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Shell Sola Refinery Decommissioning

Practical use of risk based remediation targets for hydrocarbon fractions according to the hazard index principle

NORDROCS 2006
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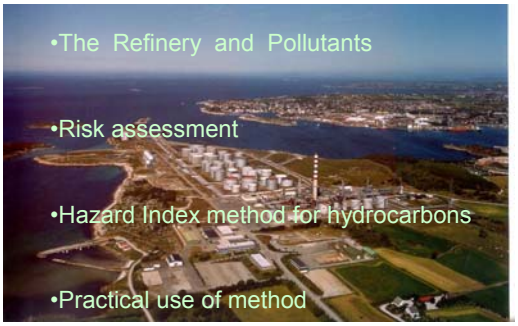
Shell Sola Refinery

- Former refinery near Stavanger, south-western Norway
- Closed down April 2000 after 32 yrs of operation
- Standard small refinery with a capacity to process 2.6 mill tonnes of crude oil per year
- Storage facilities for 200,000 tonnes of crude oil in one conventional aboveground tank and four underground rock caverns
- Tank storage for 220,000 tonnes of products
- Investigations, assessments and regulatory processes from August 1999 to January 2002
- Ground remediation completed in 3 yrs, January 2005

Shell Sola Refinery



Geology, soils and groundwater

The ground is bedrock, blasted rock fill and local sand, silt and clay.

The process area, most tank farms, pipelines, and sludge / waste handling areas are situated on native soil and fill in a depression between rock ridges

Groundwater level is 1-2 m below grade in the process area and tank farms.

The groundwater gradient falls towards the sea from a divide near the process area

Soil Contamination

- **Oil products** Soil in process-, storage- and transport areas impacted to below the groundwater level. Some bedrock also impacted
- Great variations in the hydrocarbon composition across the site
- **Metals** in tank farms and waste fill area with catalyst and sludge As, Cr, Cu, Pb, Zn, Co
- **TEL** OCTEL area

Groundwater Contamination

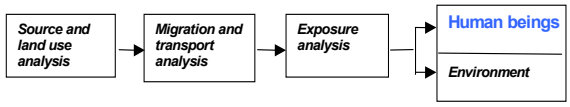
- **TPH** from 1 to 100 mg/l, partly with free product. Some phenols
- **MTBE** Groundwater, one tank locality
- **Metals** Groundwater only slightly impacted, except for Co in waste fill area
- No contaminant migration of environmental concern to the sea. Proven by marine studies

Soil Remediation

- Remediation completed in 3 years, January 2005
- 1.2 mill tons of soil excavated and classified
- 460 000 tons needed treatment, carried out on site by:
  - Biopiles, composting
  - Soil washing
  - Thermal treatment
- Excavation and off site disposal of waste fill site
- Groundwater treatment, free phase removal

Risk assessment

- Based on the guidelines of the Norwegian Pollution Control Authority (SFT)



- Human health risk found to be the controlling factor
- Additional criteria to cater for terrestrial ecology
- Developed through comparative ecotoxicological testing of contaminated, treated and uncontaminated soils

Future land use Environmental targets

- Site sold before remediation on the condition that the entire site should be made suitable for industrial and recreational development by the new owners
- Main environmental targets
  - There shall be no unacceptable risk to human health or the environment from contaminated ground
  - There shall be no unacceptable migration of contaminants hazardous to human health or the environment
  - There shall be no adverse effect on the marine environment beyond that of the established background level
  - There shall be no unacceptable odour from the ground

Risk assessment human health, oil products

- The SFT guidelines considers:
  - **BTEX components**
  - **Six fractionated groups of aliphatic hydrocarbons**
- Fractions and assigned toxic properties are as identified by the Total Petroleum Hydrocarbon Working Group (TPHCWG)
- SFT requested development of additional acceptance criteria for aromatic fractions > BTEX
  - **Six additional fractionated groups of aromatic hydrocarbons in accordance with the TPHCWG**

Risk assessment human health oil products 2

- Human health based acceptable risk criteria were finally given for:
  - **Accute toxicity, 10 hydrocarbon fractions**
  - **Cancerous properties, benzene and PAH**
- Both the toxicity and cancerous criteria must be satisfied

Risk based soil remediation targets, SSTLs

Chemical	SFT Norm Most sensitive land use	Industry		Recreation	Combined Industry and Recreation
		Open surfaces	Paved / built surfaces		
PAH total	2	11	2868	18	11
Benzo(a)pyren	0.1	0.67	179	1.1	0.67
Benzene	0.005	312	0.05[4]	474	0.05[4]
Toluene	0.5	> 10 000	1.4	> 10 000	1.4
Ethylbenzene	0.5	> 10 000	1.8	> 10 000	1.8
Xylene	0.5	> 10 000	2.7	> 10 000	2.7
Aromatics >C07-C08	None	> 10 000	15	> 10 000	15
Aromatics >C08-C10	None	8 400	20	2 600	20
Aromatics >C10-C12	None	8 400	110	2 600	110
Aromatics >C12-C16	None	8 400	570	2 600	570
Aromatics >C16-C21	None	6 300	4 400	2 000	2000
Aromatics >C21-C35	None	6 300	> 10 000	2 000	2000
Aliphatics > C5-C10	7	> 10 000	24	> 10 000	24
Aliphatics >C10-C12	30	> 10 000	117	> 10 000	117
Aliphatics >C12-C16	100[3]	> 10 000	561	> 10 000	561
Aliphatics >C16–C35		> 10 000	> 10 000	> 10 000	> 10 000

