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STRATEGY FOR ALLIED RADIOECOLOGY

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PU	Public	
RE	Restricted to a group specified by the partners of the [STAR] project	RE
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List of Acronyms and Abbreviations

CEZ:	Chernobyl Exclusion Zone
COMET:	Project Coordination and Implementation of a Pan-European Instrument for Radioecology (proposal submitted under FP7 EURATOM)
ERICA:	FP6 EURATOM funded project Environmental Risk from Ionising Contaminants: Assessment and Management
GIG:	Polish Central Mining Institute (Główny Instytut Górnictwa)
ICRP:	International Commission on Radiological Protection
IUCN :	International Union for Conservation of Nature
MAV:	Multi-attribute value
MCDA:	Multi-criteria decision analysis
NEA:	Nuclear Energy Agency
NPP:	Nuclear power plant
OECD:	Organisation for Economic Co-operation and Development
PSRER:	Polesye State Radiation Ecological Reserve
ROC method:	Rank-order centroid method
SRA:	Strategic Research Agenda
STAR:	FP7 EURATOM funded project Strategy for Allied Radioecology
TLD:	Thermoluminescent dosimeter
USCB:	Upper Silesian Coal Basin

BfS:	German Federal Office for Radiation Protection, Germany
CIEMAT:	Research Centre in Energy, Environment and Technology, Spain
IRSN:	French Institute of Radiation Protection and Nuclear Safety, France
NERC:	Natural Environment Research Council, United Kingdom
NRPA:	Norwegian Radiation Protection Authority, Norway
SCK•CEN:	Belgian Nuclear Research Centre, Belgium
STUK:	Radiation and Nuclear Safety Authority, Finland
SU:	Stockholm University, Sweden
UMB:	Norwegian University of Life Sciences, Norway

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1 Observatory concept

To help address the challenges presented by STAR's research aims our Joint Programme of Activities includes a powerful integrating mechanism in the form of **Observatories for Radioecological Research**. The concept of observatories was presented in an OECD/NEA report in which the point was made that

"…environmental data collected over the last half century by the nuclear industry for surveillance purposes has not been utilised in an efficient, co-ordinated manner. Therefore it is proposed that a useful development would be an international network that allowed researchers to co-ordinate and understand research in relevant fields. This "observatory" would be grounded on past and ongoing observations in the real environment and allow them to be linked with laboratory and theoretical developments."

For STAR the intention was that one or more contaminated field sites would be chosen to enable the Network of Excellence to test hypotheses and approaches developed by the work packages. Focused research at common sites will lead to the iterative improvement of methods and models, leading to an enhanced understanding of radionuclide behaviour and effects. All data collected from these sites will be made accessible from the STAR webportal. Over the years, the collective efforts will result in a valuable European data set derived from the Observatory locations. Such a pooled, consolidated effort will maximize the sharing of data and resources as well as provide excellent training and education sites. Research at the Observatory sites is planned by members of the COMET consortium (the radioecology consortium that follows STAR) and the European Radioecology ALLIANCE.

2 Selection methodology

Suitable field sites for becoming Radioecological Observatories were selected by combining multi-criteria decision analysis (MCDA), group discussions and recommendations provided by invited external experts. The structured, progressive approach was transparent and objective to the greatest possible extent. The aim was to maximize both the efficiency in selecting the optimum candidate site and the degree of acceptance among the STAR partners. The major steps of the selection process were the development of a list of selection criteria, the selection of an appropriate MCDA method, the suggestion of candidate sites that comply with the mandatory criteria and the application of the agreed MCDA method to derive the preference ordering.

2.1 Development of a list of selection criteria

The first logical step was to jointly compile a list of criteria that an ideal candidate site should meet. Here, the key was making the criteria explicit and classifying them as being mandatory (exclusion criteria) or not (evaluation criteria). The criteria comprised specific requirements for STAR (exclusion criteria), scientific issues (evaluation criteria), infrastructure aspects (evaluation criteria), administrative/legal constraints (evaluation criteria) and financial considerations (evaluation criteria). A candidate site that failed one (or more) of the exclusion criteria was excluded from further evaluation. Evaluation criteria were used to judge the degree of compliance of a site.

2.2 Selection of an appropriate MCDA method

The preference ordering among the suggested candidate sites was formally derived by applying the weighted linear average method. Inputs were the normalised weights, *i.e.* scaling factors which reflect the relative importance of each of the criteria, and the scores for all candidate sites relative to each criterion. The result of the weighted linear average method, commonly known as multi-attribute value (MAV), quantifies the overall performance of a candidate site.

The STAR partners refrained from applying highly sophisticated schemes aiming at eliciting exact weights. However, they felt reasonably confident in the ranking of the evaluation criteria and therefore selected a rank-based method for generating approximate criteria weights. Rank-based methods represent excellent compromises between ease of assessment and efficiency in selecting the optimum alternative. The rank-order centroid (ROC) method was selected because of its sound scientific justification.

A coarse scale with integers from 0 to 5 was considered to be an acceptable compromise between sufficient flexibility to evaluate an option in reasonable detail and the confidence with which an organization is realistically able to rate the compliance of a candidate site with a criterion.

Since a simple central tendency measure is considered to be acceptable to aggregate the individual results provided by the group members, the final STAR results were calculated as the arithmetic mean of the STAR partners' individual results. This approach is blind to dominant group members by balancing extreme views.

2.3 Suggestion of candidate sites and their preselection based on the exclusion criteria

The suggested candidate sites for becoming a European Observatory for Radioecological Research that comply with the exclusion criteria were:

- Coal mining area in Upper Silesia, Poland
- Chernobyl Exclusion Zone, Ukraine and Belarus
- Former uranium mine Les Bois Noirs, France
- Uranium tailing Schneckenstein, Germany

2.4 Application of the agreed MCDA method

Each STAR partner organization independently ranked the set of criteria and derived an individual set of criteria weights. The final STAR weight of each criterion was calculated as the arithmetic mean of the STAR partners' individual weights. Then, each partner organization independently scored the candidate sites against the evaluation criteria and calculated MAVs based on the final STAR weights. The final STAR MAV of each candidate site was calculated as the arithmetic mean of the STAR partners' individual MAVs.

The Polish coal mining area in Upper Silesia and the Chernobyl Exclusion Zone performed best with respect to the list of evaluation criteria and hence were selected as Radioecological Observatories. These two sites have almost identical MAVs and complement each other. The Polish coal mining area is a typical mixed contaminant situation with moderate dose rates to reference organisms. The Chernobyl Exclusion Zone offers a contamination gradient with high maximum dose rates to reference organisms. Relevant amounts of non-radioactive pollutants, however, are absent. The combination of focused field investigations at these two sites with their complementary characteristics and dedicated laboratory experiments represent an excellent starting point to address the research lines of the Strategic Research Agenda (SRA). Section 3 provides a detailed description of both sites.

3 Description of Radioecological Observatories

The two selected Radioecological Observatories, the Upper Silesian Coal Basin and the Chernobyl Exclusion Zone, differ largely concerning their size and the amount of published information. The level of detail with which both sites can reasonably be described in this report differs correspondingly.

3.1 Chernobyl Exclusion Zone (CEZ)

3.1.1 General information

The Chernobyl Exclusion Zone (CEZ) is the radioactively contaminated area surrounding the Chernobyl Nuclear Power Plant. Established shortly after the accident in 1986, the CEZ initially existed as an area with a 30-km radius around the Chernobyl Nuclear Power Plant. Over the last 25 years the borders have expanded (**Figure 1**). The purpose of the CEZ is to restrict public access, reduce the spread of radioactive contamination and provide a site for ecological monitoring activities (http://en.wikipedia.org/wiki/Chernobyl_Exclusion_Zone). The CEZ is one of the most radioactively contaminated sites in the world. The CEZ includes portions of Ukraine and Belarus. The latter is designated as the Polesye State Radiation Ecological Reserve (PSRER).

Figure 1. The Chernobyl Exclusion Zone circles the Chernobyl Nuclear Power Plant and includes portions of Ukraine and Belarus.

Numerous books and thousands of scientific articles have been published on Chernobyl. A literature search, conducted in February 2013, using SCOPUS and the term “Chernobyl” resulted in 8855 documents. No attempt was made herein to summarize such a vast amount of literature although it is likely that many of these consider Chernobyl fallout in areas other than the CEZ.

Latitude/longitude

Chernobyl Nuclear Power Plant: 51.3º N, 30.005º E

Owner

In the Ukraine, the State Agency of Ukraine on Exclusion Zone Management is responsible for administering the exclusion zone. Foreign research institutes that want to conduct research within the CEZ collaborate with Ukrainian institutes who have programmes of work approved by the State Agency, and obtain the required permission for the foreign institutes to work in the CEZ. Several STAR partners (*e.g.* IRSN, NERC-CEH) have previously worked in the CEZ and have experience collaborating with key Ukrainian institutes.

In Belarus, the Polesye State Radioecological Reserve (PSRER) is administered by the Ministry of Emergency Situations of the Republic of Belarus, Department for Mitigation of the Consequences of the Catastrophe at Chernobyl NPP. Mikalai TSYBULKA is the Deputy Director of the Ministry and main contact for PSRER affairs. Pjotr Mikhajlovtish KUNDAN is the Director General of PSRER, and Yuri BONDAR is the Deputy Director for Science.

Previous/current use

The Exclusion Zone covers an area of approximately 2600 km^2 in Ukraine and 2160 km^2 in Belarus. The predominantly rural woodland and marshland area was once home to 120,000 Ukrainians and 25,000 Belarusians. The modern town of Pripyat supported workers at the Chernobyl nuclear complex. All 49,300 residents of Pripyat were evacuated 36 hours after the accident. An additional 67,000 people from the Ukrainian portion of the CEZ and 25,000 within Belarus were evacuated. The area has had limited anthropogenic pressure for the last 25 years (http://www.iaea.org/newscenter/features/chernobyl-15/cherno-faq.shtml).

3.1.2 Climate

The climate at Chernobyl is temperate-continental. The growing period starts around mid-April and ends in late October. Snow cover remains for about 80 days, with significant deviations in some years. Average weather by month is presented in **Table 1**.

Table 1. Average monthly weather at Chernobyl

Month	Temperature (°C)				Average rainfall (mm)		Average snow days	Average fog days
	average		absolute		daily	monthly		
	max	min	max	min				
January	-2	-6.4	16	-27	1.1	33	12	5
February	-2.2	-7.9	17	25.9	0.8	24	8	3
March	4	-2.4	22.6	19.5	0.7	21	4	8
April	11.9	3.6	47	-6	1	30	1	3
May	18.3	8.9	30	-3.1	1.6	48	0	1
June	20.4	12.1	32	2	1.9	57	0	1
July	21.4	13	33.6	7	2.5	75	0	2
August	22.7	12.4	34	15.6	1.5	45	0	3
September	16.6	8.6	28.6	0	1.4	42	0	6
October	10.9	4.1	25.6	-9.5	0.9	27	0	7
November	3.2	-0.8	15.2	-20	1.5	45	5	8
December	-1	-4.8	21	-27	1.2	36	11	7

3.1.3 Topography

The area is a vast, relatively flat (~ 100-200 m above sea level) plain with low land marshes. The Pripyat River, one of the largest European rivers and a main tributary of the Dnieper, runs through the CEZ for about 80 km. The two rivers combine and then flow south to the Kiev reservoir. Spring flows of the Pripyat River typically have discharges of 800 to 2200 $m^3 s^{-1}$, with maximum rates exceeding 5000 $m^3 s^{-1}$ (Onishi *et al.*, 2007).

