VOPAK-EXPERO3 - LIFE09/ENV/B/000407

Final Report - Annex 7267

Report on the validation of the technique using a multi criteria analysis

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List of abbreviations

11-DCA	1.1-dichloroethane
111-TCA	1.1.1-trichloroethane
BATNEEC	Best Available Technology not entailing excessive costs
BOD	Biological oxygen demand
BTEX	Benzene, toluene, ethylbenzene, xylene
CATOX	Catalytic oxidation
CAH	Chlorinated aliphatic hydrocarbons
COD	Chemical oxygen demand
DOC	Dissolved organic carbon
vGAC	Granular Activated Carbon for vapour phase
wGAC	Granular Activated Carbon for water phase
EC	European Commission
EX	Explosion sensitive
H&S	Health and safety
ISCO	In situ chemical oxidation
LEL	Lower explosion limit
MCA	Multi-criteria analyses
MPE	Multi phase extraction
NAPL	Non aqueous phase liquid
mbgl	Meter below ground level
OVAM	Openbare Vlaamse Afvalstoffenmaatschappij (Public Waste Agency)
PID	Photo ionisation detector
P&T	Pump and treat
RAP	Remedial Action Plan
SVE/BLE	Soil vapour extraction
TOC	Total organic carbon
TPH	Total petroleum hydrocarbons
VOC	Volatile organic chlorocompounds

1 INTRODUCTION

This report discusses the validation of the ISCO remediation strategy using a multi-criteria analysis. The multi-criteria analysis used in this report is based upon the code of good practice “BATNEEC evaluation for soil remediation projects using CO_2 calculator” (OVAM, April 2013). This multi criteria analysis takes into account climate change and sustainability (energy and material consumption).

Following criteria and remedial strategies are discussed in the next paragraphs:

Criteria

- Environmental criteria: clean–up targets, mass removal, emission, and time/policy, consumption raw materials and production non recycle waste
- Technical and safety criteria: obstacles and nuisance during remediation, limits of site use, damage due to remediation, safety measures
- Financial criteria: remediation cost and (negative) value of the remaining contamination

For each criterion and for each remediation strategy, a value between 1 and 13 (when comparing 3 strategies) is given. The sum of the assigned values for each criterion always needs to be 15. The higher the assigned value, the better the score of the remediation strategy.

Remedial strategies

1. Excavation after a period of P&T contaminant control;
2. Source excavation in combination with in-situ chemical oxidation (ISCO) using perozone;
3. Source excavation in combination with multi-phase extraction (MPE).

Applying remedial strategies 1 and 3, extracted contaminants are transferred to the vapour phase and treated using a catox since the vGAC treatment is not economic feasible. In remedial strategy 2, a minimum of contaminants is transferred to the soil vapour phase using an optimised perozone injection scheme. The vGAC treatment of remedial strategy under these conditions is economic feasible and applied in the MCA of next paragraphs.

The technical and economic feasibility and the benefits of these remedial strategies are discussed in annex 7265 and annex 7266 of the final report. Please refer to these documents for more details used in the next paragraphs.

The MCA is carried out separately for the remediation of plume zone areas and for the remediation of plume and source zone areas. Due to the differences in remediation time, remediation cost, consumption of energy and materials (carbon foot print) and waste production, criteria scores for these approaches are different.

2 ENVIRONMENTAL CRITERIA

2.1 Local

Clean- up targets for soil and groundwater

Clean-up targets for both remedial strategy 2 and 3 are risk based in order to prevent the migration of contaminants. The clean-up targets have been defined in the remedial action plan as 10 x soil remediation value (SRV). Clean-up targets of the remedial strategy 1 are equal to 80% of the remediation value.

The assigned value is inversely proportional to the clean-up value as indicated in the table below.

Remedial strategy	Clean-up target	Assigned value
1	0.8 * SRV	6
2	10 * SRV	4.5
3	10 * SRV	4.5
		15

Contaminant mass removal

The assigned value is proportionally to the mass reduction as indicated to the table below.

Remediation strategy	Clean-up target	Remaining contaminant mass (ton)	Mass reduction (%)	Assigned value
1	SRV	1	99	5,4
2	10*SRV	14	88	4,8
3	10*SRV	14	88	4,8
initial contaminant mass		121		15

Immediate emission

The assigned value is proportionally to the emitted contaminant mass as indicated in the table below.

