Contaminated Site Investigation & Remediation

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RISK ASSESSMENT ANALYSIS

Kap Temporary PCB Storage

Montenegro

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1 Introduction

The objective of this report is to assess human health and ecological risks arising from the residual contamination at the former PCB storage area inside the industrial facilities of the aluminium plant (KAP plant) in Podgorica, Montenegro. Human health and ecological risks related to the residual soil pollution in the immediate vicinity of the former PCB storehouse were also assessed.

The presented Risk Assessment (RA) report is a follow-up to the results of the field survey of the PCB storage area and the analytical evaluation of collected samples of ambient air, soil, groundwater and construction materials (concrete and wall surface in the storehouse). These results are summarized in the “Final Report on Analysis of Soil, Concrete, Underground Water, Air and Wipe Testing in the Area of KAP Temporary PCB Storage” [4].

An environmental and human health risk assessment is the process to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future. The human health risk assessment includes 4 basic steps:

- Hazard Identification **-** Examines whether a contamination has the potential to cause harm to humans and/or ecological systems, and if so, under what circumstances.
- Dose-Response Assessment **-** Examines the numerical relationship between exposure and effects.
- Exposure Assessment **-** Examines what is known about the frequency, timing, and levels of contact with the contamination.
- Risk Characterization **-** Examines how well the data support conclusions about the nature and extent of the risk from exposure to the contamination.

2 Hazard Identification

The determination of priority contaminants and the risk assessment within the considered exposure scenarios are based on the results of the site investigation and sampling work carried out on the PCB storage area. Physical, chemical and toxicological information regarding the individual pollutants and the possibility of their spreading into the environment was taken into account. Mandatory regulations and methodical instructions used in the risk assessment are listed in Table 1.

Table 1 – Summary of mandatory regulations and methodical instructions

Residual Screening Levels (US EPA) – January 2017 [1]
RAIS (The Risk Assessment Information System) [2]
US EPA Risk Assessment Guidelines [3]
Dutch limit values for soil and groundwater (2009) [5]

The content of hazardous and harmful substances in soil is regulated in Montenegro Rulebook on permitted amounts of hazardous and harmful substances in soil and methods of investigation ("Off. Gazette of Montenegro", No. 18/97). The Rulebook provides the maximum allowable amount of hazardous and harmful substances in the soil, which can lead to its pollution and resulting improper use of fertilizers and pesticides by individuals and legal entities as well as the discharge of waste from various sources. The maximum concentration for PCBs in agricultural soil is 0.004 mg/kg (for each of congeners: 28, 52, 101, 118, 138, 153 and 180).

"JUS.Z.BO.001" concerning maximum allowable concentration of harmful gases and vapours in the atmosphere of work premises and work sites defines maximum allowable concentrations for PCBs of 1 mg/m^3.

Montenegro ratified the Convention on Long Range Trans-Boundary Air Pollution with 3 protocols of which one is the Protocol on Persistent Organic Pollutants. According to the POPs Protocol that has stricter provisions regarding the relevant PCBs the parties are obliged to eliminate the use of PCBs in equipment (transformers, capacitors and the like) containing more than 5 dm^3 or concentration equal to or exceeding 0.005% PCBs no later than 31 December 2015 in case of countries with economies in transition.

2.1 Identification and Explanation of Priority Pollutants and Other Risk Factors

This chapter summarizes the analytical results and identify the priority contaminants, for which risk scenarios are considered and health risks are calculated.

As a part of the investigation work at PCB storage area the following sample types were taken:

- Soil samples in the PCB storage area in the surface layer. A total of 44 soil samples were taken, of which 28 samples at a depth level of 0-20 cm and 16 samples at a depth level of 20 - 40 cm.
- Soil samples in the PCB storage area in the boreholes. A total of 67 soil samples were taken from 3 boreholes at a depth level of 0-23 m.
- Groundwater samples. A total of 10 groundwater samples were taken from the wells and piezometers in the vicinity of PCB storage area.
- Concrete samples. A total of 30 samples of concrete plateau in front of the PCB storehouse as well as concrete floor in the storehouse building.
- Wall surface samples. A total of 30 wipe samples of dust were taken inside the storehouse with two different heights.
- Air samples. A total of 3 samples of ambient air were taken in the PCB storage area. All samples were 24 hour ambient air samples. First sample was taken before the start of soil sampling at the PCB storage area. Second sample was taken during the soil sampling and third sample was taken after the completion of soil sampling at the PCB site.

For a detailed description of sampling activities including the sampling location and methodology description see the investigation report [4].

The extent of the chemical analyses carried out on the samples taken in the field investigation work is shown in Table 2 below [4].

Table 2 – Overview of the analyses done within the project

Parameter	**Number of analyses**
Analyses – soil/concrete	
PCBs-soil (0-20 cm and 20-40 cm)	44
PCB-soil (3 borehole)	67
PCB-concrete	30
Metals (As, Hg, Cd, Zn, Pb, Cu, Ba, Ni, V, Cr, Sn, Co)-soil	1

Total petroleum hydrocarbons (TPH)-soil	1
Polycyclic aromatic hydrocarbons (PAH)-soil	1
Analyses – wall samples (wipe)	
PCBs	30
Analyses – groundwater	
PCBs	10
Analyses – ambient air	
dl-PCB - coplanar, PCB-indicator + selected set of polycyclic aromatic hydrocarbons (PAHs - set of 16 by US EPA standard)	3

The results of laboratory analyses are presented in tables and commented on in the field investigation report [4]. The following tables show the maximum and average PCB concentrations found in the individual media monitored at the site.

Table 3 – Average and maximum values of the PCB concentrations for the surface soil samples 0 - 20 cm and surface concrete in front of PCB storehouse

mg/kg	Total PCB	Σ7PCB congeners[1)]	Ratio: Dioxin-like PCBs[4)]/Total PCBs [%]	Comment
Average	1690	359	2.4-6.6	-
Max	25593	4984		Sample ID 518/11
Intervention level[2)]	-	2.1	-	-
Permissible level for industrial area[3)]	33	33	-	-
US EPA screening level for soil [5)]	0,22	-	-	-
1) Σ7PCB= 28, 52, 101, 118, 138, 153 and 180				
2) Dutch Ministry of Housing, Land Planning and Environment, 2009 (correction for organic matter content)				
3) UNIDO "POPs Contaminated Site Investigation and Management Toolkit"				
4) ΣDioxin-like PCBs congeners = 81, 77, 123, 105, 126, 167, 157, 169, 189				
5) RAIS (The Risk Assessment Information System) [2]				

Table 4 – Average and maximum PCB and PAH concentrations in ambient air samples outside the former PCB storehouse

ng/m³	Total PCB	Σ12PCB congeners[1)]	ΣPAH	Comment
Average	566	159	123	-
Max	620	173	136	-
MATC level [2)]	500	-	-	-
1) Σ12PCB= 18, 28, 31, 52, 44, 101, 149, 118, 153, 138, 180 and 194				
2) MATC = maximum acceptable toxicant concentration, Dutch Soil Remediation Circular 2009				

Table 5 – Average and maximum PCB concentrations of floor concrete and wall surface samples inside the PCB storehouse

mg/kg	Total PCB	Σ12PCB congeners[1)]	Comment
Average	54	14	-
Max	921	270	Sample ID: 509/11 (floor concrete)
Permissible level for industrial area[2)]	33	33	
1) Σ12PCB= 18, 31, 28, 44, 52, 149, 101, 118, 138, 153, 180 and 194			
2) UNIDO "POPs Contaminated Site Investigation and Management Toolkit"			

Table 6 – Average and maximum PCB concentrations in borehole soil samples

mg/kg	Total PCB	Σ7PCB congeners[1)]	Comment
Average	258	47	-
Max	10868	1904	Zone 27, Sample ID 564/11, 0-1 m bellow surface
Intervention level[2)]	-	2.1	
Permissible level for industrial area[3)]	33	33	
US EPA screening level for soil [4)]	0,22		
1) Σ7PCB= 28, 52, 101, 118, 138, 153 and 180			
2) Dutch Ministry of Housing, Land Planning and Environment, 2009 (correction for organic matter content)			
3) UNIDO "POPs Contaminated Site Investigation and Management Toolkit"			
4) RAIS (The Risk Assessment Information System) [2]			

Table 7 – Average and maximum PCB concentrations in groundwater samples

µg/l	Total PCB	Σ7PCB congeners[1)]	Comment
Average	< 0,002	< 0,002	-
Max	< 0,002	< 0,002	-
Target level[2)]	-	0,01	
Intervention level[2)]	-	0,01	
1) Σ7PCB= 28, 52, 101, 118, 138, 153 and 180			
2) Dutch Ministry of Housing, Land Planning and Environment, 2009			

The results of the survey confirmed that the priority pollutant is the group of polychlorinated biphenyls (PCBs). Apart from groundwater, concentrations of PCBs in the collected soil samples exceed the Dutch intervention level, as well as the permissible level for industrial area according to UNIDO "POPs Contaminated Site Investigation and Management Toolkit", as can be compared in the presented tables.

PCBs are toxicologically important substances with proven toxic and carcinogenic effects, which due to their persistence and ability to spread in the environment represent a significant risk factor from the health and environmental point of view. A description of the toxicological properties of PCBs follows.

Characteristic and toxicology of PCBs

Polychlorinated biphenyls (PCBs) are organochlorinated synthetic compounds that belong to the group of industrial persistent pollutants, presented in Annex A, Part II of the Stockholm Convention. Chlorinating of biphenyls in the presence of catalysts results in obtaining PCB with different share of Chlorine which generates 209 congeners, of different characteristics. Out of the total 209 congeners, only 19 PCBs are counted into commercial products, because they are stable at room temperature. Due to its dielectric features they have been used as fluids in transformers, capacitors (high and low voltage), hydraulic systems, heat transfer systems, eclectic-magnetic, fluorescent lighting connectors, fluid filled cables, gaskets, disconnectors, voltage regulators, vacuum pumps, microwave ovens, electronic equipment, pesticide additives, ink, lubricants, carbonless copy paper, additives for paints, plastics and plastic products.

Increasing environmental contamination, together with knowledge of their persistence and adverse health effects, led to a ban on their production in the 1970s. Like PCDD and PCDF, they adsorb onto solid particles and sediments in the environment. They accumulate in the adipose tissue of animals upon entering the food chain.

In terms of toxicological properties, PCB congeners can be divided into two groups. Of the 209 PCB congeners, 12 showed dioxin-like activity (non-ortho and mono-ortho PCBs). Congeners structurally similar to 2,3,7,8-TCDD, similar to PCDD and PCDF, have the ability to react with Ah receptors and thereby induce toxic effects of the dioxin type. The higher content of PCBs is often accompanied by the presence of PCDD and PCDF.

In monitoring PCB exposure, 7 so-called non-dioxin-like congeners, which are most commonly found in the environment, food and the human body, are usually monitored.

