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Remediation of contaminated soil at Fornebu Airport – Norway Stabilisation and re-use of PAH-contaminated soil

Assainissement du sol pollué à l'aéroport de Fornebu en Norvège Stabilisation et réutilisation de terre contaminée par les HAP

Vidar Ellefsen, Tone Westby & Rolv Anders Systad
Norwgian Directorate of Public Construction and Property (Statsbygg),
P.O Box 8106 Dep, N-0032 Oslo, Norway
e-mail: postmottak@statsbygg.no

ABSTRACT

The former Norwegian main airport (at Fornebu) will become a residential and commercial area with large green areas and nature reserves. Strict requirements are set for remediation of the polluted soil. Directorate of Public Construction and Property (Statsbygg) is responsible for the remediation.

The main clean-up has been carried out during a 4-year project, starting in year 2000 and completed in year 2003. After treatment, the former contaminated soil was used for landscaping in accordance with the overall plan for soil management. Reuse of treated soil (together with asphalt and concrete) is one of the main environmental objectives for the development of the Fornebu area.

One of the biggest challenges at Fornebu was to work out how to deal with asphalt and sub-base contaminated with tar (PAH) under the oldest runways. The area involved was up to 200,000 m^2, and the contamination was very unevenly distributed. In the most contaminated areas PAH from the sub-base had penetrated 2-4 cm into the overlying asphalt.

20.000 tonnes of PAH-contaminated soil was stabilised with 3% bitumen in a stabilisation plant using a cold mix process. The prduct was then used as foundation for a new road at Fornebu. This PAH-contaminated material would normally have been transported to a hazardous waste disposal facility, at more than the triple costs. In addition to the stabilised material, 80.000 tons of PAH-contaminated soil was also re-used in the same foundation without stabilisation. Another 60 000 m^3 has later been used for road construction and appr. 80 000 m3 has been used in construction of new terrain, without stabilisation.

Of more than 200 000 m^3 PAH contaminated mass, not more than 15 000 m^3 had to be disposed off as hazardous waste.

RÉSUMÉ

L'ancien principal aéroport norvégien situé à Fornebu deviendra un site résidentiel et commercial avec de vastes espaces verts et des réserves naturelles. De strictes conditions sont requises pour l'assainissement du sol pollué. La Direction des travaux et des biens publics (Statsbygg) est chargée de cet assainissement.

La majeure partie du nettoyage a été effectuée au cours d'un projet étalé sur quatre ans qui a commencé en 2000 pour s'achever en 2003. Après le traitement, le sol anciennement contaminé a de nouveau été utilisé pour l'aménagement paysager conformément au plan global d'aménagement du sol. La réutilisation du sol traité (avec asphalte et béton) constituait l'un des principaux objectifs environnementaux pour le développement du terrain de Fornebu.

Parvenir à travailler avec de l'asphalte et une sous-couche de fondation contaminée par du goudron (HAP) sous les plus anciennes pistes a constitué l'un des plus grands défis sur le site de Fornebu. La superficie du terrain concerné atteignait 200 000 m² et sa contamination était très irrégulière. Dans les zones les plus contaminées, les HAP de la sous-couche de fondation avaient pénétré l'asphalte sus-jacent sur 2 à 4 cm.

20 000 tonnes de terre contaminée par les HAP ont été stabilisées avec 3 % de bitume dans une usine de stabilisation utilisant un processus de mélange à froid. Le produit a ensuite servi aux fondations d'une nouvelle route à Fornebu. La matière contaminée par les HAP aurait autrement dû être transportée dans un dépôt de déchets dangereux, et ce, à un coût trois fois plus élevé. Outre la matière stabilisée, 80 000 tonnes de terre contaminée par les HAP ont également été réutilisées, sans stabilisation, dans les mêmes fondations. 60 000 m^3 supplémentaires ont plus tard servi à la construction des voies et environ 80 000 m3 ont été repris sans stabilisation pour la construction du nouveau profil.