Remedial Strategy	extracted OC (ton)		emitted OC (ton)	Assigned value
1	13	90% catox efficiency	1,3	6,7
2	3	captured by SVE/vGAC*	0	7,5
3	107	90% catox efficiency	10,7	0,8
OC: organic compounds; *under optimised injection regime				15

Remediation time and policy

The assigned value is inversely proportional to the remediation time. The policy requires to distinguish remediation times less than 2 years, between 2 and 5 years and more than 5 years.

Remediating only plume zone areas, the remediation time is less than 4 years for both MPE and ISCO using perozone. The latter can (was) effectively be executed in less than 4 years. For the excavation after P&T, active hydraulic containment measures using P&T remains in function until the end of the industrial activities.

Remediating the source and plume zone areas, the remediation time based o will be more than 30 years for remedial strategy 1. For ISCO using perozone, the remediation duration on actual information would be between minimum 12 and 17 years (see annex 6265 – report on feasibility – page 8) or an average of 15 years. For MPE, the remediation time is estimated at 8 years.

Remedial strategy	Remediation of plume zone areas		Remediation of source and plume zone areas	
	Time (year)	Assigned value	Time (year)	Assigned value
1	30	1,6	30	3.3
2	4	6,7	15	5.4
3	4	6,7	8	6.4
		15		15

2.2 Regional

Consumption of raw materials

Raw materials are fuel, electricity and materials (such as HDPE/PVC conducts..) etc. The consumption generates CO_2 which is emitted to the atmosphere. The CO2 emission is calculated using the CO_2-calculated of the code of good practice on BATNEEC evaluation for soil remediation project (OVAM, April 2013). The CO_2 calculator is available through the OVAM website www.ovam.be. The calculated results are available in the report on the benefits of remediation strategies (annex 7256 of the final report.

The assigned value is inversely proportional to the CO_2 emission which depends upon the estimated remediation time.

	Remediation of plume zone area only			Remediation of migration & source zone		
Remedial strategy	Remediation time (year)	CO_2 emis-sion (ton)	Assigned value	Remediation time	CO_2 emis-sion (ton)	Assigned value
1	30	1160	2.7	30	1160	4.3
2	4	334	6.1	15	1006	4.7
3	4	313	6.2	8	530	6.0
			15			15

Production of waste

Waste is a product which cannot be recycled. Treated soil and removed concrete are recycled and not considered as waste. We consider the wGAC in P&T and MPE systems (contaminants are stripped out of the groundwater) and the vGAC in the ISCO using perozone system (treating the soil vapour extraction flow) as waste.

The assigned value is inversely proportional to GAC waste, which depends upon the estimated remediation time.

	Remediation of plume zone area only			Remediation of migration & source zone		
Remedial strategy	Remediation time (year)	GAC (ton)	Assigned value	Remediation time	GAC (ton)	Assigned value
1	30	442	1,9	30	442	3,0
2	4	0,1	7,5	15	0.3	7,5
3	4	147	5,6	8	294	4,5
			15			15

3 TECHNICAL AND SAFETY CRITERIA

Obstacles and nuisance during remediation

During the installation phase, nuisance is related to transport activities, noise and vibration. Excavation on the other hand will generate dust, noise, vibration, and transport activities. It is assumed that contaminated soil from excavation will be transported by barge, thus minimising transport by road to mobilisation of equipment.

During the operational phase, ozone and hydrogen peroxide of the ISCO treatment could create dangerous situations for the environment.

The assigned values are shown in the table below.

Phase	Installation/excavation	Operational	Assigned value
Remedial strategy	Obstacles and nuisance	Dangerous products	
1	Dust, transport, noise and vibration	Contaminants	5.5
2	transport, noise and vibration	Contaminants H_20_2, O_3	4
3	transport, noise and vibration	Contaminants	5.5

Limit of site use

Contrary to MPE and ISCO using perozone, there are no limits on the site use after full scale excavation. MPE and ISCO remediation strategies are risk based and in function of the current industrial site use. The future use is restricted to industrial activities. The assigned values are indicated in the table below.