3.1.4 Geology

The CEZ is located on a sedimentary sequence of loose, mostly clastic deposits, with a shallow (3-5 m) water table. The unsaturated zone and the unconfined aquifer are composed of Pliocene and Pleistocene-Holocene deposits of about 30 m thickness (Matoshko *et al.*, 2004). See **Figure 2** for details.

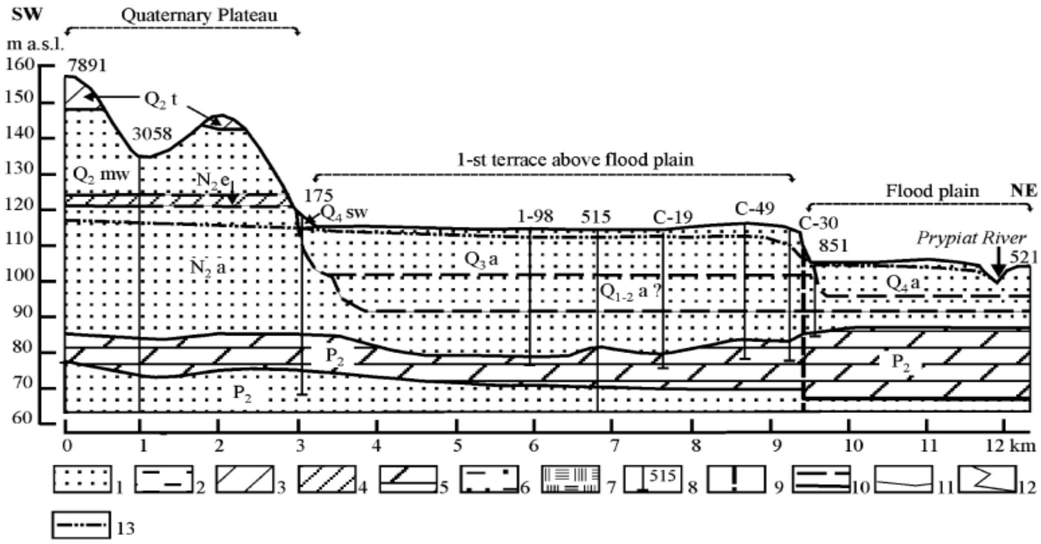

Figure 2. Regional geologic cross-section of the area around the Chernobyl Nuclear Power Plant (from Matoshko *et al.*, 2004). 1 = sands; 2 = silts; 3 = basal till; 4 = clay; 5 = marl; 6 = inter-bedding of sands and silts; 7 = peat and peaty sand; 8 = boreholes (numbered); 9 = inferred fault; 10 = boundaries between suites: supposed (upper) and established (lower); 11 = boundaries between depositional facies; 12 = facial replacement; 13 = groundwater level. *Indices*: Q_4=Holocene, $Q_{3\text{-}4}$=Upper Pleistocene-Holocene unstratified, Q_3=Upper Pleistocene; $Q_{1\text{-}2}$= Lower Pleistocene-Middle Pleistocene unstratified, N_2= Pliocene, P_2=Eocene. Genetic types of deposits: *a* alluvial, *mw* melt-water, *eol* aeolian, *e* presumably waste mantel, *sw* slopewash. Facies: *ob* overbank, *ch* channel, *a-ch* abandoned channel

3.1.5 Hydrology and hydrogeology

The CEZ contains standing water bodies (lakes, ponds and reservoirs), flowing waters (streams and rivers) and wetlands. The Belarusian area is crossed by numerous drainage canals that have now become abandoned. Periodic flooding causes significant transport and deposition of radionuclides (Burrough *et al.*, 1996; Freed *et al.*, 2004). Some information on ground water flow is available and studies of radionuclide transfer in ground waters (*e.g.* from waste trenches) have been conducted. Considerable efforts and research over the last 25 years have tried to mitigate radionuclide contamination of water bodies contaminated by the accident (see review by Onishi *et al.*, 2007).

3.1.6 Contamination situation

The contamination situation can be separated into three phases based largely on the decay of short-lived radionuclides: (1) the first month after the accident, (2) the first year after the accident, and (3) a chronic exposure period where dose rates are less than 1% of the initial values (**Figure 3**). During the first 20 days after the accident radionuclides ^{99}Mo, ^{132}Te/^{132}I, ^{133}Xe, ^{131}I and ^{140}Ba/^{140}La dominated exposures. Now, long-lived ^{137}Cs, ^{90}Sr, Pu-isotopes, ^{241}Am and U-isotopes remain as important radionuclides within the CEZ.

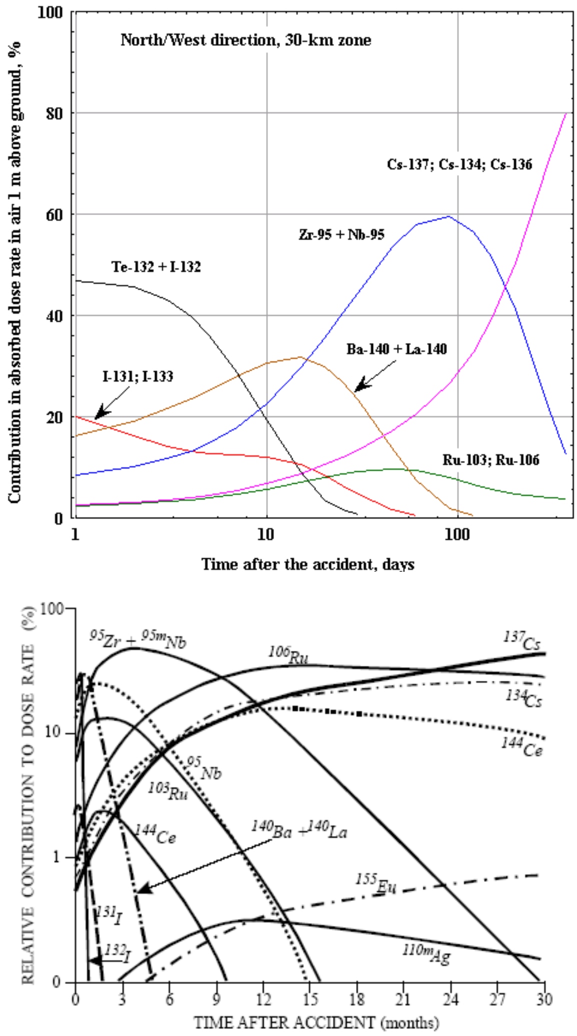

Figure 3. The abundance of short-lived radionuclides during the first month and the first year after the accident resulted in dose rates that were orders of magnitude greater than what currently exists (UNSCEAR 1996; IAEA 2006).

A key characteristic of the Chernobyl contamination is the extensive heterogeneity in deposition that was governed by climatic conditions over the 10 day period of release (**Figures 4-7**). In addition to relatively large scale spatial differences within the CEZ, dose rates can vary by orders of magnitude within several meters distance.

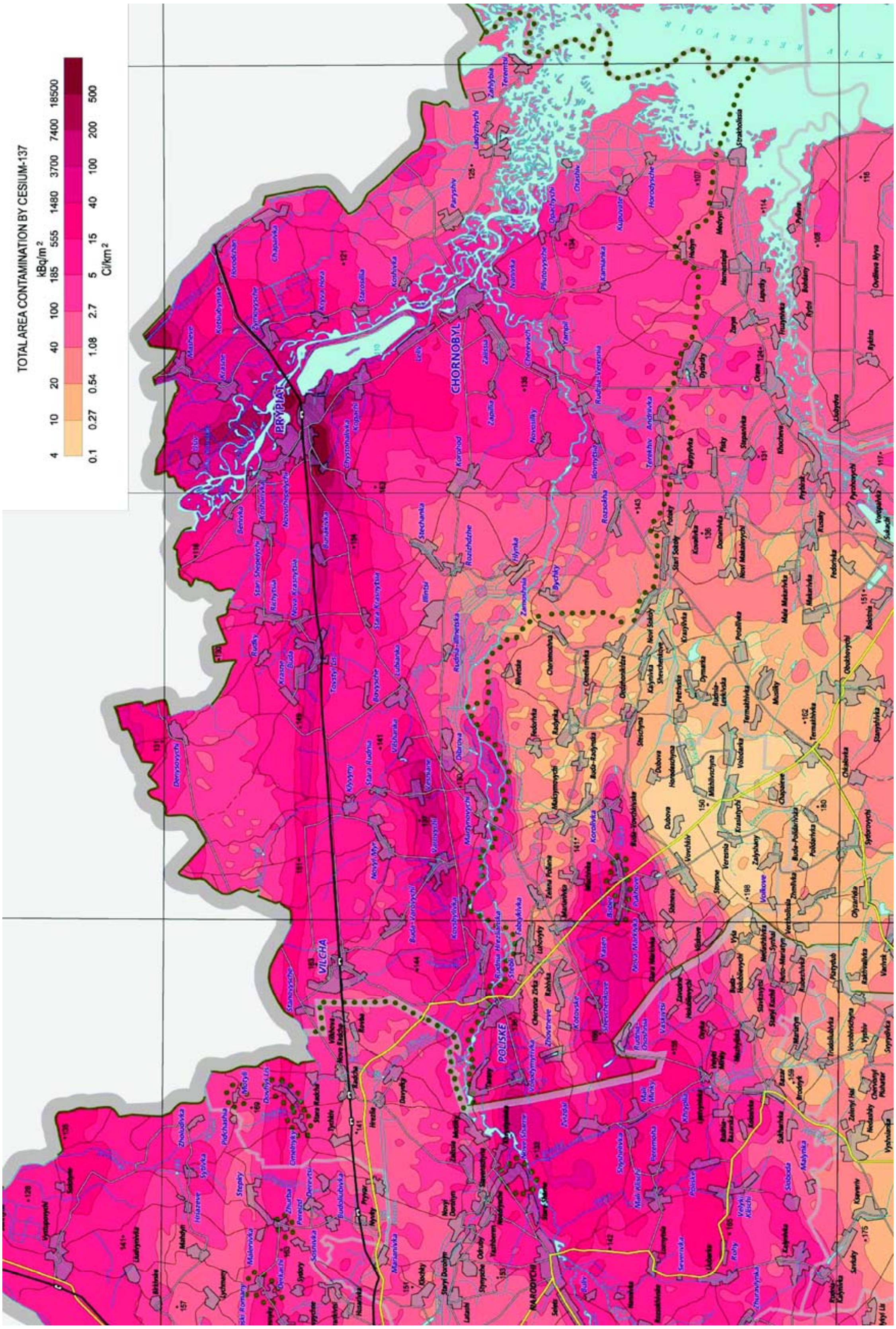

Figure 4. Contamination of the CEZ with ^{137}Cs as of May 2006 (Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of Chornobyl Catastrophe, 2008)

