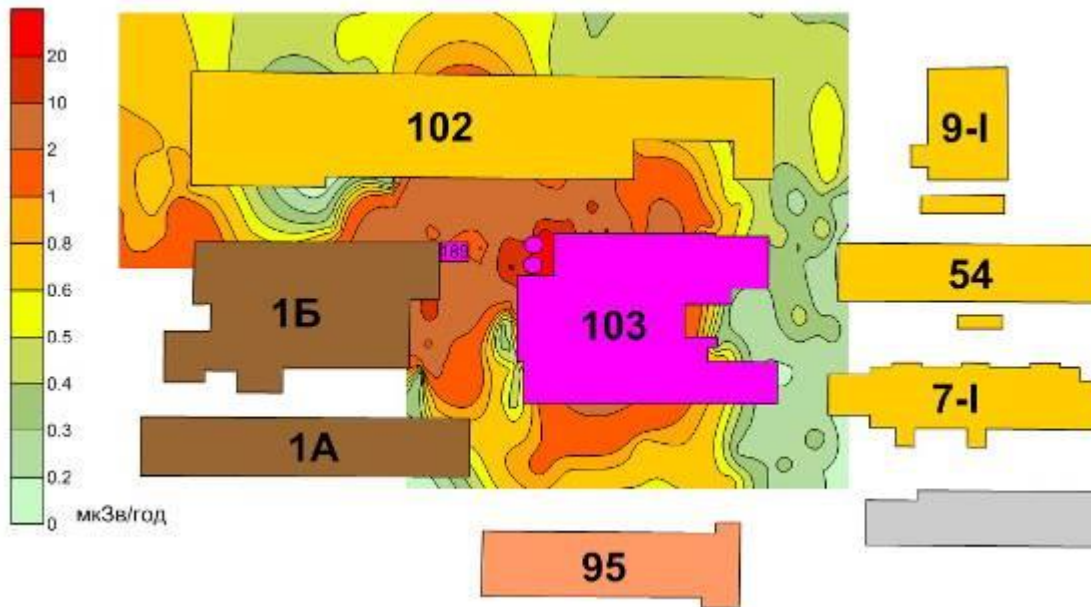


Picture Courtesy: Khalchenkov et al.,2016. Probl. of Nucl. Power Plants Safety & Chornobyl

Maximum U238 concentration in the nearest residential point is 2 orders of magnitude less than regulatory value

# CFD modeling of radionuclides transport from contaminated building

- OpenFoam CFD code
- Conservative scenario of contaminants ventilation from the broken windows of Building 103