Remedial strategy	Limit on site use	Assigned value
1	No	6
2	Industrial	4.5
3	industrial	4,5

Damage because of remediation

Full scale excavation requires the demolition, the decommissioning, dismantling and disposal of the industrial infrastructure in place. These works can only be carried out on condition that industrial activities are stopped.

MPE and ISCO using perozone can be carried out when industrial activities are still on-going. However, concrete covers have to removed and renewed for the source excavation and installation works.

The assigned values are indicated in the table below.

Remedial strategy	Damage	Assigned value
1	Demolition, dismantling, decommissioning Disposal	3
2	Concrete cover removal and renewal	6
3	Concrete cover removal and renewal	6

Safety measures during remediation

ISCO using perozone requires safety measures during remediation since facility is Ex-rated. These safety measures are described in detail the health and safety plan (annex 7244 of the final report). The main reason is that oxidants such as ozone and hydrogen peroxide can create explosive reactions with hydrocarbons and other chemicals once released to the environment. The safety measures include the fortnightly control of different environmental compartments (subsurface, sewage, atmosphere etc.)

The safety measures related to MPE and/or excavation techniques concerns the control of quality of the environment due to human exposure and due to the exceedance of LEL. The risk for explosive reactions is far less if no oxidants are stored at the chemical facility.

The assigned values are indicated in the table below.

Remedial strategy	Safety measures	Assigned value
1	Moderate	6
2	Intensive	3
3	Moderate	6

4 FINANCIAL CRITERIA

Remediation cost

We are referring to the report on the technical and economic feasibility (annex 7265 of the final report). The assigned value is inversely proportional to the remediation cost as indicated the table below.

	Remediation of plume zone area only			Remediation of migration & source zones		
Remedial strategy	Remediation time (year)	Cost (million euro)	Assigned value	Remediation time	Cost (million euro)	Assigned value
1	30	3,2	3,1	30	3,2	4.3
2	4	0,9	6,2	15	2.4	5.1
3	4	1,3	5,7	8	1,9	5.6
			15			15

Value of remaining contaminated soil

The basic assumption is that the soil has been remediated respecting the clean-up targets as defined within each of the strategies. However, reaching these clean-up targets does not mean that the remaining soil is clean enough to be freely used outside the site.

The remaining soil with a contamination level below the clean-up targets but above the threshold levels for free use of soil represent a negative value. If this soil would be excavated afterwards because of infrastructural or other works, then the excavated soil needs to be treated in a soil treatment centre.

For the calculation of this value, the upper soil layer gets a weight of 2 (because more frequently excavated). The deeper soil gets a weight of 0.5. The assigned value is inversely proportional to the weighted volume as shown in the table below.

Remedial strategy	Volume (m^3) upper 2 m	Volume (m^3) deeper than 2-bgl	Weighted volume (m^3)	Assigned Value
Weight factor	2	0.5		
1	2000	0	4000	6,85
2	9000	750	21250	4,07
3	9000	750	21250	4,07
			24750	15

5 SUMMARY AND CONCLUSION

The detailed results of the MCA analysis are included in annex 2.

The treatment of the plume zone areas by ISCO using perozone is considered as the most appropriate remediation strategy. The main reason is the absence of direct emissions and the low quantity of produced waste. This remediation strategy is successful at the VOPAK site: former drum storage area and parts of the central road.

However, if applied in source zone areas, the ISCO remediation strategy will ~~take~~ last longer due to the low ozone injection rate as a result of safety restrictions. In source zone areas, the remediation could take minimum 12-17years, depending on the amount of contaminant mass. The latter should be evaluated on the basis of soil samples analyses.

Due to this long remediation time, the remediation cost and the carbon foot print (use of energy and materials) are higher resulting in the lowest total score (compared to MPE extraction of 8 years). Therefore, we don't advise to continue with this remediation strategy in the source zone areas.

Remediating the sources zone areas needs a more powerful contaminant removal remediation strategy. We suggest implementing the multi-phase extraction system as long as the removal rate is significant higher than the removal rate of ISCO using perozone, actually estimated at 33 g/hr. Most likely, the extracted vapour should be treated using catalytic oxidation since mass load would be high. The GAC vapour treatment technique is economic not feasible when confronted with high vapour mass output. However, it is advised to evaluate the feasibility of GAC treatment at lower vapour concentrations levels if ISCO using perozone still remains less effective.