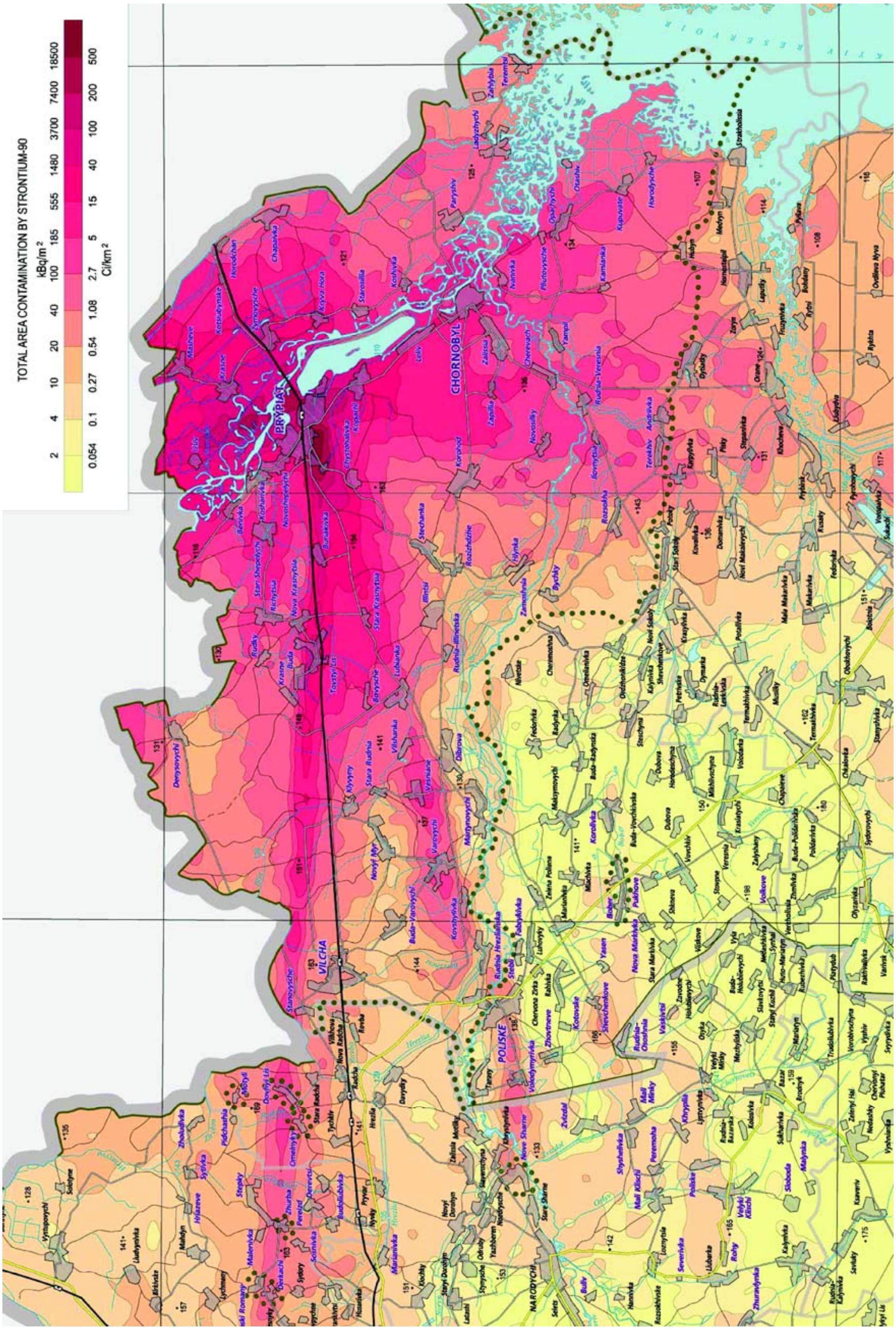

Figure 5. Contamination of the CEZ with ^{90}Sr as of May 2006 (Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of Chornobyl Catastrophe, 2008)

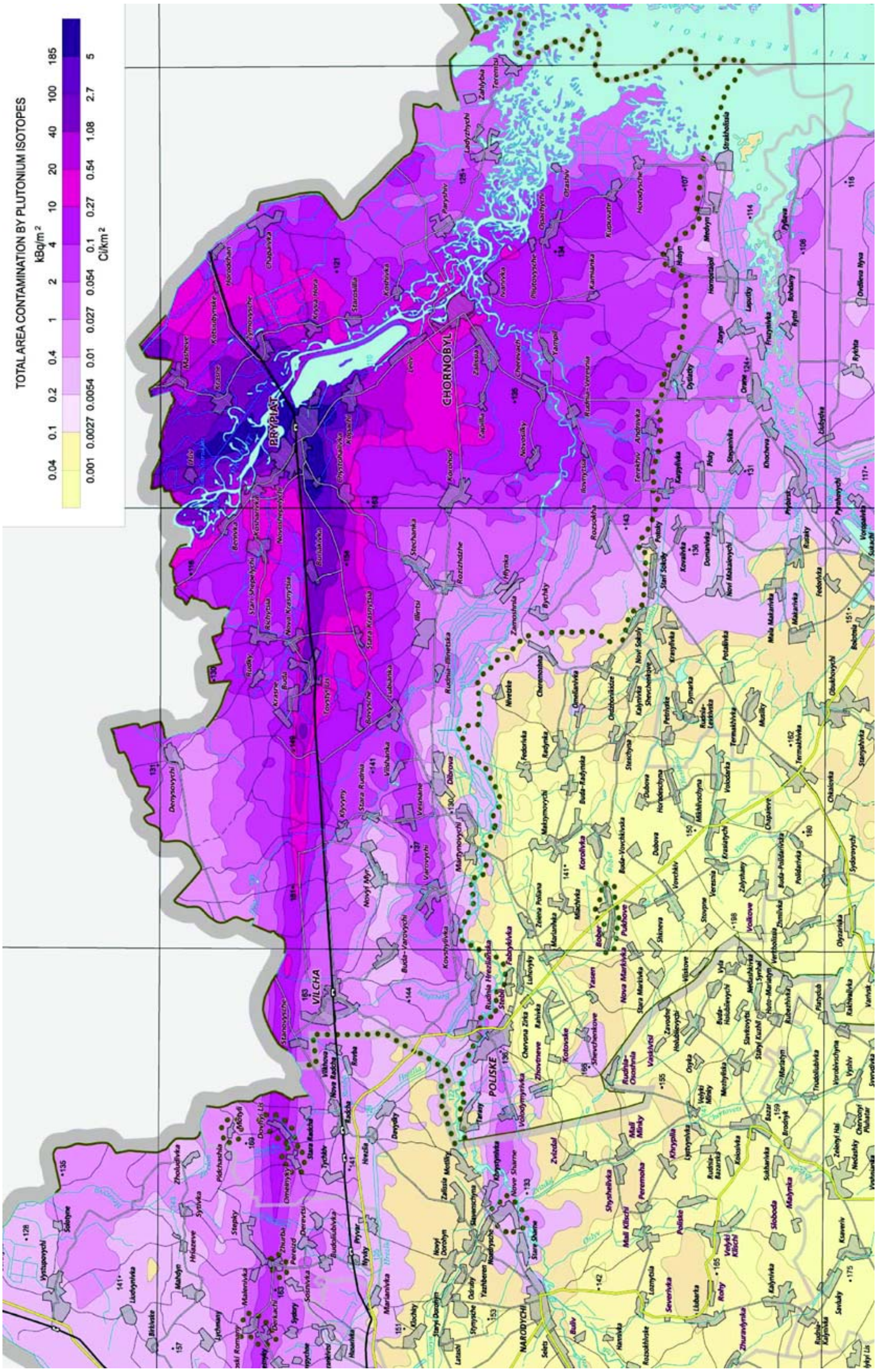

Figure 6. Contamination of the CEZ with Pu isotopes (Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of Chornobyl Catastrophe, 2008)

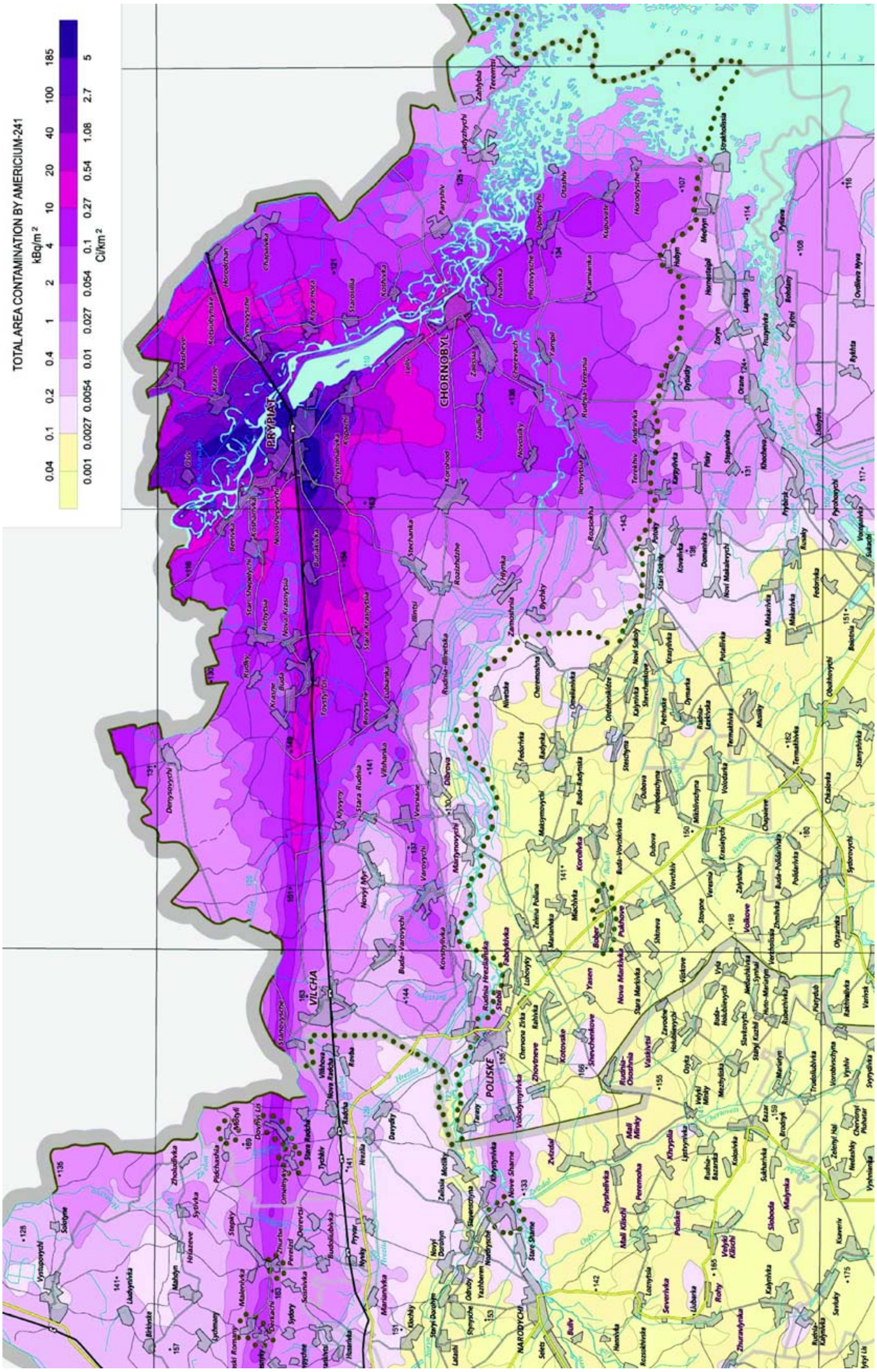

Figure 7. Contamination of the CEZ with ^{241}Am (Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of Chornobyl Catastrophe, 2008)