PCBs can be found in all components of the environment. Soil contamination occurs in different ways: releases from industrial facilities and waste, accidents, atmospheric deposition, sediment and sludge application from wastewater treatment, erosion and leaching from adjacent contaminated sites. After absorption by organic carbon in the soil they are relatively persistent. The congeners of PCBs in soils and sediments change over time by the activity of either aerobic bacteria that degrade less chlorinated congeners and also anaerobic bacteria, which can cause partial dechlorination of more chlorinated congeners.

The behaviour of these substances in the natural environment depends on the degree of chlorination, persistence increases with an increasing number of Cl atoms. In natural waters and soils, low-chlorinated PCBs are only degraded by slow biodegradation, and PCBs with 5 or more Cl atoms in the molecule are also resistant to it. The major part of PCB in water is adsorbed to sediments and organic substances, the more chlorinated molecules are adsorbed more strongly. Thus, less chlorinated PCBs are present in water, while more chlorinated are present in the sediment. Due to the higher specific weight compared to water, they can penetrate vertically to the subsoil of the aquifer. Of note is the volatility of dissolved PCBs from the surface of the water or the topsoil of the soil, which decreases with the number of chlorine atoms in the molecule, so that the proportion of more chlorinated PCBs in the soil increases. Accumulation in aquatic organisms is also important. Although PCBs are chemically stable, they are subject to slow chemical changes to form dimers, trimers and oxygen compounds (dibenzofurans and diphenyl esters). Substances produced by slow degradation show higher toxicity than the original PCBs. In the atmosphere, the effluent PCBs react with hydroxyl radicals to form monochlordiphenyl and heptachlordiphenyl.

All PCBs have a density higher than water (about 1440 kg/m^3), are poorly water-soluble (0.7 mg/l) and have a very low vapour pressure (<1 Pa). They are soluble in most organic solvents and in fats. They are also chemically and physically stable (even at temperatures around 300 °C).

From water and river sediments, PCBs are accumulated by algae and plankton and reach the food chains in such a way. Fish living for a long time in water contaminated with trace concentrations of PCBs have concentrated these substances in their bodies up to a thousand times. The most endangered group of organisms are marine mammals, whose reproductive capacity can be strongly affected. PCBs are also toxic to other aquatic organisms. Birds are another group at risk for PCBs.

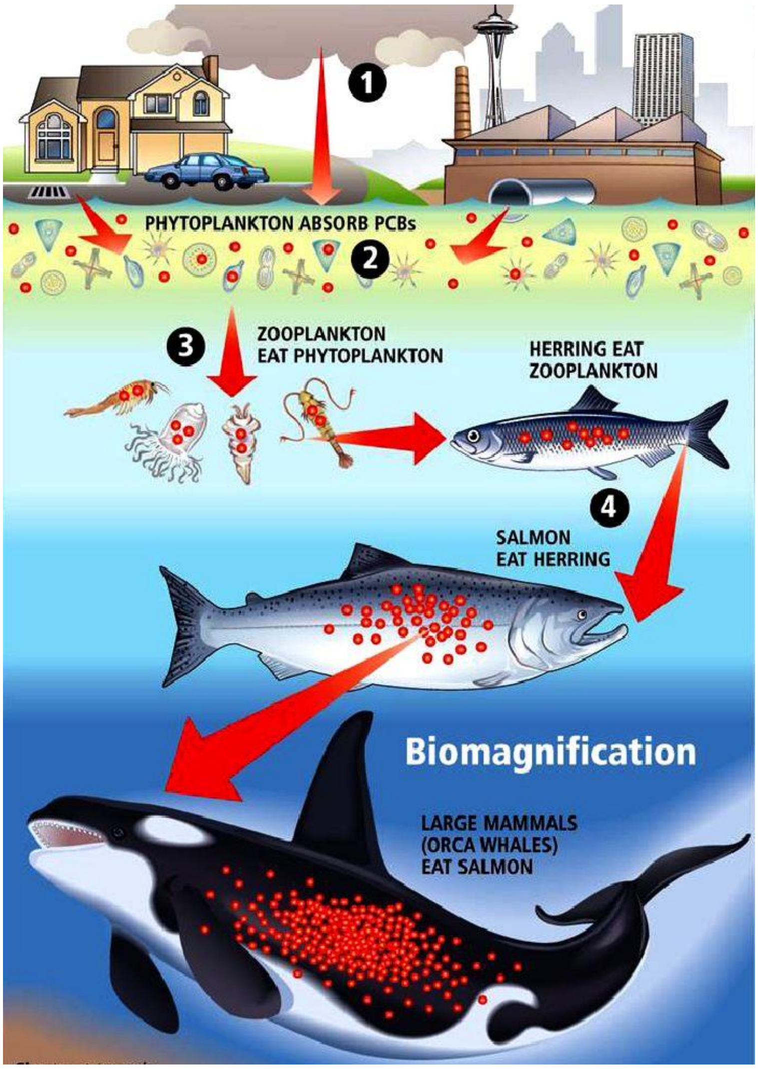

Figure 1: Biomagnification of PCBs in an aquatic food chain (source [9])

PCB entry into the body is possible through the digestive tract, lungs, and skin. Food, in particular, its fat component of animal origin, accounts for over 90% of total exposure. The dermal and inhalation routes are generaly of minor importance except for the professionally exposed persons.

PCBs are rapidly absorbed from the gastrointestinal tract and accumulate in adipose tissue. They also cross the placental barrier. The major metabolic pathway is hydroxylation and subsequent conjugation. Some metabolites of non-dioxin-like congeners are also toxicologically important.

The main elimination pathway is fecal excretion, significantly less in the urine. Breast milk is a specific elimination pathway for PCBs. Biotransformation and persistence in the organism vary considerably between congeners, the elimination half-life for multiple chlorinated congeners is, on average, between 8 and 15 years. Congeners with fewer chlorine atoms can be more easily metabolized and excreted.

In humans, increased incidence of certain tumours, adverse effects on fetal development, decreased sperm mobility, neurological defects, impaired immunity, and dermatological changes have been reported in association with PCB exposure.

Evidence of PCB developmental toxicity to humans has been shown by some studies in which lower birth weight and delayed neural development of children were found when the mother was exposed to the consumption of fish with high PCB content.

Studies in various species of experimental animals, including primates, have shown developmental toxicity of orally received PCBs, particularly neurological defects and impaired immune function.

Like PCDD and PCDF, PCB is one of the so-called endocrine disruptors that interfere with the hormonal functions of the endocrine system. This effect, for example on thyroid hormone secretion, may explain one possible mechanism of PCB developmental toxicity.

Chronic toxicity mainly causes skin symptoms (edema, acne, pigmentation) that affects the reproductive organs of adults and damages the nervous system (headache, drowsiness, weakness, tingling in the arms and legs) when exposed to high levels. PCBs substituted with chlorine in p-positions cause liver damage.

In 2015, IARC classified PCB in Group 1 as a proven carcinogen. This group also includes the dioxin-like PCB congeners with the Ah receptor mechanism of carcinogenic effect, but the carcinogenicity of PCBs cannot be explained by the effect of these congeners according to the IARC. PCBs occur and act in complex compositions that produce both genotoxic and non-genotoxic effects associated with carcinogenesis and cancer development. Reliable PCB carcinogenicity has been demonstrated in experimental animals. PCBs are also classified as a positive teratogen.

The WHO does not anticipate a direct genotoxic effect of PCBs and, in 2003 for the quantitative risk assessment of PCB mixtures, assumed a value of 0.02 µg/kg per day as TDI (in food or drinking water). This value was derived in 2000 by the US ATSDR (Agency for Toxic Substances and Disease Registry) as a chronic MRL (Minimal Risk Level). This was based on multiannual experimental studies in monkeys exposed to Aroclor 1254 and the critical effect of immune system impairment.

According to ATSDR, this MRL is also supported by a human developmental toxicity study. For shorter exposure times ranging from 15 days to 364 days, ATSDR derived a subchronic MRL of 0.03 µg/kg per day. The background was a LOAEL dose of 7.5 µg/kg per day for developmental neurotoxicity in monkeys.

The National Institute of Public Health and the Environment of the Netherlands (RIVM) has set 7 indicator non-dioxin-like TDI congeners of 0.01 µg/kg per day for oral intake. It was based on TDI 0.02 µg/kg per day for the Aroclor 1254 mix and about 50 % of the 7 indicator PCB congeners in the mix.

The US EPA did not set a reference dose to assess the risk of non-carcinogenic effects of PCB sum. In 1997, however, the PCBs were classified as likely carcinogens for humans (group B2) and, in order to assess the risk of carcinogenic effects, EPA established carcinogenic risk guidelines at different levels according to the exposure route. The reason is different behaviour and risk level of different PCB congeners both in their transport in the environment and in bioaccumulation in the food chain and human organism.

In the US EPA RSL database, the PCB concentration of 0.23 mg/kg in the residential environment and 0.94 mg/kg in the industrial zones are recalculated to a standard carcinogenic risk rate of $1x10^{-6}$. In drinking water, the RSL database reports a concentration of 0.044 ug/l corresponding to a carcinogenic risk of $1x10^{-6}$.

The WHO did not set the recommended limit PCB concentration in drinking water. In the USA, the target MCLG concentration for PCB content in drinking water, as with other substances suspected of carcinogenicity, is zero.

For the sum of PCB congeners, the US EPA has established carcinogenic risk guidelines at different levels by exposure route. The reason is different behaviour and risk level of different PCB congeners both in their transport in the environment and in bioaccumulation in the food chain and human organism. US EPA assumes the highest degree of risk of carcinogenic effects for food chain exposure, soil and sediment ingestion, dust and aerosol inhalation, absorption factor dermal exposure, and early exposure from all routes.

For these exposure routes, the carcinogenic risk guideline of SF, corresponding to a dose of 1 $mg.kg^{-1}$ per day at SF = 2 as the upper estimate and SF = 0.07 $(mg/kg\text{-}day)^{-1}$ as the lower estimate were established.

The mean value describes a typical individual risk, while using an upper estimate reduces the likelihood of an underestimation of risk. However, the upper estimate does not yet guarantee risk coverage for a sensitive part of the population (children, pregnant women, and elderly people). In our case - exposure of employees and external workers (mostly adult men) we consider the mean value of SF, also because dioxin-like PCBs represent only a low % of the total PCB contamination present at the site.

For the ingestion of water-soluble congeners, inhalation of PCB congeners in the form of vapours and for dermal exposure assessed without the use of the absorption factor, lower carcinogenic risk guidelines of SF = 0.4 and 0.3, respectively, apply.

As for ecological risk, the group of PCBs has the following hazard statements according to European regulation on classification, labelling and packing of chemical substances and mixtures (CLP):

H400: Very toxic to aquatic life

H410: Very toxic to aquatic life with long-lasting effects

PCBs have never been produced in the territory of Montenegro, but there has been production and overhaul of equipment containing PCBs in the factory “19 decembar” in Podgorica (transformers and capacitors), which resulted in import of fluids containing PCBs.