Sur plus de 200 000 m^3 de masse contaminée par les HAP, le volume ayant dû être éliminé en tant que déchet dangereux n'a pas dépassé 15 000 m3.

1 INTRODUCTION

The main basis for adapting the clean-up operation at Fornebu to the land use plan lies in the development of the site-specific risk guide. This also includes the development of models for re-using soil locally. These models have subsequently been employed in similar clean-up projects.

Very little was known about the re-use of contaminated soil when the clean-up operation started at Fornebu in 1998, nor were there any clear requirements from the authorities. Therefore, the project had to collect information from other countries (primarily Denmark and Sweden), as well as implement its own tests in order to document the impact of re-using contaminated material.

In addition to PAH being found in the sub-base under the asphalt, in 2002 it was discovered that components in the asphalt (and especially paint and asphalt binder) contained PCB. The tests therefore focused on the mobility of PAH- and PCB-contaminants in soil and asphalt, and the work was carried out in cooperation with the Road Research Laboratory and Danish engineering consultant DHI.

2 BASIS FOR THE RE-USE OF CONTAMINATED MATERIAL

The re-use of contaminated material requires licensed permission from both the State Pollution Control Authority (SFT) and the local planning authority (Bærum kommune). Acquiring such permission is time-consuming (with inter alia public hearings and political processing) and must be taken into account in the project planning.

To optimise the recycling and treatment of contaminated soil, storage areas, intermediate storage areas and general logistics also need to be well-planned in order to avoid unnecessary transport, loading/unloading and impact on the environment.

The goal for re-use was set to 75% of the total amount of soil handled.

Where soil is to be re-used in structures (roads/embankments), consideration must also be given to technical quality requirements in relation to strength, deformation and frost susceptibility.

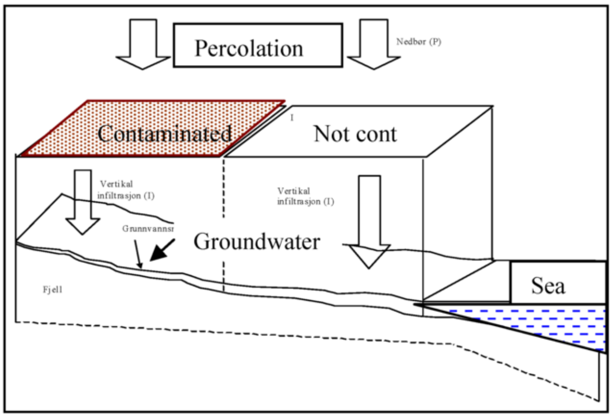

Figure 1 Principle model for calculating dispersal to recipient (SFT 99:01)

In accordance with SFT's framework licence from 1998 for the clearing and treatment of contaminated soil at Fornebu, the acceptance criteria for contaminated soil must be satisfied in terms of both land use and dispersal. When the material is included in the construction of a road, it is the dispersal criteria that determine the calculation of acceptance criteria for re-use. A hydrogeological survey of the discharge areas and recipients is therefore necessary in addition to collecting data about the contaminants' mobility.

For calculating the leaching of contaminants from recycled material the PEC (Predicted Environmental Concentration) is given. The critical levels of recipients are based on PNEC (Predicted No Effect Concentration) values for the various hazardous materials. For calculating the dispersal from recycled material to recipient (PEC) consideration is given to dilution by precipitation and ground water transport to the recipient, where PNEC values must not be exceeded, cf. figures 1 and 2 below. At Fornebu, the ground water will not be used for drinking water and therefore the acceptance criteria will be determined by ecotoxicological criteria in the recipient.