Recently, STAR partners (NRPA and UMB) collaborated with scientists from PSRER and the Ukraine on a NATO Science for Peace Project. They summarized the available data on radionuclide levels in the soil. The research included sequential extractions to examine the mobility of the radionuclides, radionuclides in freshwater reservoirs, radionuclides in plants and calculations of transfer factors, radionuclides in wildlife, GIS mapping of contaminant densities in portions of the area, as well as some modelling assessments of the risks of radioactivity spreading by forest fires. Their data show the heterogeneity of ^{90}Sr contamination over a relatively small area in the Belarus portion of the CEZ (**Figure 8**).

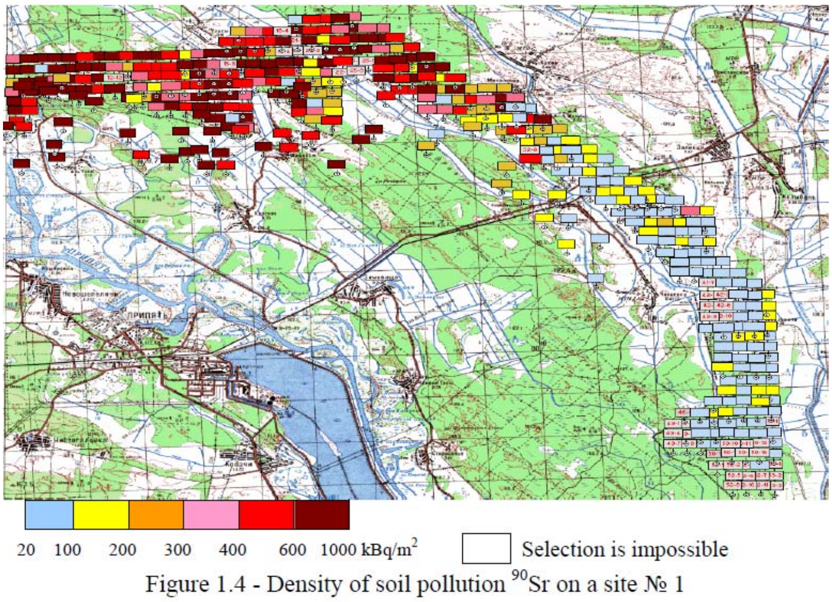

Figure 8. Heterogeneity of ^{90}Sr density in a portion of the Belarus section of the Chernobyl Exclusion Zone (from Bondar and Brown, 2011)

The CEZ also provides opportunities to study longer lived radionuclides released by the accident including ^{99}Tc, ^{14}C and ^{129}I, which have received relatively little attention in the exclusion zone (*e.g.* Mikhajlov *et al.* 2004; Uchida *et al.* 1999; Sahoo *et al.* 2009).

In the CEZ the concentration of natural uranium in the top 10 cm of soil ranges from $2 \cdot 10^{-7}$ g g^{-1} to $3.4 \cdot 10^{-6}$ g g^{-1} (Mironov *et al.*, 2002). The vertical distribution of natural uranium varies considerably, even in similar soil types. The concentration of irradiated uranium varies from $5 \cdot 10^{-12}$ g g^{-1} to $2 \cdot 10^{-6}$ g g^{-1} depending on the distance from the Chernobyl NPP.

Research has also been conducted in the exclusion zone using additional tracer radionuclides to study transfer to crops (*e.g.* Kasparov *et al.* 2005a,b,c; 2007a,b; 2008, in-press). The contaminated lysimeters used for these studies still exist and provide an additional research opportunity. There is the opportunity to use radioactive tracers within the CEZ to conduct additional studies. The ability to use radioactive tracers in the field is very limited and thus this potential within the CEZ provides access to a powerful research tool. It should also be possible to conduct field lysimeter type studies adding chemical contaminants to soils already contaminated with radionuclides, and thus the opportunity to study mixed contaminants exists.

Non-radioactive contaminants

There is some speculation that stable Pb and Ba concentrations should be elevated as a consequence of these having been dropped onto the burning reactor. We are not aware of evidence to support this.

3.1.7 Ecosystems

Information on ecosystems in the CEZ was largely taken from Gashchak *et al.* (2006) *Vertebrate fauna of the Chernobyl Exclusion Zone (Ukraine)* and an information flyer on the Polesye State Radiation Ecological Reserve, produced by the Ministry for Emergency Situations of the Republic of Belarus, Department on Mitigation of the Consequences of the Catastrophe at the Chernobyl NPP).

The Ukrainian portion contains forests, including coniferous plantations (some planted subsequent to the accident), deciduous and the heavily impacted 'Red Forest', abandoned farmlands, wetlands, flowing waters, standing waters, deserted villages and urban areas. Information on soil types within the Ukrainian portion of the CEZ is presented in **Table 2**.

Table 2. Soil types present in the exclusion zone (from Beresford and Wright, 1999)

Ukrainian soil index	Soil description	% clay	% organic carbon	pH	Exchangeable K (meq/100 g)
1	soddy pseudopodzolic sandy soil	6.7	0.5	4.8	0.083
2	soddy podzolic sandy and loamy sand soil	10.0	0.4	4.6	0.127
4	soddy podzolic sandy loam soil	14.2	0.7	5.5	0.180
6	soddy pseudopodzolic and low podzolic sandy and loamy sand gleyed soil	7.2	0.6	4.9	0.064
7	soddy low podzolic sandy loam gleyed soil	14.2	0.7	5.5	0.180
9	soddy low podzolic sandy and loamy sand gleyed soil	10.0	0.4	5.1	0.064
10	soddy podzolic sandy loam soil	9.1	0.8	5.3	0.149
16	podzol-soddy gley soils	5.0	0.9	5.0	0.160
133	bogged soil	11.2	3.4	5.7	0.081
135	bog soil	10.6	29.0	6.0	0.297
136	bog peaty soil	10.6	29.0	6.0	0.297
138	peat-bog	8.2	33.6	5.2	0.297
159	meadow gleyed sandy and loamy sand soil	6.1	1.1	5.5	0.076
160	sandy low humic soil	4.8	0.3	4.7	0.036
161	soddy sandy loam	10.0	1.0	5.6	0.040
162	meadow gleyed sandy loam soil	11.5	1.8	5.3	0.072
167	meadow podzolized soil	19.4	1.8	5.3	0.072

The Belarus portion is a land of swamps, marshes and peat-bogs. It is the largest such area in Europe (http://www.kresy.co.uk/polesie.html). During 1966-1990, more than 2.6 million ha of wetlands were drained in the southern Belarusian area of Polesye. 1.1 million ha were converted to agricultural use through amelioration projects. The entire Pripyat River catchment area was affected by the intensive drainage and land reclamation activities. Around 20% of its total area was drained and most of the small rivers were converted to channels. Within the Belarus portion, former agricultural lands now make up 35% of the total area of the PSRER. Forest land occupies 51% of the territory, which exceeds the national average index (38%). Pine plantations dominate (44% of forest area), and also birch (30% of forest area), black alder (12% of forest area), while broad-leaved trees (oak, hornbeam, maple, ash, elm) occupy 7% of the area. Middle-aged plantations (48%) and saplings (46%) dominate in forest age structure. Areas not covered with forest are mostly former reclaimed agricultural lands and meadows. Bogs occupy 4% of the territory and 2% of the PSRER is covered with water. Sod-podzolic (47%) and turfy (32%) soils predominate.

The abandoned buildings, gardens and orchards within the CEZ are an important component of the ecosystem and provide food and cover for many species of wildlife.

Animal and plant species

There is a wide range of terrestrial and freshwater organisms present encapsulating all of the current ERICA Tool reference organisms and the proposed revised list (see https://wiki.ceh.ac.uk/x/IgDdCQ) including freshwater turtles (freshwater reptiles having been 'missed' from the initial ERICA listing of European protected fauna types). For vertebrates Gashchak *et al.* report a probable 59 species of fish (*Osteichthyes*), 1 lamprey (*Cyclostomata*) species, 11 species of amphibians, 7 species of reptiles, 253 species of birds (168 of which breed in the zone) and 73 species of mammals in the Ukrainian exclusion zone.

Types of ICRP reference animals and plants

Species falling specifically within the taxonomic families for all terrestrial and freshwater reference animals and plants, as defined in ICRP Publication 108 and ICRP Publication 114, are present in the exclusion zone.

Rare animal and plant species

There are *c.* 57 species of protected vertebrates from the Ukrainian Red List (*e.g.* brown bear, lynx, birch mouse, bats, Przewalski's horses (introduced), common crane, eagle owl, black stork), including five species having 'endangered' or 'vulnerable' status in the European Red List (greater noctule bat, barbastelle bat, pond bat, otter, greater spotted eagle), and a number of plants and invertebrates protected under the Ukrainian Red List and various international conventions.

In 2007 Przewalski's horse (*Equus przewalskii*) migrated to the PSRER from the Ukrainian side of the zone, where it was introduced in the late 1990s. Of the 44 species of mammals (excluding bats) within the PSRER, six species are currently listed in the Red Book with an international conservation status: the European bison (*Bison bonasus*), brown bear (*Ursus arctos*), European lynx (*Lynx lynx*), badger (*Meles meles*), loir (*Myoxus glis*), and hazel dormouse (*Muscardinus avellanarius*).

There are 994 recorded species of vascular plants in the PSRER, 39 of which are in the Red Book of Belarus. Ten species of rare plants are listed in the Red Book of the International Union for Conservation of Nature (IUCN).

The PSRER is used by 212 bird species, 54 of these are included in the Red Book of Belarus. Five rare species of birds are within the IUCN Red List (ferruginous duck, white-tailed eagle, spotted eagle, corncake, and aquatic warbler).

Of the 13 species of amphibians found throughout all of Belarus, 10 inhabit the PSRER and 3 of these are in the Red Book of Belarus. A rare European species, the crested newt, is registered annually.

3.1.8 Potential exposure routes

Human – Some data are available for human foodstuffs produced (and consumed) within the exclusion zone. Current estimates are that food (including livestock) is produced by 'self-settlers' at 40 locations within the zone. Experimental studies have been conducted in the exclusion zone to study the transfer of radionuclides to both farm animals and crops (see papers listed below).