2.2 Basic Characteristics of the Risk Receptors

The following risk receptors were determined on the basis of the survey carried out at the PCB storage area.

- KAP employees carrying out regular work at the former PCB storage area, as well as inside the former PCB storehouse. The employees thus come in contact with contaminated surface soil (and dust on the concrete surface) in the vicinity of the former PCB storehouse, breathe potentially contaminated ambient air and get in contact with the building structures of the storehouse (walls and concrete floor) containing residual pollution.
- Workers carrying out earthworks – excavation works or remedial works at the PCB storage area.
- Groundwater, which can spread the pollution further outside the PCB storage area, thus affecting the water quality in the groundwater collector, as well as quality of groundwater used by the residents living nearby the site. Based on the results of the site survey (zero concentration of PCBs in groundwater in the monitored wells around the site), it can be concluded that the local residents living around the former PCB storage site are (currently) not in risk by usage of groundwater.
- Agricultural land surrounding the site can be affected, for example, by wind-spread of contaminated dust, which can have a negative impact on the terrestrial food chains which are depending on the agricultural land.

2.3 Summary of Transport Pathways and an Overview of Potential Exposure Scenarios - Conceptual Model

An exposure scenario can be defined as a sequence of processes through which the contaminant gets from its source through elements of the environment to the person, object (e.g. groundwater body) or ecosystem at risk. The exposure scenarios are based on the characteristics of the transport pathways and on the type of risk receptors specified in the previous chapter. Based on all the available information the following exposure scenarios were defined for the former PCB storage area:

No.	Scenario description
1	Dermal contact of KAP employees with the contaminated surface soil and contaminated concrete at the PCB storage area.
2	KAP employees who accidentally ingest soil and dust from surfaces at the PCB storage area.
3	Inhalation of contaminated ambient air by KAP employees due to the volatilization of volatile PCBs and dust particles from the contaminated surface soil and concrete dust at the PCB storage area.
4	Air transport of dust particles outside the PCB storage area and negative impact on quality of agricultural land, as well as quality of agricultural products.
5	Dermal contact of KAP employees with the building structures (dust from walls and concrete floor) containing residual pollution inside the former PCB storehouse.
6	KAP employees who accidentally ingest dust (dust from walls and concrete floor) in the former PCB storehouse.
7	KAP employees who inhale contaminated air in the former PCB storehouse.
8	Dermal contact of the workers carrying out earthworks or remedial works with the contaminated soil of the unsaturated zone at the PCB storage area.
9	Accidental ingestion of contaminated soil of the unsaturated zone by workers carrying out earthworks or remedial works at the former PCB storehouse area.
10	Inhalation of contaminated soil particles by workers carrying out excavation works within the earthworks or remedial works at the former PCB storage area.
11	Groundwater may be contaminated by the potential spread of pollution from the PCB storage area.

All exposure scenarios described are schematically shown in conceptual site model (Figure 2). The following table 8 summarizes the transport pathways and potential exposure scenarios for the former PCB storage area.

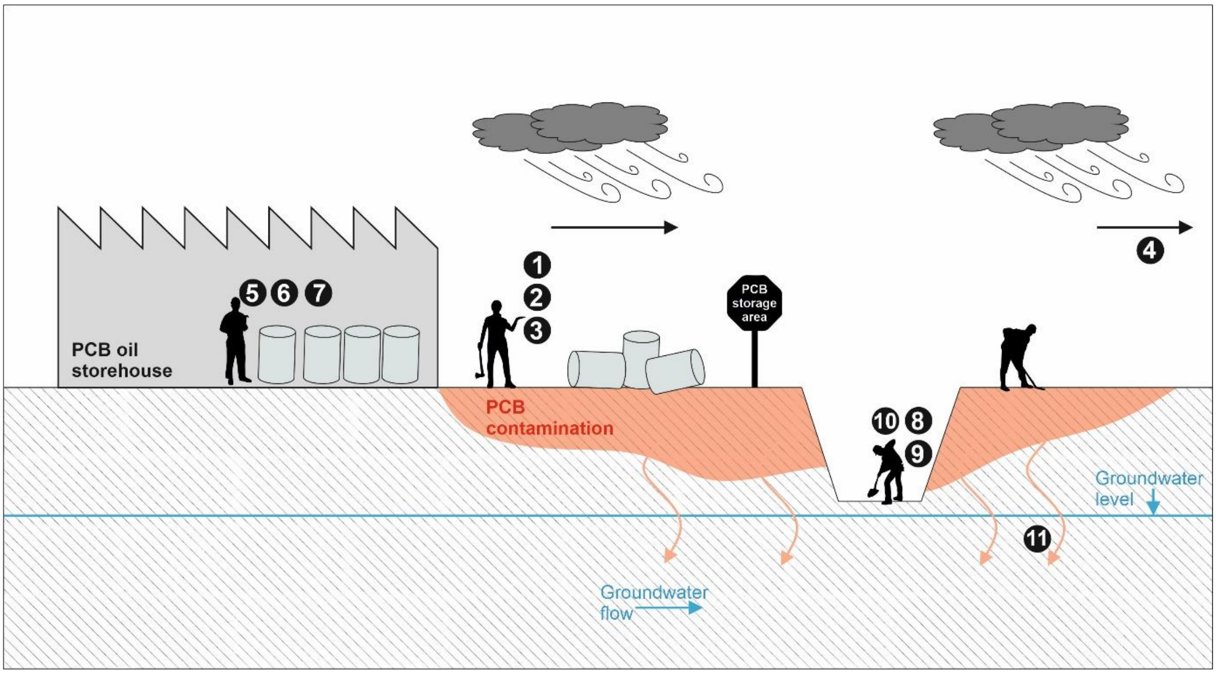

Figure 2: Conceptual site model representation

Table 8 - Summary of potential exposure scenarios

Medium	Contamination source	Transport way	Risk receptor	Way of exposure	Collected samples	Real scenario based on investigation performed (Yes/No/N.A.)
Surface concrete and surface soil	PCB storage area	Direct contact with surface soil and concrete	Local workers	Dermal contact	Concrete samples in front of PCB storehouse and surface soil samples 0 -20 cm	YES
				Accidental ingestion		
		Air transport inside the PCB storage area	Local workers	Inhalation of dust	Ambient air samples	YES
		Air transport outside the PCB storage area to the surrounding land	Residents consuming crops (and animal products) grown on fields in the vicinity of PCB storage area	Food and animal products consumption - Bioaccumulation in agriculture crops and animals	N.A.	N.A.
Construction materials of PCB storehouse – wall dust and floor concrete	PCB storehouse	Direct contact with construction materials	Local workers	Dermal contact	Construction samples – wipe tests (storehouse walls) and concrete floor samples	YES
				Accidental ingestion		
				Inhalation of dust	N.A.	N.A.
Unsaturated zone	PCB storage area	Direct contact with soil	External workers (Earthwork + remedial works)	Dermal contact	Unsaturated soil samples up to 23 m below surface	YES
				Accidental ingestion		
				Inhalation of soil particles		

Groundwater	PCB storage area	Soil → Groundwater → wells in residential area	Residents	Dermal contact	Groundwater samples	NO
				Ingestion		
		Soil → Groundwater → wells in residential area → crops watering	Residents	Consumption of crops and vegetables (and animal products)		
		Soil → Groundwater	Groundwater resources for drinking water supply	N.A.		

N.A. = not available

No data was available for the scenarios No. 4 and 7, i.e. concentrations of PCBs in agricultural soil from the vicinity of the site and concentrations of PCBs in air inside the former PCB storehouse, respectively.

3 Human Health Risk Assessment

Human health risk assessment was done according to the methodology of the US EPA [3], which distinguishes between the assessment of substances with carcinogenic (stochastic) effects and the assessment of substances with non-carcinogenic (systematic) effects.

Mechanisms of the affection of these two types of contaminants are different. In the case of substances with a carcinogenic effect even a small number of changes at the molecular level and may cause uncontrolled cell proliferation or develop malignancies. It is derived from the existing idea about the origination of malignancies, when the initiating moment may be any contact with carcinogenic substances. Because theoretically there is no safe level of exposure to such substances, the mechanism of action is described as a non-threshold. In the case of systemic toxicity, toxic effect of pollutants must overcome a first some (threshold) physiological detoxification capacity, compensation and defence mechanisms of the body. So, it is possible to identify the rate of exposure which is safe for the human body and does not cause a negative effect under normal circumstances. For the evaluation of the chronic influence of contaminants from the environment on the human body, the fact is characteristic that as a rule it concerns the affection of very low concentrations where the toxic effect must be extrapolated from areas of high concentrations.

For the assessment of systemic toxicity, the US EPA introduced reference doses, RfD [$mg.kg^{-1}.day^{-1}$]. The RfD value represents the level of everyday oral exposure dose of the contaminant that the population (including sensitive groups) can be exposed to throughout lifetime without any probable adverse health effects. From the point of view of systemic toxicity, daily intake under the RfD level do not need to be, in all probability, considered to be hazardous.

For the assessment of relative toxicity of substances with carcinogenic effect, the US EPA uses the cancer slope factor (SF), which is the upper limit of the estimate of the likelihood of malignant tumour occurring above the usual average probability of occurrence related to the unit of the oral exposure dose received throughout the individual's lifetime, which is expressed in [$mg.kg^{-1}.day^{-1}$]. SF is related to the unit reception of the contaminant, so it is a risk of carcinogenic effects of the substance at the received amount of 1 $mg.kg^{-1}.day^{-1}$. The unit of SF is therefore expressed as [$mg.kg^{-1}.day^{-1}$]$^{-1}$.

For the calculation of risks in case of PCB storage area the RfD and SF values from the US EPA [1] and RAIS [2] databases are used.

If the contaminant concentration in the monitored medium is constant throughout the exposure period, the amount of the substance entering the organism can be expressed as average chronic daily intake [$mg.kg^{-1}.day^{-1}$], which can be calculated in the following manner:

CDI = (C x CR x FI x EF x ED) / (BW x AT)

CDI Chronic Daily Intake [$mg.kg^{-1}.day^{-1}$]
C contaminant's concentration in the monitored medium [$mg.kg^{-1}$, $mg.m^{-3}$]
CR contact rate: rate of contact with the contaminated medium [$kg.day^{-1}$, $L.day^{-1}$, $m^3.day^{-1}$] (e.g. soil ingestion, food consumption or air inhalation per day)
FI fraction ingested from the contaminated source [0 – 100 %]
EF exposure frequency [$day.year^{-1}$]
ED exposure duration [year]
BW bodyweight: average bodyweight of exposed individual [kg]
AT the period over which exposure is averaged [day]

For substances with no carcinogenic effect, AT corresponds to exposure duration while for substances with carcinogenic effect the exposure doses are accumulated throughout the individual's lifetime. Therefore, the average daily intake is related to life expectancy (usually 70 years) and in this case the exposure is expressed as Lifetime Chronic Daily Intake (LCDI).