What the SFT Guidelines don't tell you

- Each SSTL is calculated under the assumption that no other hydrocarbon fractions are present
- Real life soil is contaminated by mixtures of several hydrocarbon fractions. Both the number of fraction groups and relative quantity present will vary throughout the soil
- The mass fractions of the mixture then have to be considered to determine the accept criterion for the mixture
- **Each soil sample will then have its own and unique accept criterion**, for the Sola site varying from < 100 to >> 2 500 mg/kg dry matter

Hazard Index = HI (= Toxic Units principle)

The total petroleum hydrocarbon accept criterion $SSTL_{TPH}$ defined by the TPHCWG method is: **$SSTL_{TPH} = C_{tot} / HI$**

C_{tot} = total concentration of all fractions

HI = Hazard Index = $\sum_{i=1}^{n} HQ_i = \sum_{i=1}^{n} Min\left[\left(\frac{c_i}{SSTL_i}\right);\left(\frac{C_{sati}}{SSTL_i}\right)\right]$

HQ = Hazard Quotient, for each TPH fraction

c_i = concentration of fraction "i"

$SSTL_i$ = the site specific target level for fraction "i"

C_{sati} = upper-bound value, the saturation concentration for the TPH fraction "i" at which absorptive limits of soil particles, solubility limits of soil pore water, and saturation limits of soil pore air are reached.

For soil to be acceptable HI < 1

C_{sat}

- For most petroleum hydrocarbons, C_{sat} is much lower than the concentration at which mobile free product or separate phase would be present.
- Site specific C_{sat} values

TPH fraction	C_{sat} aliphatics mg/kg	C_{sat} aromatics mg/kg
>C6-C10	129	1237
>C10-C12	77	565
>C12-C16	34	262
>C16-C35	23	92

Practical use of the HI principle

- Simplified assessment based on four hydrocarbon fractions seemed to be sufficiently accurate
- HI calculation based on a combination of parameters for aliphatic and aromatic components:

TPH fraction	SSTL mg/kg aliphatic fraction values	C_{sat} mg/kg aromatic values
>C6-C10	24	1237
>C10-C12	117	565
>C12-C16	561	262
>C16-C35	5000 (imposed by SFT)	92

Site procedures

- Chemical analysis of every 100 m^3 excavated soil < 50 mm
- Chemical analysis of every 100 m^3 treated soil
- Analytical program
  - Four THC fractions
  - PAH, if indicated by THC analysis
  - BTEX
- PC program flagged any sample with HI > 1
- Just as easy to manage as normal, fixed hydrocarbon criteria

Verification testing

- Some (24) verification tests with four aromatic and four aliphatic fractions analysis (HI-8)
- Mostly on soils with HI near 1
- Results:
  - HI-4 higher than HI-8 in 63 % of the samples
  - HI-4 disapproved soil acceptable by HI-8 method in 2 cases
  - HI-4 approved soil rejected (marginally) by HI-8 method in one case
  - That sample was untypical for the site, due to 30% content of heavy aromatics

Lessons learned

- The fractionated hydrocarbon criteria gave a more accurate evaluation of the remediation needs than the standard Norwegian risk based method
- It enabled use of high SSTL for heavy fractions, which would otherwise not have been accepted by the SFT
- This was important for a site with considerable variations in contaminant composition and concentrations, and considering the large quantities of soil to be treated
- The simplified HI-4 approach seems on the safe side compared to the use of more fractions, and satisfactory with regards to limiting the amount of soils needing treatment
- Almost back to the national system with a limited set of fraction groups, except for the HI evaluation system

Lessons learned

- Full use of all the 13 fractions according to the TPHCWG method, or the reduced packet of 8 fractions tried in this project is impractical at the remediation stage, due to the time and cost required for the fractionated analyses
- Use of the full (13 or 8) fraction system could possibly have resulted in a more accurate and cost saving evaluation of some borderline soils and assisted the management of biological treatment processes, but this was not an optimal procedure in this case
- It would have been more efficient to fine tune the choice of SSTL and C_{sat} parameters for some sub-areas with uniform contamination properties, to improve the accuracy of the HI-4 method

Main participants

- IWACO BV (Netherlands) and sub-contractor Norconsult AS (Norway); Main environmental site investigations (Phase II ESA), environmental risk assessment, evaluation of remediation needs
- NIVA (Norwegian Institute for Water Research); Marine investigations
- Multiconsult AS (formerly NOTEBY AS); Environmental advisor to Shell; Phase I ESA, management/coordination of risk assessments, permitting and regulatory matters, preparation of tender documents, works supervision, supplementary ESA II investigations, marine environmental surveys (with NIVA)
- T. Stangeland Maskin AS, Contractor for the remediation works, with subcontractors SITA Remediation (all soil treatment plants) and DNV Consulting
- AnalyCen; main chemical testing laboratory during remediation

Excavation and classification

Excavation and classification

Biopiles with air injection / extraction

Washing and thermal treatment

Process area “oil field”

Light products

Spill from former Sludge basins

THE END