Wildlife – Data are available for activity concentrations in a wide range of species over a number of years (see papers listed below). These are predominantly for ^{137}Cs and ^{90}Sr with more limited data for Pu-isotopes and ^{241}Am (and very limited data/observations for other radionuclides including ^{99}Tc and ^{14}C). Many of these data can, and have been, used to derive concentration ratio values. Some data for external dose as recorded by TLDs attached to small mammals exist. The Chornobyl Center for Nuclear Safety, Radioactive Waste and Radioecology (http://www.chornobyl.net/en/) has unique live-monitoring equipment for determining ^{137}Cs and ^{90}Sr activity concentrations in small animals (rodents, small birds, bats etc.).

3.1.9 Absorbed dose rates to wildlife

Approximation ranges in weighted absorbed whole-body dose rates to terrestrial reference organisms of the ERICA Assessment Tool are given in **Table 3**. The values were derived assuming the default transfer parameters and default occupancy factors of the ERICA Assessment Tool. Radionuclides considered include ^{137}Cs, ^{90}Sr, ^{241}Am and Pu (assumed ^{239}Pu). Soil activity concentrations were estimated from the Ukrainian contamination atlas (Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of Chornobyl Catastrophe, 2008). **Figure 9** shows likely dose rates to small mammals in the exclusion zone as estimated from deposition maps, the ERICA Assessment Tool, results of live-monitoring (^{137}Cs and ^{90}Sr) and TLDs attached to animals in 2005 (Beresford *et al.*, 2008).

Table 3. Approximation ranges in weighted absorbed whole-body dose rates to ERICA terrestrial reference organisms. For details see text.

Organism	**Weighted absorbed dose rate ($\mu Gy\ h^{-1}$)**
Amphibian	<0.02 - >129
Bird	<0.02 - >114
Bird egg	<0.02 - >177
Detrivorous invertebrate	<0.02 - >95
Flying insects	<0.01 - >37
Gastropod	<0.01 - >50
Grasses & herbs	<0.01 - >59
Lichen & bryophytes	<0.08 - >592
Mammal (deer)	<0.06 - >404
Mammal (rat)	<0.05 - >345
Reptile	<0.17 - >1442
Shrub	<0.03 - >130
Soil invertebrate (worm)	<0.01 - >66
Tree*	<0.01 - >87

*Estimates based upon measurements of *Pinus sylvestris* were *c.* 1-order of magnitude above the upper range shown here (Yochenko *et al.*, 2011).

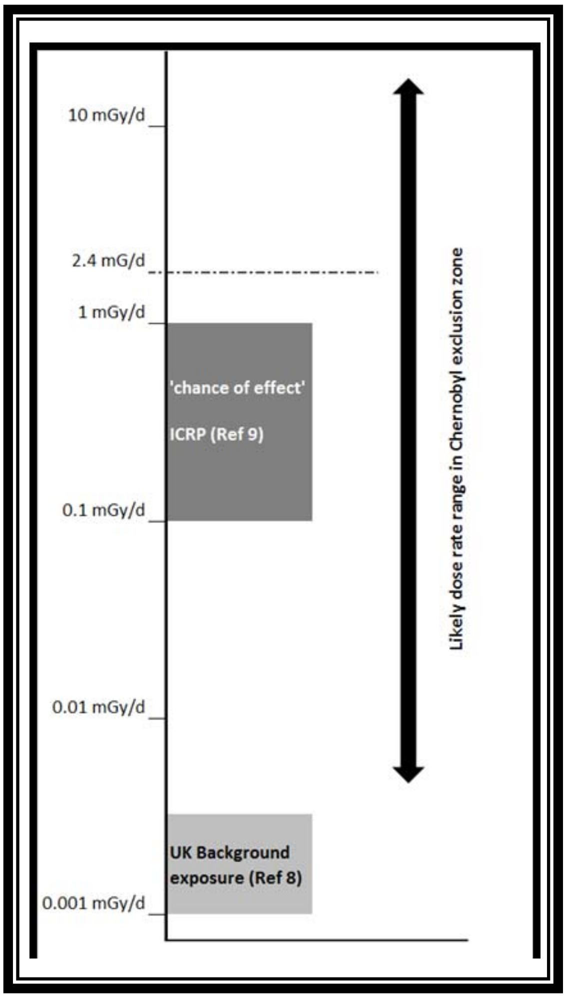

Figure 9. Likely dose rates to small mammals in the exclusion zone compared with various benchmarks. UNSCEAR suggest that a dose rate of <2.4 mGy d^{-1} to the most exposed individual is unlikely to have significant effects on terrestrial communities (dashed line).

3.1.10 Long-term availability and basic authorization

A potential exists that some of the less contaminated settlements may be re-inhabited over coming years. However, in the time frame of STAR it is unlikely that there will be any changes with regard to habitation of the exclusion zone, but rather that the status of contaminated areas outside of the exclusion zone may change. The cooling pond of the Chernobyl NPP (22 km^2) is being planned to be remediated in the near future (although a timetable has not been set). This may impact the hydrology, microclimate and ecology of the surrounding areas. These changes may represent additional research opportunities for STAR.

The Ministry of Emergency Situations is interested in keeping the PSRER a State Reserve, rather than turning the land over to other interests (such as agricultural use). They thus welcome research and collaborators that bring international attention to the PSRER and help them espouse the importance of the site as a reserve. Many institutes of the Belarus National Academy of Science in Minsk, including the Institute of Radiobiology of the NAS, the

Institute of Radiology, and the Republican Centre of Radiation Control and Environmental Monitoring, are involved in research on the PSRER.

The PSRER conducts limited economic activities related to research on the dynamics of radionuclides in agricultural systems and experimental remediation work. An operating livestock farm exists within the PSRER, housing 250 pedigree horses, 45 breeding hogs, 45 cattle, an experimental orchard, a nursery for planting stock and an apiary for 80 bee families.

In the Ukraine, the State Agency of Ukraine on Exclusion Zone Management is responsible for administering the exclusion zone. Foreign research institutes that want to conduct research within the CEZ collaborate with Ukrainian institutes who have programmes of work approved by the State Agency, and obtain the required permission for the foreign institutes to work in the CEZ. Research within the PSRER will require negotiations and collaborative contracts to be established. Currently several individual members of the STAR consortium are conducting research within the PSRER and a number have existing or previous studies within the Ukrainian sector of the CEZ.

3.1.11 Type and extent of implementable remedial measures

Type and extent of remedial measures that can be implemented are largely unlimited for terrestrial, freshwater and urban areas. The PSRER has an active farming operation within the contaminated zone. The purpose is to document uptake of radionuclides within agricultural systems. This attribute of PSRER makes it unique and adds a dimension that the Ukrainian section of the zone does not offer. The Japanese have visited the PSRER and are interested in conducting remediation studies at PSRER that might be of value to work at Fukushima.

3.1.12 Other relevant information

The following sources provide spatial datasets of activity concentrations, maps (land-use, geology, soil type, some soil chemistry, forest composition, distribution of protected vertebrates) as well as information on the physical-chemical forms of fallout, including fuel particles, and their evolution in time:

- UIAR (2001). *Contamination of the ChNPP 30-km zone*
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3.2 Upper Silesian Coal Basin

3.2.1 General information

The Upper Silesian Coal Basin (USCB) is a post-industrial landscape that has been and still is heavily affected by coal production. About 50 underground hard coal mines are in operation. About 800,000 m^3 of mine waters must be pumped to the surface each day. These highly mineralized brines often contain elevated levels of radium isotopes and heavy metals. Due to the origin of these waters, high concentrations of uranium and thorium are usually absent. Before discharging the saline waters into rivers, any suspended load must be removed. Currently, there are 25 settling ponds in use which contain in total 5,000,000 m^3 of sediment with enhanced levels of radium isotopes and heavy metals as a result of the cleaning process.

The Radioecological Observatory in the USCB comprises five different sites that are affected by coal mining activity:

- Site #1: Upper Vistula river, a natural river which is affected by the discharge of mine brines with high activity levels of radium over a length of about 60 km
- Site #2: Former mine settling pond Rontok Wielki (surface area 32 ha) filled with fresh water
- Site #3: Mine settling pond Kaniów (surface area 4.5 ha)
- Site #4: Former mine settling pond Bojszowy where technical land reclamation was carried out (surface area 16 ha)
- Site #5: Country borough Świerklany which is contaminated by radium over a length of about 2 km along the former stream bed

Location of the sites

All sites are located in the Silesian voivodeship (province) in southern Poland at distances of not more than 60 km or less from Katowice, the capital of the voivodeship (**Figures 10, 11**).

Figure 10. Location of the Silesian Voivodeship

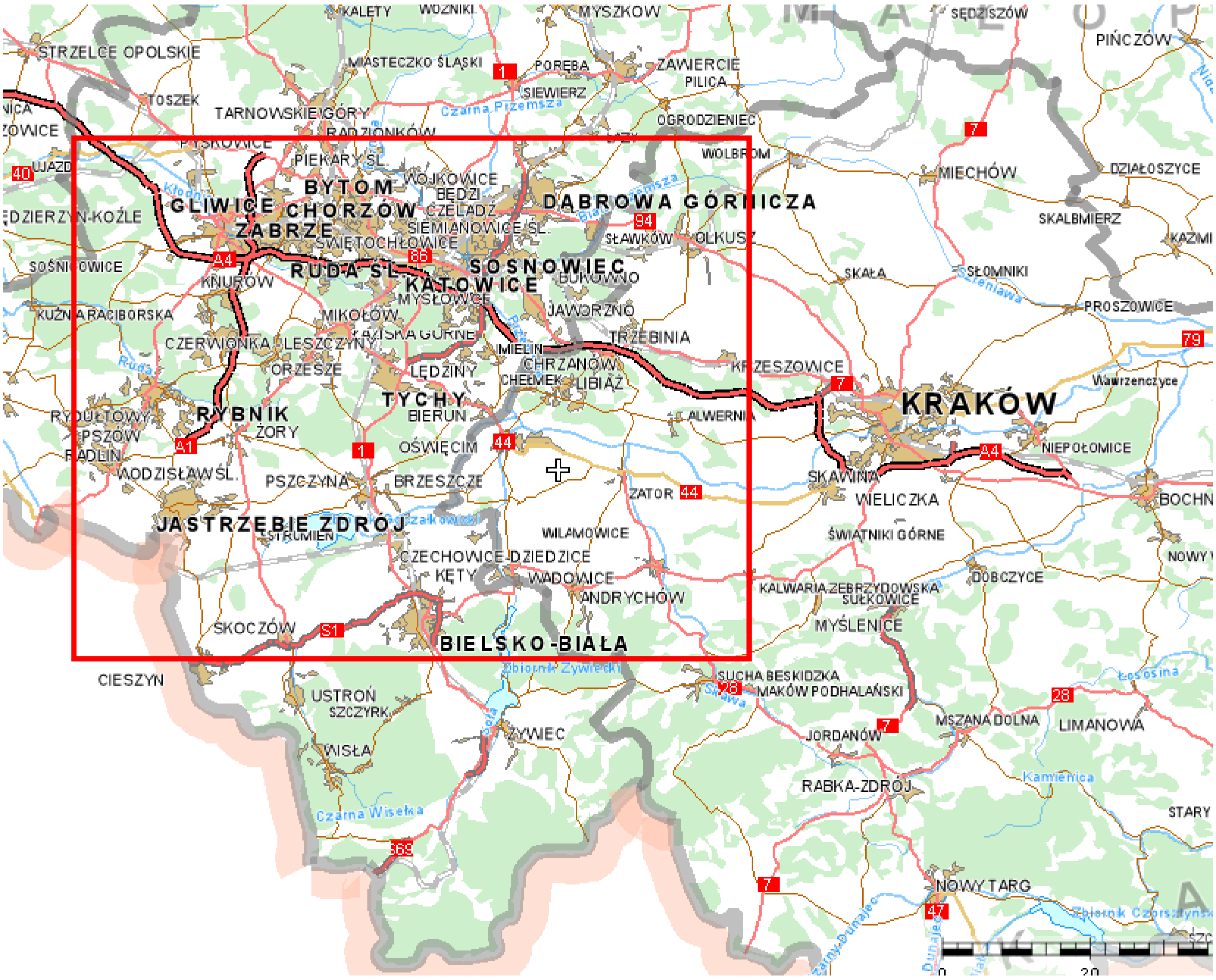

Figure 11. Location of the Polish Observatory sites (red square)