The objective of **risk characteristics** is to summarize all data and information collected in the previous steps and to express quantitatively the rate of the real specific human health risk caused by chronic contaminant exposure in the given situation, which can be used as a source for making decisions on measures, i.e. for risk management. A recommended indicator of the hazardousness of substances with no carcinogenic effect is the Hazard Quotient (HQ) expressed as a ratio of Chronic Daily Intake to the relevant reference dose (RfD).

In the assessment of the impact of non-carcinogenic substances, if Chronic Daily Intake (CDI) is lower than the reference dose (i.e. it results in HQ < 1), the exposure dose is so low that in all probability it causes no human health risk. If HQ > 1, there is theoretical risk of a toxic effect. Therefore it is necessary to obtain more detailed information on the monitored substance and on the manner of exposure or, if necessary, begin to implement suitable remedies. For reasons of a conservative approach to risk assessment, US EPA recommends a HQ threshold of 0.5.

As a criterion of the risk of carcinogenic effect in exposed population, Excess Lifetime Cancer Risk (ELCR) is used, which is a theoretical number of statistically expected cases of tumour disease per exposed persons. ELCR can be obtained as a multiplication of Lifetime Chronic daily Intake (LCDI) and Slope Factor according to the relation applicable to relatively low risks of up to 1×10^{-2} [3]:

ELCR = LCDI x SF

ELCR Excess Lifetime Cancer Risk [-]
LCDI Lifetime Chronic Daily Intake [$mg.kg^{-1}.day^{-1}$]
SF Cancer Slope Factor [$mg.kg^{-2}.day^{-1}]^{-1}$

In the event of contaminant reception through a larger number of exposure pathways the total cancer risk can be calculated by adding up the risks resulting from all manners of exposure considered.

The following ELCR [3] values are regarded as an acceptable risk rate – depending on the size of the exposed population:

1×10^{-6} (cancer probability in 1 person per million) in the assessment of regional negative influences: usually over 100 persons at risk

1×10^{-5} (cancer probability in 1 person per 100,000) in the assessment of local negative influences: approximately between 10 and 100 persons at risk

1×10^{-4} (cancer probability in 1 person per 10,000) in the assessment of individual negative influences: up to 10 persons

For the purpose of this risk analysis, ELCR of 1×10^{-4} for all scenarios was chosen as an acceptable level of carcinogenic risk.

In the case of exposure by more contaminants, their individual contributions to non-carcinogenic risk are summed (synergistic effect) and then it is necessary to consider the summary quotient of risk or ELCR:

- $HQ_{total} = HQ_1 + HQ_2 + HQ_3 + ... + HQ_n$
- $ELCR_{total} = ELCR_1 + ELCR_2 + ELCR_3 + ... + ELCR_n$

In general, however, in the risk analysis, based on US EPA guidelines, it is preferable to overestimate the risk in a qualified way than to underestimate it. Such an approach ensures a more reliable definition of the potential hazard and a timely and relevant response if adequate remedial action is applied.

3.1 Exposure Assessment

The evaluation of exposure was conducted for the selected exposure scenarios. Within the principle of preliminary caution, the calculation of exposure doses in all cases was performed for the maximum and average ascertained concentration of PCB_S in surveyed media. The PCBs concentrations in the monitored matrices are combined with the exposure parameters characterizing the receptor of risks taken from US EPA (2011). The precautionary principle was applied in conservative choice of exposure parameters. In all cases, exposure of an adult male is assumed.

For the evaluation of the exposure, the status of the evaluated area without rehabilitation action is assumed.

In all the cases, total PCB content in the subject media was assumed. The analytical results indicated that the dioxin-like PCBs represented only up to 6% of the total PCB content.

In the case that human health risks are not related to the maximum concentration, the evaluation of risks for lower concentration are out of the question.

3.2 Human Health Risk Assessment

3.2.1 *Exposure of KAP´s employees working at contaminated site*

Employees of KAP are in contact with the contaminated surface soil and concrete in the PCB storage area and inside the former PCB storehouse (concrete and walls) through long-term inhalation of dust particles, dermal contact with soil/dust and accidental ingestion of soil and dust particles. A limited group up to 10 employees is considered for the risk evaluation. Their exposure can be characterized by the exposure parameters presented in the following table.

Table 9: Exposure parameters for employees of KAP

Exposure parameter	Symbol	Unit	Value
Average weight of the individual	BW	kg	70
Average length of life	LT	year	70
Frequency of exposure	EF	day/year	250
Frequency of exposure		hour/day	8
Duration of exposure	ED	year	25
Amount of accidentally consumed soil	IR	mg/day	50
Fraction ingested from the contaminated source	FI	-	0.75
Fraction of contaminant absorbed in gastro-intestinal tract	ABS_{GI}	-	1
Contaminant-specific dermal absorption factor	ABS_d	-	0.14
Exposed body surface	SA	cm^2	5700
Adhesion factor of the soil to the skin	AF	mg/cm^2	0.2
Volume of inhaled air – medium activity	IR_A	m^3/hours	2.5
Conversion factor (mg to kg)	CF	-	0.000001

Exposure of KAP's employees through unintentional ingestion of soil, inhalation of dust particles and dermal contact with soil, both outside and inside the former PCB storehouse can be expressed on the basis of the following equations.

Accidental ingestion of soil and dust

Exposure of workers due to unintentional ingestion of the contaminated soil and dust during the stay at the contaminated site can be quantified by the following equation:

$$CDI = \frac{Cs\ x\ IR\ x\ FI\ x\ EF\ x\ ED}{BW\ x\ AT}$$

where:

CDI chronic average daily intake ($mg.kg^{-1}.day^{-1}$)
C_S concentration of the contaminant in the surface soil [$mg.kg^{-1}$]
IR volume of soil consumed per day [$mg.day^{-1}$]
FI fraction ingested from the contaminated source
EF frequency of exposure [$day.year^{-1}$]
ED duration of exposure [year]
BW average body weight (kg)
AT time of averaging [day]
AT for non-carcinogenic effect: ED (year) x 365 $days.year^{-1}$, for carcinogenic effect: 70 years x 365 $days.year^{-1}$

The following tables present the results of calculations of non-carcinogenic (HQ) and carcinogenic risks (ELCR) for exposure scenarios No.2 and No.6, i.e. for unintentional ingestion of soil and dust particles contaminated by PCBs outside and inside the former PCB storehouse, respectively.

Table 10: Human health risks connected with exposure scenario No.2 - accidental ingestion of soil and dust outside the PCB storehouse

Scenario	Contami-nant	C_S	RfD_{oral}	SF_{oral}	CDI	LCDI	HQ	ELCR
		(mg/kg)	(mg/kg/d)	$(mg/kg/d)^{-1}$	(mg/kg/d)	(mg/kg/d)		
No. 2	$\sum PCB_{maximum}$	25593	2×10^{-5}	0.4	9.4×10^{-3}	3.4×10^{-3}	469.5	1.3×10^{-3}
	$\sum PCB_{average}$	1690			6.2×10^{-4}	2.1×10^{-4}	31.0	8.9×10^{-5}

Table 11: Human health risks connected with exposure scenario No.6 – accidental ingestion of soil and dust inside the PCB storehouse

Scenario	Contami-nant	C_S*	RfD_{oral}	SF_{oral}	CDI	LCDI	HQ	ELCR
		(mg/kg)	(mg/kg/d)	$(mg/kg/d)^{-1}$	(mg/kg/d)	(mg/kg/d)		
No. 6	$\sum PCB_{maximum}$	921	2×10^{-5}	0.4	4.5×10^{-4}	1.6×10^{-4}	22.5	6.4×10^{-5}
	$\sum PCB_{average}$	54			2.6×10^{-5}	9.4×10^{-6}	1.3	3.8×10^{-6}

* average concentration of total PCBs in dust from the walls and the floors of the storehouse

<u>Dermal contact with soil and dust</u>

The exposure due to dermal contact with the contaminated soil and dust during the stay at the site can be quantified by the following equation:

$$CDI = \frac{Cs \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}$$

where:

CDI chronic average daily intake ($mg.kg^{-1}.day^{-1}$)
C_S concentration of the contaminant in the surface soil [$mg.kg^{-1}$]
SA exposed surface of the skin [$cm^2.day^{-1}$]
AF adherence factor of soil [$mg.cm^{-2}$]
ABS dermal absorption factor of the contaminant (dimensionless)
EF frequency of exposure [$day.year^{-1}$]
ED duration of exposure [year]
BW average body weight (kg)
AT time of averaging [day]
AT for non-carcinogenic effect: ED (year) x 365 $days.year^{-1}$, for carcinogenic effect: 70 years x 365 $days.year^{-1}$

The following tables present the results of calculations of non-carcinogenic (HQ) and carcinogenic risks (ELCR) for exposure scenarios No. 1 and 5, i.e. for dermal contact with soil and dust particles contaminated by PCBs outside and inside the former PCB storehouse, respectively.

<u>Note</u>: RfD_{dermal} and SF_{dermal} corresponds to RfD_{oral} and SF_{oral}, because the coefficient ABS_{GI} = 1 for all contaminants.

Table 12: Human health risks connected with exposure scenario No.1 – dermal contact with soil and dust outside the PCB storehouse

Scenario	Contami-nant	C_S	RfD_{oral}	SF_{oral}	CDI	LCDI	HQ	ELCR
		(mg/kg)	(mg/kg/d)	$(mg/kg/d)^{-1}$	(mg/kg/d)	(mg/kg/d)		
No. 1	$\sum PCB_{maximum}$	25593	2×10^{-5}	0.4	4.0×10^{-2}	1.4×10^{-2}	1998.4	5.7×10^{-3}
	$\sum PCB_{average}$	1690			2.6×10^{-3}	9.4×10^{-4}	132	3.8×10^{-4}

Table 13: Human health risks connected with exposure scenario No.5 – dermal contact with soil and dust inside the PCB storehouse

Scenario	Contami-nant	C_S*	RfD_{oral}	SF_{oral}	CDI	LCDI	HQ	ELCR
		(mg/kg)	(mg/kg/d)	$(mg/kg/d)^{-1}$	(mg/kg/d)	(mg/kg/d)		
No. 5	$\sum PCB_{maximum}$	921	2×10^{-5}	0.4	1.4×10^{-5}	5.1×10^{-4}	71.9	2.1×10^{-4}
	$\sum PCB_{average}$	54			8.4×10^{-6}	3.0×10^{-5}	4.2	1.2×10^{-5}

* average concentration of total PCBs in dust from the walls and the floors of the storehouse

Inhalation of contaminated soil and dust particles

The exposure doses due to the inhalation of the contaminated soil and dust particles from an ambient air due wind blow-off and re-suspension of soil particles from the surface while occurring in the outdoor environment at the site can be derived using the following equation. The data on contamination of the indoor environment in the PCB storehouse are not available.

$$CDI = \frac{Ca \ x \ IRa \ x \ FI \ x \ EF \ x \ ED}{BW \ x \ AT}$$

where:

CDI	chronic average daily intake ($mg.kg^{-1}.day^{-1}$)
C_a	concentration of the contaminant in the air - outdoors [$mg.kg^{-1}$]
IR_a	inhaled volume of air [$m^3.hour^{-1}$]
EF	frequency of exposure outdoors [$hour.year^{-1}$]
ED	duration of exposure [year]
BW	average weight of the adult [kg]
AT	time of averaging [day]

AT for non-carcinogenic effect: ED (year) x 365 $days.year^{-1}$, for carcinogenic effect: 70 years x 365 $days.year^{-1}$

The following table present the results of calculations of non-carcinogenic (HQ) and carcinogenic risks (ELCR) for exposure scenario No. 3, i.e. for inhalation of soil and dust particles contaminated by PCBs outside the former PCB storehouse.