ANNEX

ANNEX 1
OZON PRODUCTION AND ENERGY

Energy consumption of the ozone generator during the life project

Start	Stop	installation	Ozone production (hour)	Ozone production (kg)	Energy (kWh)	Hydrogen peroxide (kg)	O_3/ H_2O_2 ratio
18-june-2014	27-january-2015	1 ozone generator	3033	139	18198	8.370	16
27-march-2013	27-january-2015	2 ozone generators Incl oxymat*	8067	1410	112938		
27-january-2015	5-june-2017	1 ozone generator Incl oxymat *	9440	630	103840	25.081	4
Total during 4.2 year				2.179	234976	33.451	
*for oxygen production; at 50% of capacity related to stripping effect							

ANNEX 2
RESULTS OF MULTI-CRITERIA ANALYSIS

Remediation at the plume zone area

	Remedial strategy 1	Excavation after P&T control			
	Remedial strategy 2	ISCO using perozone and source excavation			
	Remedial strategy 3	MPE with catox and source excavation			
	Criteria	Weigth	Score	Score	Score
			Remedial strategy 1	Remedial strategy 2	Remedial strategy 3
	Environmental				
	Local				
1	Level clean-up target - soil	6,6	6	4,5	4,5
2	Level clean-up target - soil	6,6	6	4,5	4,5
3	Total contaminant mass removal	6,6	5,4	4,8	4,8
4	Immediate emission to other environmental cor	6,6	6,7	7,5	0,8
5	Duration and policy	6,6	1,6	6,7	6,7
	XM (higher if actual risc increases)	33			
	Subtotal		169,3	184,9	140,7
	Regional/global				
6	Consumption of raw materials	8,0	2,7	6,1	6,2
7	Production non recycle waste during remediati	4	1,9	7,5	5,6
	XM (higher if actual risc increases)	12			
	Subtotal		29,0	78,9	72,1
	Technical and safety				
8	Obstacles and nuissance during remediation	5,5	5,5	4	5,5
9	Limit of site use	5,5	6	4,5	4,5
10	Damage because of remediation	5,5	3	6	6
11	Safety measures during remediation	5,5	6	3	6
	XT (higher in function of safety/environmental risc)	22			
	Subtotal		112,8	96,3	121,0
	Financial				
12	Remediation cost	22	3,1	6,2	5,7
13	Value of remaining contaminated soil	11	6,85	4,1	4,1
	XF (lower if actuals risc increases)	33			
	Subtotal		143,8	181,2	170,1
	Total	100	**454,8**	**541,3**	**503,9**

Remediation at the contaminant migration and source zones

Remedial strategy 1	Excavation after P&T control			
Remedial strategy 2	ISCO using perozone and source excavation			
Remedial strategy 3	MPE with catox and source excavation			
Criteria	Weigth	Score Remedial strategy 1	Score Remedial strategy 2	Score Remedial strategy 3
Environmental				
Local				
Level clean-up target - soil	6,6	6	4,5	4,5
Level clean-up target - groundwater	6,6	6	4,5	4,5
Total contaminant mass removal	6,6	5,4	4,8	4,8
Immediate emission to other environmental cor	6,6	4,0	7,5	3,5
Duration and policy	6,6	3,3	5,4	6,4
XM (higher if actual risc increases)	33			
Subtotal		162,7	176,1	156,2
Regional/global				
Consumption of raw materials	8,0	4,3	4,7	6,0
Production non recycle waste during remediatio	4	3,0	7,5	4,5
XM (higher if actual risc increases)	12			
Subtotal		46,2	67,6	66,2
Technical and safety				
Obstacles and nuissance during remediation	5,5	5,5	4	5,5
Limit of site use	5,5	6	4,5	4,5
Damage because of remediation	5,5	3	6	6
Safety measures during remediation	5,5	6	3	6
XT (higher in function of safety/environmental risc)	22			
Subtotal		112,8	96,3	121,0
Financial				
Remediation cost	22	4,3	5,1	5,6
Value of remaining contaminated soil	11	6	4,5	4,5
XF (lower if actuals risc increases)	33			
Subtotal		161,0	161,7	172,3
Total	100	**482,6**	**501,7**	**515,7**