Latitude/longitude

The geographic coordinates of Katowice and the Polish Observatory sites are:

- Katowice: 50º 16’ 15.22” N, 19º 1’ 35.47” E
- Site #1: 50º 3’ 26.15” N, 19º 9’ 42.93” E
  (main water discharge point to the Vistula river)
- Site #2: 49º 56’ 50.28” N, 19º 0’ 15.05” E
- Site #3: 49º 56’ 41.77” N, 19º 1’ 14.97” E
- Site #4: 50º 3’ 24.67” N, 19º 7’ 48.95” E
- Site #5: 50º 3’ 1.4” N, 18º 34’ 40.46” E

Owner

The owners of the sites are:

- Site #1: Regional Office for Water Management (Regionalny Zarząd Gospodarki Wodnej) in Gliwice. It is the regional state authority responsible for inland water management.
- Site #2: Coal joint stock company (Kompania Węglowa S.A.), department responsible for the disposition regarding the estate of closed mines (Oddział Zakład Zagospodarowania Mienia) in Katowice
- Site #3: Mining company SILESIA Ltd. (Przedsiębiorstwo Górnicze "SILESIA" sp. z o.o) in Czechowice-Dzidzice
- Site #4: Coal joint stock company (Kompania Węglowa S.A.), coal mine PIAST (Kompania Węglowa S.A. KWK PIAST) in Bieruń
- Site #5: Local municipality Świerklany

Previous/current use

The upper Vistula river (site #1) is a natural river with side streams. All mine settling ponds were used in the past or are currently being used for clearing mine waters from suspended matter and the controlled discharge of saline waters into inland waters. The former mine settling pond Rontok Wielki (site #2) is a natural pond with a surface area of 32 ha that was adapted in the past as settling and retention pond for mine waters. It is currently excluded from technological processes and filled with fresh water. The mine settling pond Kaniów (site #3) is a semi-artificial pond with a surface area of 4.5 ha which replaced the Rontok Wielki settling pond. The bottom sediments of the former mine settling pond Bojszowy (site #4; surface area 16 ha) were covered by a layer of an inert material after technical land reclamation. Country borough Świerklany (site #5) is contaminated with radium over a length of about 2 km along the former stream bed. Contaminated sediments were dredged and deposited close to the stream banks. The contamination affects residential areas and arable land.

3.2.2 Climate

The climate at the Polish Observatory sites is characteristic of the transition zone between a temperate oceanic and a temperate continental climate. There are typically cold, cloudy, moderately severe winters with frequent precipitation and mild summers with frequent showers and thundershowers. The monthly average weather conditions along with exceptional weather occurrences are presented for Katowice in **Table 4**. The climate profile is based on data collected over the past two decades (weather2, 2013).

Table 4. Weather conditions at Katowice

Month	Temperature (°C)				Average precipitation (mm)	Average rain / drizzle days	Average snow days	Average fog days
	average		absolute					
	max	min	max	min				
January	1	-5	15	-29	42	13	13	6
February	4	-4	19	-23	39	12	13	5
March	8	-1	22	-21	33	15	9	4
April	14	3	27	-8	45	16	3	4
May	20	7	32	-4	78	17	0	3
June	22	11	35	2	83	17	0	3
July	24	13	35	5	105	16	0	3
August	24	12	36	3	77	14	0	4
September	18	9	29	-2	54	15	0	6
October	14	4	27	-9	49	16	1	9
November	7	0	20	-16	45	16	7	9
December	2	-2	18	-24	48	14	14	7

3.2.3 Topography

The Polish Observatory sites are located in the Silesian Upland. It is a plateau with heights between 200 and 300 m, divided into distinct ridges by river valleys. The Silesian Upland is part of the Lesser Poland Upland, a belt varying in width from ninety to 200 kilometers, formed by the gently sloping foothills of the Sudeten and Carpathian mountain ranges and the uplands that connect the ranges in south central Poland. The Silesian Upland is a highly industrialized region with a high population density. It includes a large part of the Upper Silesian coal field. The largest river in the area of the Polish Observatory sites is the Vistula river. At Krakow its flow rate varies between 19 m^3 s^{-1} in summer and 81 m^3 s^{-1} in spring, with an annual average of 53 m^3 s^{-1} (Skwarzec and Jahnz, 2007).

3.2.4 Geology

The Upper Silesian Coal Basin was formed during the Variscan orogeny and rejuvenated during the Alpine orogeny. The coal-bearing Carboniferous is of molasse association, composed of clastic rocks and coal seams. The lack of limestone is a characteristic feature of this association. The coal-bearing Carboniferous is a typical multi-facies formation built of groups of rocks deposited in specific sedimentary environments, limnic, brackish and marine.

The Carboniferous rocks are overlain by younger deposits, mainly Tertiary and Quaternary series that were deposited under continental conditions, are undisturbed by faults and occur as continuous layers. The thickness of the overlain is up to 700 m. Two different styles of tectonics are observed. The western portion of the basin is characterised by a dominantly elastic deformation with folding (site #5). In the remainder the deformation is dominantly fault controlled with the common development of "horst und graben" structures. The major faults trend east to west. Geological maps of the Upper Silesian Coal Basin are shown in **Figure 12**.

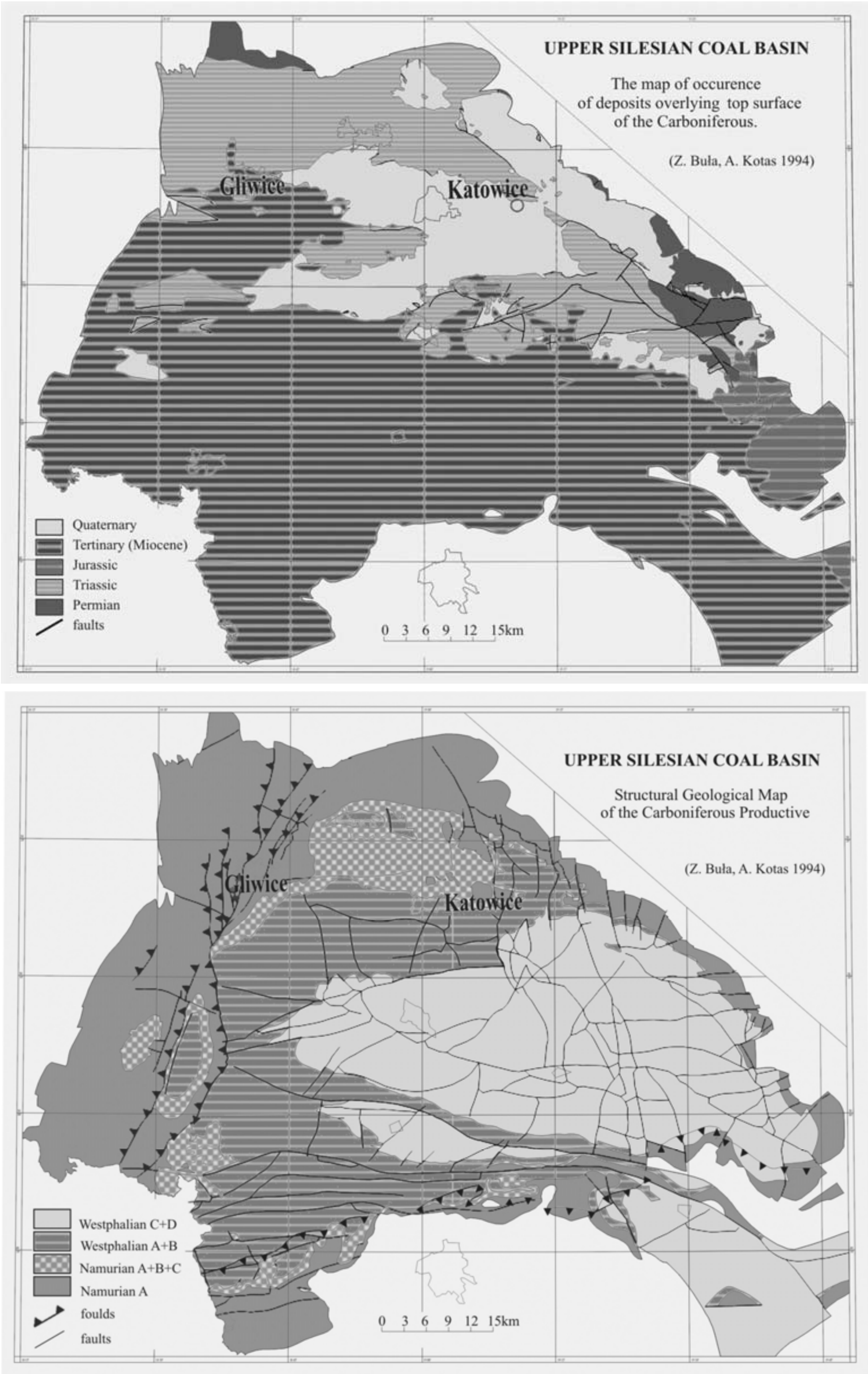

Figure 12. Geological maps of the Upper Silesian Coal Basin

3.2.5 Hydrology and hydrogeology

Two hydrogeological regions are recognised at the Upper Silesian Coal Basin. The first is located in southern and western Silesia where there is a thick cover of up to 700 m of impermeable Miocene clays and silts (sites #1, #4, #5). Such strata restrict the migration of meteoric waters and gases.