Note: Because of lack of data, the RfD and SF for oral exposure was used also for inhalation exposure.

Table 14: Human health risks connected with exposure scenario No.3 – inhalation of soil and dust particles outside the PCB storehouse

Scenario	Contami-nant	C_S*	RfD_{oral}	SF_{oral}	CDI	LCDI	HQ	ELCR
		(ng/m^{-3})	(mg/kg/d)	(mg/kg/d)$^{-1}$	(mg/kg/d)	(mg/kg/d)		
No. 3	∑$PCB_{maximum}$	620	2×10^{-5}	0.4	9.3×10^{-6}	3.3×10^{-6}	0.5	1.3×10^{-6}
	∑$PCB_{average}$	566			8.5×10^{-6}	3.1×10^{-6}	0.4	1.2×10^{-6}

3.2.2 Exposure of workers during earthwork or remedial work

The workers who will eventually conduct any earthwork – excavation (in terms of development of the area - foundations of future buildings) or any soil clean-up activities will get in direct and intensive contact with the contaminated soil and dust (trough inhalation of dust particles, dermal contact with soil/dust and accidental ingestion of soil and dust particles) at the PCB storage area. Such activities are considered temporary – up to 1 year and up to 30 days per year of a group up to 10 people. Because of the short-term exposure, the sub-chronic RfD for PBCs of 0.03 µg/kg determined by ATSDR was applied for non-carcinogenic risk estimation. Exposure of the workers can be characterized by the exposition parameters presented in the following. The purpose of the risk assessment in this case is primarily to assess the need for emergency measures to protect health when carrying out such work.

Table 15: Exposure parameters for workers performing earth/remedial work

Exposure parameter	Symbol	Unit	Value
Average weight of the individual	BW	kg	70
Average length of life	LT	year	70
Frequency of exposure	EF	day/year	30
Frequency of exposure		hour/day	8
Duration of exposure	ED	year	1
Amount of accidentally consumed soil	IR	mg/day	250
Fraction ingested from the contaminated source	FI	-	1
Fraction of contaminant absorbed in gastro-intestinal tract	ABS_{GI}	-	1
Contaminant-specific dermal absorption factor	ABS_d	-	0.14
Exposed area of the body	SA	cm^2	3300
Adhesion factor of the soil to the skin	AF	mg/cm^2	0.2
Volume of inhaled air – medium activity	IR_A	m^3/hours	4.8
Conversion factor (mg to kg)	CF	-	0.000001

Exposure of the workers through unintentional ingestion of soil and dermal contact with soil, i.e. with surface soil as well as soil in deeper layers under the surface outside the former PCB storehouse can be expressed on the basis of the same equations applied for exposure estimate of KAP's employees. An average concentration in soil from all three boreholes up to 23 m below ground was assumed for the calculation of an exposure dose.

The following tables present the results of calculations of non-carcinogenic (HQ) and carcinogenic risks (ELCR) for exposure scenarios No.9 and No.8, i.e. for unintentional ingestion of soil and dermal contact with soil during the remedial/excavation work, respectively.

Note: RfD_{dermal} and SF_{dermal} corresponds to RfD_{oral} and SF_{oral}, because the coefficient ABS_{GI} = 1.

Table 16: Human health risks connected with exposure scenario No.9 - unintentional ingestion of soil during remedial or excavation work

Scenario	Contami-nant	C_S	RfD_{oral}	SF_{oral}	CDI	LCDI	HQ	ELCR
		(mg/kg)	(mg/kg/d)	$(mg/kg/d)^{-1}$	(mg/kg/d)	(mg/kg/d)		
No. 9	$\sum PCB_{maximum}$	10868	3×10^{-5}	0.4	3.2×10^{-3}	4.6×10^{-5}	106.3	1.8×10^{-5}
	$\sum PCB_{average}$	258			7.6×10^{-5}	1.1×10^{-6}	2.5	4.3×10^{-7}

Table 17: Human health risks connected with exposure scenario No.8 – dermal contact with soil during remedial or excavation work

Scenario	Contami-nant	C_S	RfD_{oral}	SF_{oral}	CDI	LCDI	HQ	ELCR
		(mg/kg)	(mg/kg/d)	$(mg/kg/d)^{-1}$	(mg/kg/d)	(mg/kg/d)		
No. 8	$\sum PCB_{maximum}$	10868	3×10^{-5}	0.4	1.2×10^{-3}	1.7×10^{-5}	59.0	6.7×10^{-6}
	$\sum PCB_{average}$	258			2.8×10^{-5}	4.0×10^{-7}	1.4	1.6×10^{-7}

Concentration of the PCBs in the air C_A [$mg.m^{-3}$] was derived on the basis of average/maximum concentration of the contaminant in the soil C_S [mg.kg], and values of emission concentration of the respiratory fraction of dust particles P [$mg.m^{-3}$], which are considered at the level 2 mg/m^3, which represents lower limit for maximum concentration of dust in the working environment, as well as double of the maximum allowable concentrations for PCBs of 1 mg/m^3 according to Montenegrin standards "JUS.Z.BO.001" for work premises and work sites.

The exposure dose due to the inhalation of the contaminated soil and dust particles from air during the excavation or remedial works by the workers can be thus derived using the following equation:

$$CDI = \frac{Cs\ x\ P\ x\ CF\ x\ IRa\ x\ FI\ x\ EF\ x\ ED}{BW\ x\ AT}$$

where:

CDI	chronic average daily intake ($mg.kg^{-1}.day^{-1}$)
C_S	concentration of the contaminant in the soil [$mg.kg^{-1}$]
P	concentration of dust in air [$mg.m^{-3}$]
CF	conversion factor (mg - kg) 1.10^{-6}
IR_A	inhaled volume of air [$m^3.hour^{-1}$]
EF	frequency of exposure in the indoor environment [$hour.year^{-1}$]
ED	duration of exposure [year]
BW	average weight of the adult [kg]
AT*	time of averaging [day]

** for non-carcinogenic effect: ED (year) x 365 days.year^{-1}, for carcinogenic effect: 70 years x 365 days.year^{-1}*

The following table presents the results of calculations of non-carcinogenic (HQ) and carcinogenic risks (ELCR) for exposure scenario No. 10, i.e. for inhalation of soil particles contaminated by PCBs during the remedial/excavation work.

Note: Because of lack of data, the RfD and SF for oral exposure was used also for inhalation exposure.

Table 18: Human health risks connected with exposure scenario No.10 – inhalation of soil particles during remedial or excavation work

Scenario	**Contami-nant**	**C_S***	**RfD_{oral}**	**SF_{oral}**	**CDI**	**LCDI**	**HQ**	**ELCR**
		(ng/m^{-3})	(mg/kg/d)	(mg/kg/d)$^{-1}$	(mg/kg/d)	(mg/kg/d)		
No. 10	∑$PCB_{maximum}$	10868	3×10^{-5}	0.4	9.8×10^{-4}	1.4×10^{-5}	49.0	5.6×10^{-6}
	∑$PCB_{average}$	258			2.3×10^{-5}	3.3×10^{-7}	1.2	1.3×10^{-7}

3.3 Summary of Human Health Risks

The following tables summarise outcomes of the exposure assessment – carcinogenic and non-carcinogenic risks associated with exposure of KAP employees to the contaminated soil and dust present outdoors and indoors at the site, as well as exposure of workers performing remedial action at the site or excavation connected with eventual development of the site. The results distinguish between exposure to maximum and average level of contamination with PCBs. The obtained values of non-carcinogenic risk (HQ) and carcinogenic risk (ECLR) were compared with acceptable values of risk presented in the chapter 3, i.e. HQ ≤ 1 and ELCR ≤ 1.0×10^{-4} (for a group up to 10 individuals).

Table 19: Exposure to soil and dust outside the PCB storehouse to average concentration of PCBs

No. scenario	Exposed group	Exposure way	Non-cancer risk (HQ)	Cancer risk (ELCR)
2	KAP employees	Accidental ingestion of soil and dust	**31.0**	8.9×10^{-5}
1		Dermal contact with soil and dust	**132**	**3.8×10^{-4}**
3		Inhalation of soil and dust	0.4	1.2×10^{-6}
9	External workers (earthworks + remedial workers)	Ingestion of soil	**2.5**	4.3×10^{-7}
8		Dermal contact with soil	**59.0**	6.7×10^{-6}
10		Inhalation of soil particles	**49.0**	5.6×10^{-6}

Table 20: Exposure to soil and dust outside the PCB storehouse to maximum concentration of PCBs

No. scenario	Exposed group	Exposure way	Non-cancer risk (HQ)	Cancer risk (ELCR)
2	KAP employees	Ingestion of soil and dust	**469.5**	**1.3×10^{-3}**
1		Dermal contact with soil and dust	**1998.4**	**5.7×10^{-3}**
3		Inhalation of soil and dust	0.5	1.3×10^{-6}
9	External workers (earthworks + remedial workers)	Ingestion of soil	**106.3**	1.8×10^{-5}
8		Dermal contact with soil	**1.4**	1.6×10^{-7}
10		Inhalation of soil particles	**1.2**	1.3×10^{-7}

Based on the presented results it can be concluded that even the average level of contamination leads to unacceptable non-carcinogenic (systemic) and carcinogenic risks to the KAP employees who get into contact with the contaminated soil and dust present at the site on regular basis. The maximum concentration of PCBs leads to dramatic high non-carcinogenic risks and unacceptable carcinogenic risks. Based on these facts an urgent application of risk reduction measures is required. These measures are specified in the chapter 6.

Earthworks, i.e. remedial work or excavation work connected with the development of the site are also connected with high non-carcinogenic health risks to workers (if not equipped with appropriate PPEs) even at average levels of PCBs contamination in the soil of the unsaturated zone. These results confirm necessity of using protective equipment and secured regime of work during any excavation work or remedial work at the site.