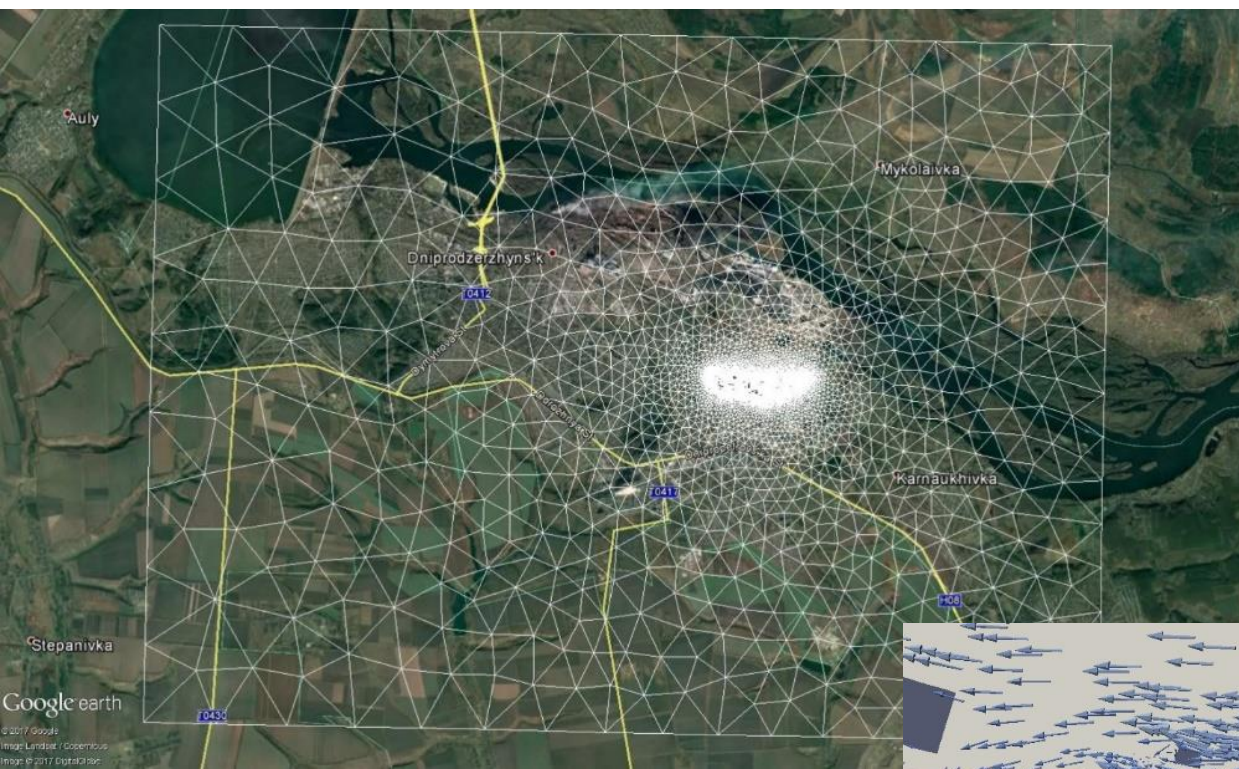


Gamma-dose rate ( $\mu\text{Sv/hr}$ )  
spatial distribution around  
former U-extraction facility  
№103 and its nearby adjacent  
infrastructure facilities

Up to 250  $\mu\text{Sv/hr}$  in some points  
of the B103

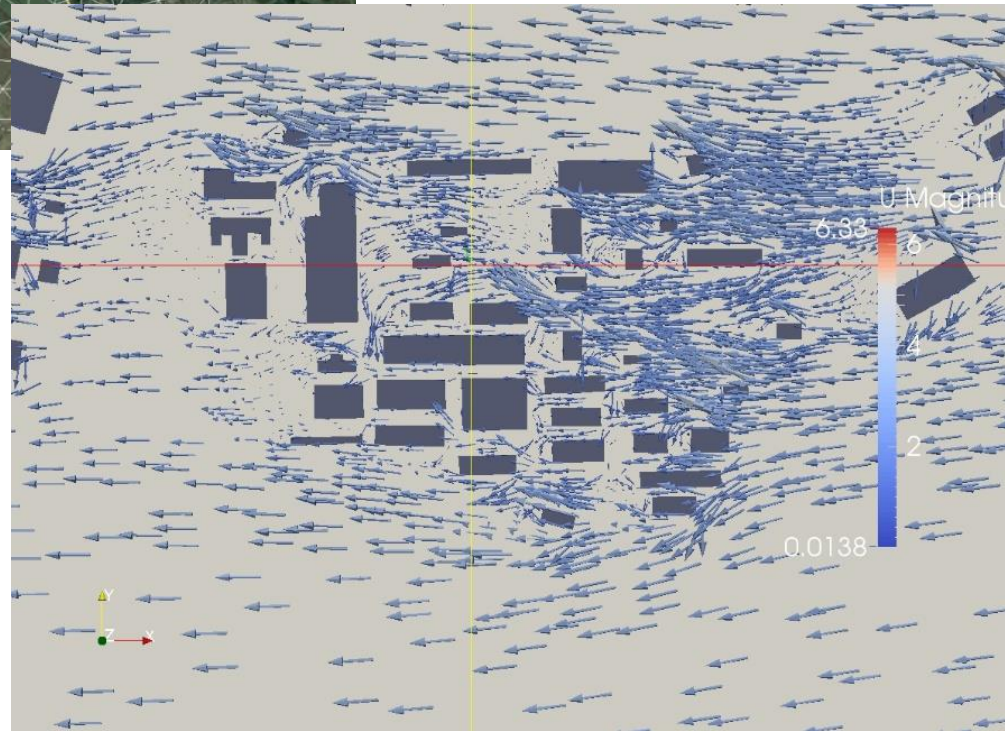
Picture from: Buchnea et al. (2014). Report of Ensure II  
Project, DOI: 10.13140/2.1.2043.4563