In the second region (northern and eastern part of Silesia) Miocene deposits do not occur. The Carboniferous strata either outcrop frequently or are covered by slightly compacted Mesozoic and unconsolidated Quaternary sediments. The oldest beds comprise isolated and strongly fissured and karstified Permian and Triassic limestone and dolomites, enabling a very easy transfer of fluids. Meteoric waters infiltrate directly into the deeper formations. The USCB mine waters have extremely high concentrations of salts, much higher than oceanic levels, and are almost saturated. The total dissolved concentration is usually about 100 kg m^{-3} but may be as high as 220 kg m^{-3}. The dominant anion is Cl^- (< 100 kg m^{-3}) whilst the concentration of HCO_3^- reaches 100 g m^{-3}. Although the dominant cation is Na^{2+} (up to 50 kg m^{-3}), there are significant concentrations of Ca^{2+} and of Mg^{2+} (up to 5 kg m^{-3}). Importantly, Silesian mine brines contain elevated concentrations of radium isotopes ^{226}Ra and ^{228}Ra.

The USCB area is divided into two river basins: the Vistula river and the Oder river. Concurrently it is the area of the main watershed of Poland. This is the reason why there are numerous small rivers and streams.

3.2.6 Contamination situation

As mentioned in Section 3.2.1, about 800,000 m^3 of mine waters must be pumped to the surface each day in the Upper Silesian Coal Basin. These highly mineralized brines often contain elevated levels of radium isotopes and heavy metals. Due to the origin of these waters, high concentrations of uranium and thorium are usually absent. Despite of their high mineralization these waters are often used as technological waters, resulting in additional contamination with hydrocarbons used as engine oil and lubricants.

Radioactive contamination

Before the saline mine waters can be discharged into rivers, any suspended load is removed in settling ponds. In some cases, natural fresh water reservoirs, *e.g.* fish ponds that were very common in the past in this region, have been adapted for this purpose. As a result of the cleaning process much of the radium isotopes and heavy metals have been concentrated in bottom sediments (tailings).

Two types of pit waste water can be distinguished based on their radium isotope ratios and their content of other ions. The water of type A contains radium and barium in high concentrations but no sulphates are present. The activity ratio of ^{226}Ra : ^{228}Ra is about 2:1. In contrast, water of type B shows high contents of radium and sulphate, but barium is absent. In type B water the isotopic ratio ^{226}Ra : ^{228}Ra is about 1:2, *i.e.* it is the reciprocal value compared with type A water. The parameters ‘‘barium content’’ and ‘‘sulphate content’’ are very important due to the fact that barium precipitates as barite if sulphate ions are present, *e.g.* in case of mixing type A water with other sulphate containing natural waters. This affects also the fixation of radium isotopes, because radium can substitute for barium in the crystal lattice forming radiobaryte (Ba[Ra]SO_4). If there are no significant amounts of barium in the water, the process of co-precipitation does not occur and radium can be adsorbed only on suspended matter in water. Since this process is not as effective as co-precipitation, significant radium activities are finally discharged into rivers with saline water.

The observed contaminations of water and sediment consist of a suite of natural radionuclides from the thorium and uranium series in different proportions and different states of equilibrium. The most important radionuclides are ^{228}Ra, ^{228}Th, ^{226}Ra, ^{222}Rn, ^{210}Pb and ^{210}Po. Usually, the decay chains start with pure ^{226}Ra and ^{228}Ra, respectively, precipitated from water and deposited in bottom sediments. Other natural radionuclides such as ^{238}U and ^{232}Th are present at levels typical for "normal" soil or carboniferous rock. Information on radium levels at the Polish Observatory sites are compiled in **Tables 5-9**.

Table 5. Radium balance in the Vistula river basin (site #1)

River	Discharging mines	Discharged activity (MBq per day)		Activity concentration in sediments (Bq kg^{-1} dry mass)	
		^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra
Gostynia	Bolesław Śmiały	101.9	188.4	323	490
	Wesoła				
	Piast				
	Ziemowit (partly)				
Goławiecki stream	Ziemowit (most of the water)	36.9	65.3	3,350	8,176
Vistula	Silesia	23.4	24.9	660* 75**	811* 207**
	Brzeszcze	1.3	1.3		

* after the Gostynia river mouth

** after the Goławiecki stream mouth

Table 6. Radium levels in sediments of the former mine settling pond Rontok Wielki (site #2)

	Activity concentration in bottom sediments ($Bq\ kg^{-1}$ dry mass), n=28	
	^{226}Ra	**^{228}Ra**
Average	5,105	1,407
Median	1,191	593
Maximum	49,151	6,388
Minimum	67	62

Table 7. Radium levels in bank sediments of the mine settling pond Kaniów (site #3)

	Activity concentration in bank sediments ($Bq\ kg^{-1}$ dry mass), n=8			
	^{210}Pb	**^{224}Ra**	**^{226}Ra**	**^{228}Ra**
Average	293	2,570	6,791	4,735
Median	204	1,541	3,975	2,917
Maximum	613	8,306	21,246	14,553
Minimum	61	296	746	577

Table 8. Radium levels in sediments of the former mine settling pond Bojszowy (site #4)

	Activity concentration in bottom sediments ($Bq\ kg^{-1}$ dry mass), n=26 (n=91)	
	^{226}Ra	**^{228}Ra**
Average	414 (1,817)*	627 (2,393)
Median	406 (862)	628 (868)
Maximum	950 (6,981)	1,705 (8,393)
Minimum	95	124

*Values in brackets measured after the settling pond had been drained

Table 9. Radium levels in soil in Świerklany (site #5)

Sampling point	Activity concentration in soil ($Bq\ kg^{-1}$ dry mass)	
	^{226}Ra	**^{228}Ra**
Soil 1	12,326	96
Soil 2	10,226	62
Soil 3	17,269	94
Soil 4	20,946	116
Control area	124	25

Figure 13 shows the deposition pattern of ^{137}Cs after the Chernobyl accident (European Communities, 2001). In 2010 the average activity concentration of ^{137}Cs in the top 10 cm of soil was 3.1 kBq m^{-2} in the Silesian voivodeship and 1.9 kBq m^{-2} in the whole area of Poland (Central Laboratory for Radiological Protection, 2012). In 2011 the average activity concentration of ^{137}Cs in Polish rivers and lakes was 2.6 mBq L^{-1} in water and 7.5 Bq kg^{-1} in bottom sediment (Central Laboratory for Radiological Protection, 2012).

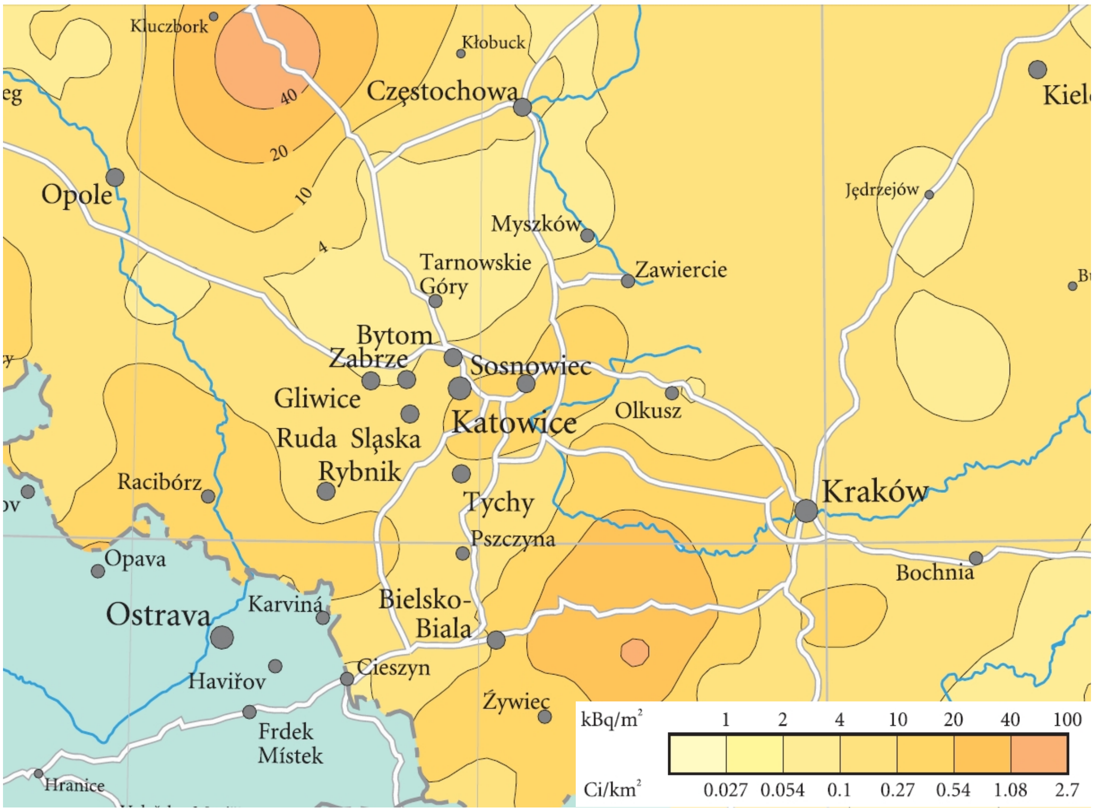

Figure 13. Deposition pattern of ^{137}Cs in the Katowice area after the Chernobyl accident (European Communities, 2001)

The average deposition of ^{90}Sr from global fallout is about 2.9 kBq m^{-2} for the latitude zone of Poland. In 2011 the average activity concentration of ^{90}Sr in water of Polish rivers and lakes was 1.9 mBq L^{-1} (Central Laboratory for Radiological Protection, 2012).

The average deposition of global fallout for the latitude zone of Poland is about 58 Bq m^{-2} for $^{239+240}Pu$ and about 2.3 Bq m^{-2} for ^{238}Pu, respectively. In the Gorce Mountains in southern Poland, however, deposition levels of up to about 155 Bq m^{-2} for $^{239+240}Pu$ were recorded (Skrzypiec, Jodłowski, Mietelski, 2013). In eastern Poland the Chernobyl fallout significantly contributes to the plutonium deposition (about 15% of total Pu). The maximum depositions of Chernobyl plutonium were observed in north-eastern Poland (about 25 Bq m^{-2} for all alpha emitting Pu isotopes, about 1 kBq m^{-2} for ^{241}Pu in 1986; Mietelski, 2001). In 2011 the activity levels of $^{239+240}Pu$ in bottom sediments of Polish rivers and lakes ranged between 3.1 and 120 mBq kg^{-1} (Central Laboratory for Radiological Protection, 2012).

Non-radioactive contaminants

As in the case of radionuclides, highly mineralised formation water is also the source of heavy metal contamination. **Table 10** shows, as an example, the concentrations of different metals in bottom sediments of the former mine settling pond Rontok Wielki (site #2; Jankowski *et al.*, 2005). Information on the metal concentrations in sediments of settling ponds of 10 different coal mines is provided in **Table 11**. Organic pollutants originate from processed water contaminated with used engine oil and lubricants.