Table 21: Exposure in the PCB storehouse to average concentration of total PCBs

No. scenario	Exposed group	Exposure way	Non-cancer risk (HQ)	Cancer risk (ELCR)
6	KAP employees	Ingestion of dust	**1.3**	3.8×10^{-6}
5		Dermal contact with dust	**4.2**	1.2×10^{-5}

Table 22: Exposure in the PCB storehouse to maximum concentration of total PCBs

No. scenario	Exposed group	Exposure way	Non-cancer risk (HQ)	Cancer risk (ELCR)
6	KAP employees	Ingestion of dust	**22.5**	6.4×10^{-5}
5		Dermal contact with dust	**71.9**	**2.1×10^{-4}**

Exposure to dust inside the former PCB storehouse results also in unacceptable non-carcinogenic risks. In case the maximum levels of concentration in dust present in the storehouse are assumed, the employees are also in dermal carcinogenic risk. These results confirm the necessity of using personal protective equipment when entering the building, as well as a secured regime of using the building until the contamination will be removed.

Exposure of employees through inhalation of dust inside the former PCB storehouse cannot be could not be quantitatively assessed, since the input concentrations of PCBs in air inside the former PCB storehouse were not available.

As was presented in the chapter 2.2, based on the results of the site survey (zero concentration of PCBs in groundwater in the monitored wells around the site), it can be concluded that, related to the potential exposure scenario No. 11, the local residents living around the former PCB storage area are (currently) not in risk from exposure to PCBs (related to the subject site) by usage of groundwater.

4 Ecological Risk Assessment

Based on the results of groundwater sampling analyses in the broader vicinity of the PCB storage area it is not possible to conclude a threat to the groundwater aquifer body and aquatic ecosystems. Therefore a realistic environmental exposure scenario was not identified, even though high levels of concentrations of PCBs in groundwater were still present in the wells around the PCB storage area in 1990s.

However, because of the very high toxicity of PCBs to aquatic life with long-lasting effects and the fact that the Zeta plain (including the area where KAP is located) is a sensitive area of the largest natural drinking water reservoir in Europe, the ecological risk cannot be completely excluded.

The subject site is fenced and terrestrial animals (especially cattle) do not have access to the site. However, due to limitations specified in chapter 5, an off-site wind transfer of contaminated soil and dust and its deposition on agricultural land located in the vicinity of the site, i.e. exposure scenario No. 4, cannot be excluded. However, since no input data for this scenario was available, it cannot be quantitatively assessed. Such contamination would lead to deterioration in soil quality and would cause threat to terrestrial food chains, incl. threats to human health through the consumption of agricultural products.

Based on these assumptions, and the uncertainty connected with potential spread of contamination from the site (i.e. scenarios No. 4 and 11), the risk analysis recommends preventive measures - to monitor PCBs concentrations in groundwater and analyse PCBs in agricultural soil surrounding the PCB storage area. The preventive measures are proposed in detail in the chapter 6.4 – Monitoring activities before and after implementation of remedial measures.

5 Limitation and Uncertainty

The evaluation of possible human health risks always relates to series of uncertainties that are derived, e.g. due to application the generally defined exposure parameters or the application of specific preconditions. Uncertainties to bring into the evaluation of risks are the method of quantitative evaluation of exposure, which includes certain simplifying preconditions, constants and empirical relations, which need not correspond to the relations of the site of interest and the actual behaviour of the risk receptors. The results of the evaluation of human health risks are restricted by the existing level of knowledge of methodology for the evaluation of the possible affection of monitored factors on human health.

The evaluation of human health risks is conducted within the submitted RA and is related mainly to the following restrictions and uncertainties:

- To ensure the safety and protection for more sensitive risk receptors during the evaluation of risks from the viewpoint of safety, conservative preconditions are introduced. Exposure parameters are defined on the side of the safety, due to which some results may be overvalued in relation to the actual status. During the evaluation of exposure, it is supposed that an individual faces contamination (in most cases, the maximum concentration of contaminants in the stated medium was considered) during the whole time of exposure. The exposure may also differ depending on the type, age, and sensitivity of the individual, etc.
- During selection of exposure parameters, in the case of uncertainty, higher values of parameters are taken into consideration that the risk analysis is on the side of caution (e.g. duration of exposure, volume of breathed air) is as objective as possible and, at the same time, aims to prevent any devaluation of risks resulting from the exposure of monitored substances.
- The evaluated exposure scenario and transport routes are models and cannot be fully applied to each individual. The submitted analysis cannot involve individual transport routes in the rate of the source of contamination → individual receptor.

- In view of these uncertainties, the highest observed concentrations of PCBs in contaminated soil have been used in the exposure assessment to reduce the likelihood of a potential underestimation of the real risk level.
- Cancer slope factors (SF) are generally derived by the use of a linearized multi-level model for the evaluation of the dose - effect relation irrespective of the mechanism of the origination of the tumour disease (US EPA 1989). This model generates the highest (i.e. conservative) values of SF compared with the other models. Most SF for priority contaminants are derived from information about the dose - effect relation from studies performed on animals. All these SF puts into the risk analysis a high level of conservatism. The extrapolation of results from tested animals on human beings may also be a source of errors due to various affecting mechanisms, target organs and the variability of the population. The values of recommended reference doses (RfD) are also derived on the side of caution.
- For PCBs specific reference doses are not known for reference concentrations for the inhalation manner of exposure. In the stated case, reference doses for oral intake were used.
- The RA focuses primary on the evaluation of PCBs and did not aim to assess risk from other identified contaminants at the site (heavy metals and PAHs). However, potential health and ecological risks connected with these pollutants are significantly lower comparing to PCBs.
- Certain level of uncertainty is connected with the fact that the soil and groundwater samples collected during the site investigation were not analysed for PCDD/PCDF, which usually accompany PCBs, as well as for Hexachlorobenzene, which was contained in piralen, which was accidentally spilled at the site. Also background samples, i.e. samples of agricultural soil around the site were not collected for analysis.
- At the former PCB storage area, no surface water of rainwater drainage system or water from the drainage storage pit was sampled and no information is available on the method of rainwater management at the site. It is therefore likely that the ecological risk from overflow of the drain pit into the environment outside the PCB storage area is high. As the surface of PCB storage area is contaminated as shown by the investigation performed, this is a potential risk that has not been verified by this risk analysis.
- As presented in the chapter 4, assessment of ecological risks is limited and is connected with high level of uncertainty. Therefore, preventive measures are recommended to verify potential impact of the site towards its surroundings and to monitor the quality of the groundwater.

Limitation of the results of the evaluation of risks by the above-mentioned type of uncertainties cannot, however, principally influence conclusions resulting from the risk assessment.

6 Recommendation of Remedial Measures

Investigation works and subsequent risk assessment analysis identified significant potential risks to human health. The surface layers of the PCB storage area (concrete and soil) as well as the unsaturated zone and the construction materials of the PCB storehouse are contaminated with polychlorinated biphenyls (PCBs). Contamination is exceeding the environmental limits described in the previous chapters and human non-carcinogenic and carcinogenic human health risks were verified for the KAPs´ employees and external workers working at the site.

In addition to human health risks, ecological risks have been confirmed and supported by the general high ecological hazard of PCBs resulting from their high toxicity, persistency and bioaccumulation potential and the fact that natural reduction of contamination level by natural attenuation processes is unrealistic for PCBs.

In order to eliminate verified human health risks to the local workers and potential future ecological risks, it is necessary to carry out the necessary remedial measures at the site, in order to reduce the identified risks to acceptable level.

Since the PCB storage area is situated in the industrial area of KAP aluminum plant, where the local workers could be at risk on a daily basis upon contact with the contaminated building structures and surface soil or concrete, the remedial measures must be divided into short-term (urgent) measures focused on immediate preventing the local workers from exposure to the contaminated material, and long-term remedial measures focused on permanent elimination of the human health risks caused by the contaminated materials.

The following chapters describe the proposed remedial measures, including the technical, time and financial scope of the measures. The final design of the measures must be described in detail in the realization project, which will be prepared by the implementer of the remedial measures before their commencement.

6.1 Short-term Remedial Measures

Short-term remedial measures are designed to immediately prevent contact of KAP local workers moving on site with contaminated materials. The aim of short-term remedial measures is to eliminate human health risks until long-term and permanent remedial measures are implemented including the design of the realization project and ensuring the financing of remedial measures.

In the short-term it is necessary to take the following remedial measures:

- It is necessary to inform the local workers about the potential risks connected with the contamination of PCB storage area. The information campaign should include training of workers on the possible risks reduction measures and usage of personal protective equipment (PPEs) to be use at the site and inside the former PCB storehouse.
- The entrance into the PCB storage area should be secured by a lockable gate with a warning sign informing about the health hazard.
- The entrance into the former PCB storehouse should be secured by a lockable door with a warning sign informing about the health hazard.
- Any entry into the PCB storage area and into the building may only be permitted with the following personal protective equipment (PPEs):
    - respirator
    - protective overall
    - protective footwear
    - protective gloves

6.2 Long-term Remedial Measures

In order to eliminate the human health risks arising from the long-term exposure of persons in the PCB storage area and inside the PCB storehouse it is necessary to carry out complete remediation of the PCB storage area including the PCB storehouse structures. The process of remedial work on the contaminated PCB storage area must be logical and timely coordinated to prevent the existing contamination from spreading to areas that are either not contaminated or less contaminated. Based on the knowledge regarding the extent of the contamination on the site the remedial measures can be summarised in the following sequential objectives:

1. **Remedial measures connected with contamination of the surface soil and unsaturated zone around the PCB storehouse**
   a. Two types of remediation limits were calculated for the surface soil and for the unsaturated zone (i.e. soil in deeper layers below the terrain).

   The remediation limit for the surface soil and depth up to 1 m below the terrain is based on the current and future usage of the area, where no construction activity or other change of land use is expected.

   By means of back-calculation and exposure parameters of the exposure scenario No. 1, the target remediation limit for the PCBs in the surface soil was determined as an acceptable residual contamination with no significant human health risks to personnel working in the PCB storage area. The target limit is based on the most risky scenario connected with the contaminated surface soil – dermal exposure of KAP employees to PCB contaminated surface soil and dust (i.e. exposure scenario No. 1).

$$Cs = \frac{HQ\ x\ RfD\ x\ BW\ x\ AT}{SA\ x\ AF\ x\ ABS\ x\ EF\ x\ ED} = 13\ mg/kg$$

   where:

HQ	hazard quotient (acceptable level = 1)
C_S	concentration of the contaminant in the surface soil [$mg.kg^{-1}$]
RfD	reference dose [$mg.kg^{-1}.day^{-1}$]
SA	exposed surface of the skin [$cm^2.day^{-1}$]
AF	adherence factor of soil [$mg.cm^{-2}$]
ABS	dermal absorption factor of the contaminant (dimensionless)
EF	frequency of exposure [$day.year^{-1}$]
ED	duration of exposure [year]
BW	average body weight (kg)
AT	time of averaging [day]

   AT for non-carcinogenic effect: ED (year) x 365 $days.year^{-1}$

   For deeper parts of the unsaturated zone bellow 1 m below the terrain the calculation is based on the theoretical possibility of excavation work and exposure of workers in the excavation pit.