Measurements by UHMI and  
Ecomonitor



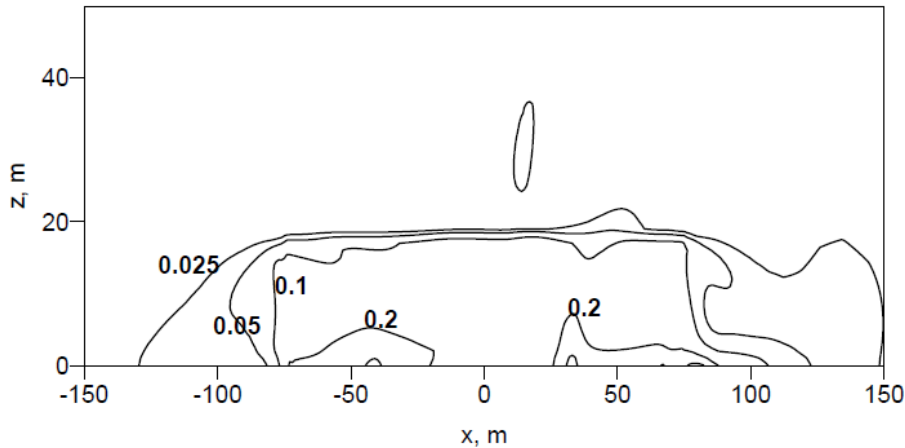
Unstructured grid  
of OpenFoam

Calculated horizontal wind field  
near Surface around buildings



Ref: Khalchenkov and Kovalets (2022)  
J. Theor. Appl. Mech., Sofia

# Results in close vicinity of B103



Isolines of C/Cb (annually averaged) near the wall of neighbor building

Yearly average ground level concentration averaged on the wall of neighbor building

<b>Rn-222</b>	<b>U-238</b>	<b>Ra-226</b>	<b>Pb-210</b>
Bq/m <sup>3</sup>	mBq/m <sup>3</sup>	mBq/m <sup>3</sup>	mBq/m <sup>3</sup>
187	2.63	0.75	0.26

Respective annual dose for workers in neighbor building evaluated as:  
1.6 mSv/yr

Picture and results from: Buchnea et al. 2014. Report of Ensure II Project, DOI: 10.13140/2.1.2043.4563

# Isolines of normalized concentrations on larger scale (Kamianske city)



In the nearest residential area concentration of Rn222 - up to 50 Bq/m<sup>3</sup>

Reference:  
Khalchenkov and Kovalets (2022)  
J. Theor. Appl. Mech., Sofia

Horizontal distribution of the normalized ground-level concentrations created by the contaminated Building No. 103 of the Pridneprovsky Chemical Plant in the area of Kamianske city (former Dniprodzerjinsk) . Isolines are plotted for the normalized concentration values: 1e-5, 1e-4, 2e-4, 1e-3, 1e-2).

# Conclusions

- Mathematical atmospheric transport models adapted and used for safety assessment of the contaminated territories of the former uranium processing facilities
- Use of ATMs effectively complemented monitoring programs, showing the most important directions of monitoring and remediation initiatives
- In particular, it can be assumed that complete inventoring of the potential sources and cleaning of the PChP territories outside tailings could be of higher importance than remediation actions aimed at reducing emissions from tailings

- Thank you for attention!

Major part of this work was supported by SIDA and INSC-funded international projects