Table 10. Concentrations of different metals in bottom sediments of the former mine settling pond Rontok Wielki (site #2; Jankowski *et al.*, 2005)

Element	**Concentration in bottom sediments (mg kg^{-1} dry weight)**	
	min	**max**
Pb	17	20
Cu	22	50
Zn	73	283
Cd	0.5	2.4

Table 11. Metal concentrations in sediments of settling ponds of 10 different coal mines

Element	Concentration in sediment (ppm), n=21	
	min	**max**
Sr	47	33,200
Pb	<1	830
Ba	240	122,000
Co	11	61
Cu	14	268
Ni	13	67
Zn	118	759

3.2.7 Ecosystems

Site #1, the upper Vistula river with its tributaries, is an ecosystem of watercourses. The relevant ecosystem components are water and bottom sediments. Nineteen fish species have been reported in the upper Vistula upstream of Kraków. The dominant species are chub (*Leuciscus cephalus*; <25% abundance, >50% biomass), crucian carp (*Carassius carassius*; <20% abundance, 10% biomass), common bleak (*Alburnus alburnus*; <20% abundance, 5% biomass), common roach (*Rutilus rutilus*; <15% abundance, <10% biomass), pike (*Esox lucius*; 2% abundance, <15% biomass) and barbel (*Barbus barbus*; <10% abundance, 1% biomass) (Tockner, Uehlinger, Robinson, 2009). The list of animals includes birds that are typical for flowing freshwater ecosystems. Some amphibians are assumed to live on the river banks. Herbaceous plants and deciduous trees are present along the river.

The former mine settling pond Rontok Wielki (site #2) is stagnant water. The relevant ecosystem components are water and bottom sediments. The list of animal species includes predators common for flowing and stagnant freshwater: catfish (*Silurus glanis*), pike-perch (*Sander lucioperca*), perch (*Perca fluviatilis*) and pike (*Esox lucius*). The predominant herbivorous fish species are common roach (*Rutilus rutilus*), crucian carp (*Carassius carassius*), carp bream (*Abramis brama*), tench (*Tinca tinca*), common carp (*Cyprinus carpio*) and grass carp (*Ctenopharyngodon idella*). Some amphibians are assumed to be present on the bank of the former settling pond. The list of birds includes the great crested grebe (*Podiceps cristatus*), mute swan (*Cygnus olor*), Caspian tern (*Hydroprogne caspia*) and grey heron (*Ardea cinerea*). The mallard (*Anas platyrhynchos*) falls within the definition of the ICRP reference duck. Earthworms and roundworms (phylum *Nematoda*) are expected to occur in bank sediments. Herbaceous plants and deciduous trees are present along the pond bank. The common reed (*Phragmites australis*) is one of the dominating species.

Site #3, the mine settling pond Kaniów, can be characterized as semi-stagnant water. Vertebrate species are absent. Some earthworms and roundworms (phylum *Nematoda*) might occur. Herbaceous plants are present along the pond bank.

The former mine settling pond Bojszowy (site #4) is a terrestrial ecosystem after technical land reclamation. Typical game species (roe deer, deer, hare, wild boar) have been observed but the area is too small to consider them as resident populations. Among vertebrate species only small rodents and amphibians form resident populations. Earthworms and roundworms (phylum *Nematoda*) occur. Herbaceous plants are present at the border of the pond. Along the pond bank coniferous and deciduous trees occur. The following ICRP reference animals and plants can be found: rat, pine tree, bee, frog, earthworm, wild grass and deer.

Site #5, the county borough Świerklany, is a terrestrial ecosystem that comprises a residential area, arable land and wastes contaminated with radium. The list of animal and plant species includes small rodents, amphibians, earthworms and roundworms (phylum Nematoda). Herbaceous plants including cereals, coniferous and deciduous trees occur.

3.2.8 Potential exposure routes

Potential exposure routes for humans include external exposure and ingestion of contaminated foodstuff. The importance of both exposure routes differs considerably from site to site.

Access to artificial or semi-artificial mine settling ponds situated on the company grounds is usually restricted to the mine staff. The public may access natural lakes or former fish ponds that were adapted in the past as settling and retention ponds and are nowadays excluded from technological processes. They are, however, no attractive recreation areas, *e.g.* the former mine settling ponds Rontok Wielki (site #2) and Bojszowy (site #4). Recent screening measurements at the county borough Świerklany (site #5) showed ambient dose rates of up to 6 $\mu Sv\ h^{-1}$ on contaminated land along the former stream.

Ingestion of contaminated foodstuff is a potential exposure route at sites #2 and #5. The Rontok Wielki pond is currently hired by a local fishing club. At Świerklany the radium contamination affects also arable land.

Exposure routes for wildlife include external exposure, root uptake and the trophic chain.

3.2.9 Absorbed dose rates to wildlife

The unweighted absorbed dose rates to non-human biota as calculated applying the approach suggested by Amiro (1997) are given in **Tables 12** (plants) and **13** (vertebrates).

The total weighted absorbed dose rates to the default reference organisms of the ERICA Assessment Tool at the Kaniów site are shown in **Figure 14**. They were calculated from the activity concentrations in soil. Except for trees, the weighted absorbed dose rates exceed the default screening level of 10 $\mu Gy\ h^{-1}$ (240 $\mu Gy\ d^{-1}$) for all default reference organisms of the ERICA Assessment Tool.

Table 12. Dose rates to plants at the sites Rontok Wielki (site #2) and Bojszowy (site #4)

	Internal dose rate ($\mu Gy\ d^{-1}$)	**Total dose rate root system ($\mu Gy\ d^{-1}$)**	**Total dose rate upper parts of plants ($\mu Gy\ d^{-1}$)**
Site Rontok Wielki			
Calamagrostis epigeios	63	1,659	861
Betula pendula	9	84	47
Phragmites australis	7	201	104
Quercus robur	5	80	43
Site Bojszowy			
Phragmites australis	5 – 10	55 – 570	30 – 290
Lepidium ruderale	7	102	54
Circium vulgare	9	46	29
Matricaria perforate	14	69	41

Table 13. Dose rates to vertebrates at the sites Rontok Wielki (site #2) and Bojszowy (site #4)

	External dose rate from terrestrial radionuclides ($\mu Gy\ d^{-1}$)	**External dose rate from radionuclides in surrounding biota ($\mu Gy\ d^{-1}$)**
Site Bojszowy	20 – 325	1.5 – 4
Site Rontok Wielki	5 – 535	0.6 – 6

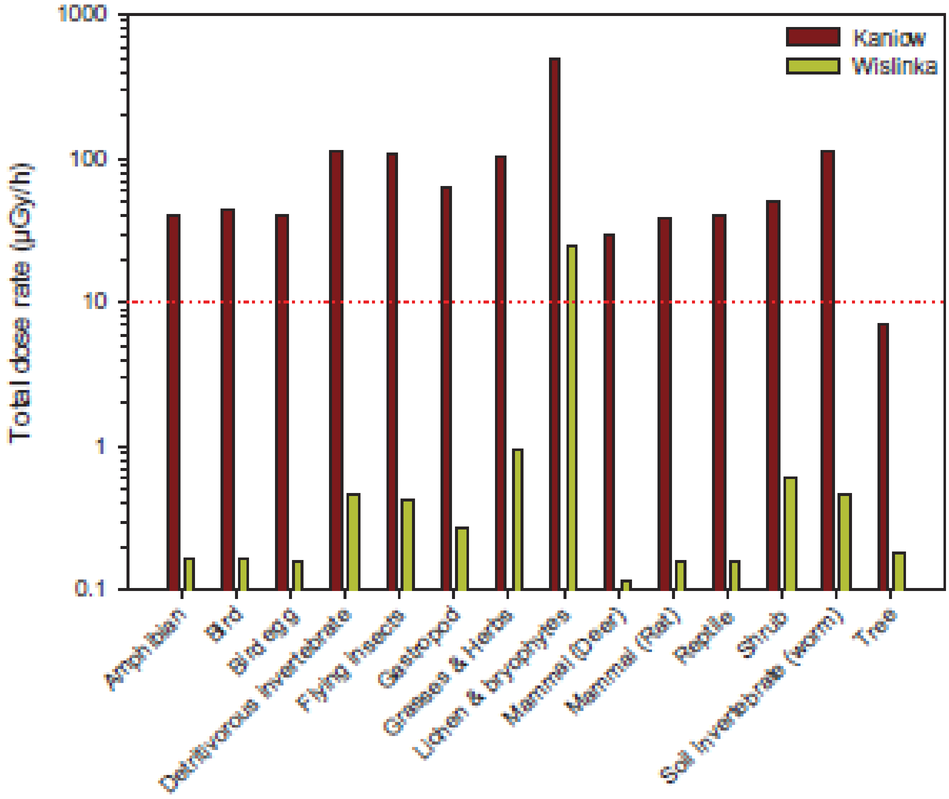

Figure 14. Total weighted absorbed dose rates to terrestrial default reference organisms of the ERICA Assessment Tool calculated from the activity concentrations in soil at the Kaniów site and the phosphogypsum waste dump Wislinka (Hosseini *et al.*, 2011). The dotted line represents the ERICA default screening level of 10 µGy h^{-1}.

3.2.10 Long-term availability and basic authorization

The long-term availability for field research without any major changes, *e.g.* resulting from remediation measures, differs from site to site:

In case of site #1 (upper Vistula river) the situation will not change significantly for the next 30 years. The mines that discharge waters into the Vistula river have licenses for coal exploitation until 2041.

The former mine settling pond Rontok Wielki (site #2) will be left in the current state. There are no legal and/or economic needs to change this site.

The sediments of the mine settling pond Kaniów (site #3) must probably be removed in the long term in order to keep the settling pond working. The removal of sediments, however, is not expected to be necessary within the next 10 years.

At site #4, the former mine settling pond Bojszowy, the owner is obliged to monitor the effectiveness of land reclamation, including its impact on the radiological situation. The final transformation into a recreation area is possible.

The fate of site #5, the county borough Świerklany, depends on the local development plans. The plans are valid for at least 5 years. Currently there are no efforts to change the status of the area of interest.

The Polish Central Mining Institute (GIG) informed the site owners that the European Network of Excellence STAR is currently exploring the possibility to establish Radioecological Observatories at the Upper Silesian Coal Basin. The site owners declared their preliminary consent that their properties could be used for long-term field investigations. GIG agreed to act as a contact point, thus facilitating the communication between the STAR consortium and the Polish site owners.

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4 Conclusions

By combining multi-criteria decision analysis, group discussions and recommendations provided by invited external experts, the STAR consortium selected contaminated field sites that perform best with respect to a list of criteria that an ideal European Observatory for Radioecological Research should meet. The Upper Silesian Coal Basin and the Chernobyl Exclusion Zone were identified as the most promising candidates for becoming Radioecological Observatories. These two sites complement each other: The Polish coal mining area is a typical mixed contaminant situation with moderate dose rates to reference organisms. The Chernobyl Exclusion Zone offers a contamination gradient with high maximum dose rates to reference organisms. Relevant amounts of non-radioactive pollutants, however, are absent. The combination of focused field investigations at these two sites with their complementary characteristics and dedicated laboratory experiments represent an excellent starting point to address the research lines of the Strategic Research Agenda.