   By means of back-calculation and use of exposure parameters of the exposure scenario No. 9, the target remediation limit for the PCBs in the unsaturated zone was determined as an acceptable contamination of soil with no significant human health risks to workers carrying out excavation work in the PCB storage area. The target limit is based on the most risky scenario connected with the contaminated soil in the unsaturated zone – accidental ingestion of soil by the workers (i.e. exposure scenario No. 9).

$$Cs = \frac{HQ\ x\ RfD\ x\ BW\ x\ AT}{IR\ x\ FI\ x\ EF\ x\ ED} = 100\ mg/kg$$

   where:

HQ	hazard quotient (acceptable level = 1)
C_S	concentration of the contaminant in the soil [$mg.kg^{-1}$]
IR	volume of soil consumed per day [$mg.day^{-1}$]
FI	fraction ingested from the contaminated source

EF frequency of exposure [$day.year^{-1}$]
ED duration of exposure [year]
BW average body weight (kg)
AT time of averaging [day]
AT for non-carcinogenic effect: ED (year) x 365 $days.year^{-1}$
The level of the remediation limit was determined also reflecting the fact that PCB contamination was not detected in the groundwater and there is currently no contamination spread outside the PCB storage area.

Remediation limits:

Depth 0 - 1 m below the terrain: C_s ∑ PCB: 13 mg/kg
Depth > 1 m below the terrain: C_s ∑ PCB: 100 mg/kg

b. The calculated remediation limits were exceeded in the following zones and depth levels according to the investigation performed:
0 – 1 m below the surface: zones 1 – 18 and zones 20 - 28
1 - 2 m below the surface: zones 21, 27
2 – 3 m below the surface: zone 27
3 – 4 m below the surface: zone 27
4 – 5 m below the surface: zone 27
5 – 6 m below the surface: zone 27

The amount of soil exceeding the level of the remediation limits can be then roughly estimated on the basis of the investigation performed at the amount of:

Depth 0 – 1 m	**1700 – 2300 m^3**
Depth > 1 m	**500 – 700 m^3**
Total volume	**2200 – 3000 m^3**

The actual amount must be verified by an updated sampling before starting the remedial measure.

Financial demands of remedial measures leading to risk elimination connected with contamination of surface soil around the former PCB storehouse and the unsaturated zone will vary according to the method of final disposal of contaminated soil. The table 23 below gives an outline of the options, financial cost and expected time demands. A detailed evaluation of the individual variants needs to be carried out in a feasibility study, which should evaluate all aspects of the individual variants, i.e. time, economic and technical feasibility. The feasibility study can also assess the combination of individual methods to optimize the resulting duration and cost.

Table 23: Financial demands of remedial measures based on the method of final disposal of contaminated soil

Option	Description of disposal method	Financial and time demands of remedial measures	Pros + / Cons -
1	Contaminated soil will be disposed of as hazardous waste in a hazardous waste incineration plant abroad	5 – 6 million € 10 – 18 months	+ Long-term and final solution - Highest cost - Transport over long distances
2	Contaminated soil will be disposed of in thermal desorption plant abroad	3 – 4 million € 10 – 18 months	+ Long-term and final solution - High cost - Transport over long distances
3	Contaminated soil will be disposed of in thermal desorption plant, which will be installed on-site	2 – 3 million € 12 – 24 months	+ Long-term and final solution + Transport elimination + Cost reduction + Soil remediation on-site + Use of clean soil for backfilling - Operating and legislative permit - Time demanding
4	Excavating the top surface layer to a depth of 0.3 m below the ground. Contaminated soil (approx. 800 - 900 m^3) will be disposed of in HW incineration plant/thermal desorption plant abroad. Underlying contaminated soil will be isolated by an insulating layer (e.g. HDPE foil) to prevent the washing of contamination by rainfall and its spreading into deeper layers of soil or into groundwater.	1 – 2 million € 9 – 15 months	+ Significant cost reduction - Limited lifetime - Rainwater management - Regular monitoring
5	Construction of a hazardous waste landfill near the PCB storage area or inside the KAP aluminum plant with the capacity up to 5000 m^3 and disposal of contaminated soil there.	0.5 - 1 million € 15 – 25 months	+ Significant cost reduction - Limited lifetime - Regular monitoring - Operating and legislative permit - Time demanding

Remark: The time demands of remedial measures do not include the permit procedure.

The following description of the remedial measures relates to the options 1, 2 and 3 (Table 23). These options are recommended because they represent a long-term and final solution comparing to the options 4 and 5, whose main disadvantage is limited lifetime and temporary solution.

c. Sampling of surface soils (Figure 3) at a depth of 0-0.2 m for the presence of PCB contamination must be performed prior to the commencement of remedial measures to eliminate human health risks. The exact location of the sampling points will be determined in the realization project prepared before the start of the remedial measures.

Figure 3: Area of remediation of surface soil and unsaturated zone

d. In places where the concentration of PCBs in soils exceeds the specified remediation limit, the soils will be selectively excavated to a depth of 1 m below the ground.

e. After removing the 0-1 m contaminated soil layer, the excavation bottom will be sampled and further excavation will be carried out to a depth of 3 m below the terrain in that places where the PCB concentration in the soil exceeds the specified remediation limit

f. After removing the 1-3 m contaminated soil layer, the excavation bottom will be sampled and further excavation will be carried out to a depth of 5 m below the terrain in that places where the PCB concentration in the soil exceeds the specified remediation limit.

g. At depths below 3 m below the terrain, geotechnical stability of slopes will be ensured by sheeting or suitable slope.

h. The excavation will be finished at a time when none of the collected soil samples exceeds the specified remediation limit.

i. The excavated contaminated soil will be deposited during the remedial work in a secured temporary landfill in order to prevent contaminant washing into the surrounding environment. The design of such a landfill will be solved by an implementation project. Upon completion of the remedial measures, contaminated soil will be disposed in a selected external facility for the disposal of contaminated soil or hazardous waste.

j. The excavated space in the area of remedial measures will be filled with clean inert soil.

k. The following personal protective equipment will be used by the workers during the implementation of the remedial measures: respirator, protective clothing covering the whole body, protective footwear and protective gloves.

l. During the remedial works, monitoring of working environment will be carried out at the PCB storage area. There will be 8-hour sampling of ambient air during the 8 h working day and continuous measurement of volatile organic compounds in the atmosphere by field analyzers once every 4 hours. Based on the results of the monitoring of working environment, the level of PPEs protection will be adjusted.

2. **Remedial measures connected with contamination of the concrete surface in front of the PCB storehouse**
   a. By means of back-calculation, the target remediation limit for the PCBs in the concrete surface was determined as a residual contamination with no significant human health risks to personnel working in the PCB storage area (see point 1 a). The target limit is based on the most risky scenario – dermal exposure of KAP employees to PCB contaminated concrete surface in front of the PCB storehouse.

   Remediation limit:

C_S ∑ PCB: 13 mg/kg

   b. In case of the concrete surface in front of the PCB storehouse the calculated remediation limit was exceeded in the following sampling points according to the investigation performed: 11, 12, 13, 14, 15, 16, 18, 21, 23, 24, 28, 29, 30
   The area of concrete surface exceeding the level of the remediation limit can be estimated on the basis of the investigation performed at the amount of **900 – 1300 m^2.** This is a rough estimate based on the sampling work performed at the PCB storage area where the exceeding PCB concentration of the concrete surface was detected. The actual amount must be verified by an updated sampling.
   c. Sampling of concrete surface at a depth of 0-0.2 cm (Figure 4) for the presence of PCB contamination must be performed prior to the commencement of remedial measures to eliminate human health risks. The exact location of the sampling points will be determined in the realization project prepared before the start of the remedial measures.

Figure 4: Area of remediation of the concrete surface in front of the PCB

   d. In places where the concentration of PCBs in concrete surface exceeds the specified remediation limit, the surface will be washed with pressurized water and detergent.
   e. The final sampling of the concrete surface must confirm PCB concentration under the risk level.
   f. If it is not possible to reduce the PCB contamination level on the concrete surface below the set risk level using pressurized water and detergent, the concrete surfaces where the PCB contamination risk is present above the limit must be removed and disposed of as hazardous waste in a selected external facility for the disposal of hazardous waste abroad.
   g. Within the implementation of remedial measures, any leakage of contaminated water into the surrounding environment must be prevented.

h. The local drainage system presented at the PCB storage area will be used to collect the contaminated water resulting from washing

i. The contaminated water resulting from washing must be analyzed in an accredited laboratory and according to the result it must be disposed of as hazardous waste according to legislation.

j. A suitable method is, for example, separation of sludge and water phase and subsequent filtration of contaminated water through activated carbon. The activated carbon is then disposed as solid hazardous waste. The exact procedure will be designed in the realization project.

k. The following personal protective equipment will be used by the workers during the implementation of the remedial measures: respirator, protective clothing covering the whole body, protective footwear and protective gloves.

l. During the remedial works, monitoring of working environment will be carried out at the PCB storage area. There will be 8-hour sampling of ambient air during the 8 h working day and continuous measurement of volatile organic compounds in the atmosphere by field analyzers once every 4 hours. Based on Montenegrin legislation (JUS.Z.BO.001) concerning maximum allowable concentration of harmful gases and vapours in the atmosphere of work premises and work sites, the maximum allowable concentrations for PCBs is 1 mg/m^3.

Duration of remedial measures leading to risk elimination connected with contamination of the concrete surface: **3 – 5 months**

Financial demands of remedial measures leading to risk elimination connected with contamination of the concrete surface: **100 – 200 thousand Euro**

3. **Remedial measures connected with contamination of the building structures of the PCB storehouse**

a. The remediation limit for the building structures was determined analogically as the limit for the surface soil (see point 1 a). By means of back-calculation of the scenario No. 5, the target remediation limit for the PCBs in the building structures of the PCB storehouse was determined as a residual contamination with no significant human health risks to personnel working in the PCB storehouse. The target limit is based on the most risky scenario – dermal exposure of KAP employees with PCB contaminated structures in the former PCB storehouse.

Remediation limit:

C_S ∑ PCB: 13 mg/kg

The area of building structures exceeding the level of the remediation limit can be estimated on the basis of the investigation performed at the amount of **300 – 400 m^2**. This is a rough estimate based on the sampling work performed at the PCB storehouse where the exceeding PCB concentration of the building structures (walls and concrete floors) was detected. The actual amount must be verified by an updated sampling.

b. Sampling of building structures - walls and concrete floors (Figure 5) for the presence of PCB contamination must be performed prior to the commencement of remedial measures to eliminate human health risks. The exact location of the sampling points will be determined in the realization project prepared before the start of the remedial measures.

Figure 5: Area of remediation of the building structures of the PCB storehouse

c. In places where the concentration of PCBs in building structures (walls and concrete floors) exceeds the specified remediation limit, the structures will be washed with pressurized water and detergent.

d. The final sampling of the building structures (walls and concrete floors) must confirm PCB concentration under the risk level.

e. The contaminated water resulting from washing must be disposed of as hazardous waste according to legislation. For collection of this water the local drainage system existing at the PCB storage area can be used.

f. If it is not possible to reduce the PCB contamination level in/on the building structures below the recommended remediation limit, the building structures where the PCB contamination risk is present should be removed and disposed of as hazardous waste in a suitable external facility for the disposal of hazardous waste abroad. Alternatively, contaminated surfaces (especially the concrete floor) might be covered by an impermeable cover layer to prevent direct contact with the surface of contaminated structures.

g. The following personal protective equipment will be used by the workers during the implementation of the remedial measures: respirator, protective clothing covering the whole body, protective footwear and protective gloves.

h. During the remedial works, monitoring of working environment will be carried out at the PCB storage area. There will be 8-hour sampling of ambient air during the 8 h working day and continuous measurement of volatile organic compounds in the atmosphere by field analyzers once every 4 hours.

Duration of remedial measures leading to risk elimination connected with contamination of the building structures: **3 – 5 months**

Financial demands of remedial measures leading to risk elimination connected with contamination of the building structures: **40 – 100 thousand Euro**

6.3 Possible risks associated with the implementation of remedial measures

The implementation of remedial measures involves a number of risks that must be taken into account and appropriately eliminated before starting the remedial measures. These risks include:

- Improper excavation of contaminated unsaturated zone and non-responsible handling the contaminated soil may cause spreading out the contamination and eventually uncontrolled washing out of PCBs into the surrounding environment.
- In case of dry and windy weather during the implementation of remedial measures, there is a risk of excessive dust particles transport out of the PCB storage area into the surrounding environment.
- During the transport of contaminated soil within or outside the PCB storage area, it must be ensured that contaminated particles do not spread through the air - therefore it is always necessary to ensure storage in UN packaging for the transport of hazardous waste, or to take other protective measures.

6.4 Monitoring activities before and after implementation of remedial measures

6.4.1 Groundwater monitoring

Investigation works performed in the vicinity of the PCB storage area did not show groundwater contamination by PCBs. However, PCB contamination has been detected in groundwater in the past. In addition, due to planned remedial measures at the site, contamination may be released during the excavation work and may be washed out into groundwater. It is therefore recommended to carry out monitoring program of groundwater in the following extent:

- Before commencement of remedial measures and 5 years after completion of remedial measures to monitor twice a year (dry and rainy period) the following monitoring wells: piezometers – P1, P7, P11, BA 01 and wells (Krstović Vukašin) Cijevna, (Savo Stijepović) Ljajkovići, (Đorđe Vulević) Cijevna, (Šefketi Faik) Cijevna, (Miljković Božo) and (Bezarević).
- Since PCBs contamination is usually accompanied with other POPs, the monitoring program should be focused not only on PCBs but also on PCDDs, PCDFs and Hexachlorobenzene. It is also recommended to monitor Total Petroleum Hydrocarbons (TPHs) as the parameter that is possible to detect in transformer oil.

If the results of the groundwater monitoring show the presence of hazardous substances such as POPs above the level of environmental indicators, it is necessary to update the risk analysis and propose additional remediation measures.

6.4.2 Soil monitoring

Due to the absence of sampling of agricultural land in the vicinity of the PCB storage area within the investigation performed, it is recommended to perform a one-time sampling of agricultural land in the vicinity of the PCB storage area for the presence of POPs. The quality of farmland significantly affects terrestrial food chains, including the quality of human health through the consumption of agricultural products. The scope of agricultural land analyzes is recommended as for groundwater: PCBs, PCDD, PCDF, Hexachlorobenzene and TPHs.

If the results of the additional sampling of agricultural land around the PCB storage area show the presence of hazardous substances such as POPs in the soil above the level of environmental indicators (i.e. Montenegrin max. concentration in agricultural soil for PCBs of 0.004 mg/kg), it is necessary to update the risk analysis, which will include a possible threat to the health of the population around the PCB storage area.

7 Conclusion

In 2019 the field investigation of the PCB storage area and the analytical evaluation of collected samples of ambient air, soil, groundwater and construction materials (walls and surface concrete) were carried out.

The evaluation of the investigation work can be summarized in the following points:

- PCB storage area contamination with PCB contamination exceeding both the Dutch intervention limit and recommended UNIDO limits for industrial areas has been confirmed. Contamination was confirmed at the surface of the site, both concrete surfaces and surface soils. In addition, contamination was confirmed in soils of the unsaturated zone to a depth of 9 m below the ground.
- PCB contamination was confirmed in the PCB storehouse in case of the concrete floor and on the walls of the building.
- PCB contamination was also confirmed in the ambient air, which was sampled in the PCB storage area.
- In groundwater sampled in the wider area of the PCB storage area, contamination has not been confirmed and contamination is not spreading outside the PCB storage area.

Based on the results of the investigation work, risk and exposure scenarios were proposed that are real on the PCB storage area. For these scenarios, health risks were calculated according to the US EPA methodology. The evaluation of risk analysis can be summarized as follows:

- Even the average level of contamination of surface soil at the former PCB storage area leads to unacceptable non-carcinogenic (systemic) and carcinogenic risks to the KAP employees who get on regular basis into contact with the contaminated soil and dust present at the site. Based on this an urgent application of risk reduction measures is required.
- Earthworks, i.e. remedial work or excavation work connected with the potential development of the site are also connected with high non-carcinogenic health risks to workers even at average levels of PCBs contamination in the soil of the unsaturated zone. These results confirm necessity of using protective equipment and secured regime of work during any excavation work or remedial work at the site.
- Exposure of KAP employees to dust on concrete floor and wall surface inside the former PCB storehouse results in unacceptable non-carcinogenic risks. In case the maximum levels of concentration in dust present in the storehouse are assumed, the employees are also in dermal carcinogenic risk. These results confirm the necessity of using personal protective equipment when entering the building, as well as a secured regime of using the building until the contamination will be removed.
- Based on the results of the site survey (zero concentration of PCBs in groundwater in the monitored wells around the site), it can be concluded that the local residents living around the former PCB storage area are (currently) not in risk from exposure to PCBs (related to the subject site) by usage of groundwater.

In order to eliminate proven current human health risks to the local employees, it is necessary to carry out the following remedial measures at the site, in order to reduce the identified risks to acceptable level:

- Short-term remedial measures should eliminate human health risks until long-term and permanent remedial measures are implemented. The short-term measures include an information campaign towards to the KAP employees and their training on the possible risks and usage of personal protective equipment (PPEs).
- Within the short-term remedial measures the PCB storage area should be secured by a lockable gate with a warning sign informing about the health hazard. Any entry into the PCB storage area and into the storehouse building may only be permitted with the suitable PPE’s.
- Long-term remedial measures should eliminate the human health risks arising from the long-term exposure of persons in the PCB storage area and inside the PCB storehouse. For this purpose the following target remediation limits of ∑PCB’s were calculated and remedial measure :

Contaminated surface soil and unsaturated zone around the PCB storehouse:

∑PCB 13 mg/kg - in case of soils 0 - 1 m below the terrain

∑PCB 100 mg/kg - in case of soils more than 1 m below the terrain

- **Option 1:** Disposal as hazardous waste in a hazardous waste incineration plant abroad

  Estimated financial demands: **5 – 6 million Euro**

  Expected duration: **10 – 18 months**

- **Option 2:** Disposal as contaminated soil in thermal desorption plant abroad

  Estimated financial demands: **3 - 4 million Euro**

  Expected duration: **10 – 18 months**

- **Option 3:** Disposal as contaminated soil in thermal desorption plant on-site

  Estimated financial demands: **2 - 3 million Euro**

  Expected duration: **12 – 24 months**

- **Option 4:** Disposal the top surface layer in thermal desorption plant abroad and installing an insulating layer to prevent the washing of contaminated subsoil by rainfall and spreading of pollution into deeper layers of soil or into groundwater.

  Estimated financial demands: **1 – 2 million Euro**

  Expected duration: **9 – 15 months**

- **Option 5:** Construction of a hazardous waste landfill near the former PCB storage area and storage of contaminated soil at this landfill.

  Estimated financial demands: **0.5 – 1 million Euro**

  Expected duration: **15 – 25 months**

The remedial options 1, 2 or 3 are recommended because they represent a long-term and final solution comparing to the options 4 and 5, whose main disadvantage is limited lifetime and temporary solution.

Contaminated concrete surface in front of the PCB storehouse: **∑PCB 13 mg/kg**

- Washing of contaminated concrete surface with pressurized water and detergent. The contaminated water must be disposed of as hazardous waste. If the remediation limit is not

confirmed, contaminated concrete must be disposed as hazardous waste in a selected external facility for the disposal of hazardous waste abroad. • Expected duration: **3 – 5 months**, • Estimated financial demands: **100 – 200 thousand Euro**
Contaminated building structures of the PCB storehouse: **∑PCB 13 mg/kg** • Washing of building structures (walls and concrete floors) with pressurized water and detergent. The contaminated water must be disposed of as hazardous waste or treated accordingly. If the remediation limit is not confirmed, contaminated building structures must be removed and disposed as hazardous waste in a selected external facility for the disposal of hazardous waste abroad. Alternatively, the building can be further used under the secured regime described in the chapter on short-term remedial measures. • Expected duration: **3 – 5 months** • Estimated financial demands: **40 – 100 thousand Euro**

Before commencement of the remedial measures, a realization project must be designed which will propose detailed technical and time procedures for remedial measures including the actual financial costs.

Upon completion of the remedial measures and after the final sampling, it is recommended to carry out an updated risk analysis to confirm the successful realization of the remedial measures.

Bibliography

1. https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables (May 2019)
2. http://rais.ornl.gov
3. https://www.epa.gov/risk/risk-assessment-guidelines
4. CETI (2019): Report of analyses of soil, concrete, underground water, air and wipe test of walls in area of KAP temporary PCB storage, Podgorica, November, 2019.
5. http://esdat.net/Environmental%20Standards/Dutch/ENGELSE%20versie%20circulaire%20Bodemsanering%202009.pdf
6. Exposure Factors Handbook, US EPA 2011
7. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment), Final, Office of Superfund Remediation and Technology Innovation US EPA, 2004
8. http://www.blue-growth.org/Plastics_Waste_Toxins_Pollution/PCBs_Poly_Chlorinated_Biphenyls.htm