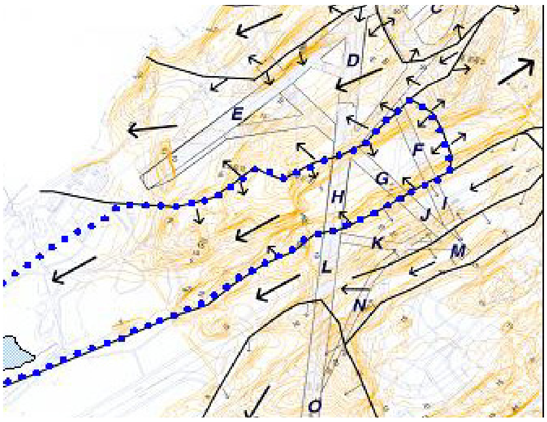

Figure 2 Discharge areas at Fornebu (A- O) with estimated dilution

Area	Dilution
Area A + B:	180
Area C:	88
Area D+E:	45
Area F+G+H:	137
Area I+J+K+L+M+N:	226
Area O:	156

3 WASTE REGULATIONS – HAZARDOUS WASTE – WORKING ENVIRONMENT

Hazardous waste is waste that contains noxious or toxic materials. Such waste must therefore be treated in a special way. Chapter 11 of the Regulations for Recycling and Treatment of Waste contains provisions for how hazardous waste has to be stored, transported and treated.

Criteria that make waste hazardous are described in a supplement to the regulations and in a separate guide from SFT, and such material must not be used for recycling purposes. There are no separate criteria for PAH, but the total concentration of Benzo(a)pyrene must not exceed 0.01% and the sum of the carcinogenic compounds must not exceed 0.1%. Carcinogenic PAH compounds are defined in the Norwegian List of Substances drawn up by SFT.

In managing this type of contaminated soil, consideration must also be given to what can be deemed environmentally safe without having to resort to special measures. The Swedish Road Authority operates with a critical limit of 1000 mg/kg for PAH (EPA 16).

4 LEACHING TEST

Two different leaching tests were carried out on material with different contamination levels – column tests and tank tests. The eluate was subjected to PAH analyses and toxicity tests in order to work out the site-specific acceptance criteria for re-use of contaminated material.

Table 1 Total content of PAH in the leaching tests (mg/kg dry material)

A	B	C	C*	D	E	Tank A	Tank B	Tank C
45	464	2605	3857	146	16	89	957	5765

Figure 3 Column test on crushed asphalt and sub-base containing PAH

4.1 *Column test*

Traditional column tests were implemented to study the Kd value, which states the relationship between concentration in solid material and in eluate. The Kd value is given in l/kg and an increasing value indicates reduced leaching.

Column tests were also used to assess the possible effect of road salt and whether the transport rate of interstitial water was significant for leaching (columns C and C*). Eluate from the column tests was also used for toxicity tests.

Table 2 Content of Sum PAH in eluates from the column tests

L/S	Column A	Column B	Column C
0,1	0,47	5,4	15
0,2	1,30	2,0	21
0,5	0,59	3,0	29
1,0	0,20	3,9	48
2,0	0,21	2,7	38
5,0	2,4	8,3	63
	Column C*	Column D	Column E
0,1	18	<0,1	0,12
0,2	28	1,6	0,22
0,5	47	1,4	0,08
1,0	48	2,2	<0,1
2,0	72	2,3	<0,1
5,0	n.a.	3,5	0,29

*) half the rate of the leaching test

4.2 *Tank test*

Tank tests were used to assess leaching from stabilised material and to prove whether leaching occurred as the result of diffusion or due to other processes.

Tank tests were also carried out during the project. Separate tests were conducted on material used in road construction in order to prove that the effect of stabilisation was as expected, based on the preliminary studies.

Figure 4 Carrying out a tank test on stabilised sub-base material

Table 3 Content of Sum PAH in eluates from the tank tests on bitumen-stabilised sub-base material or asphalt.

L/S	Tank A	Tank B	Tank C
0,25	<0,1	0,18	7,1
1	0,16	1,0	10,9
2,25	0,18	1,3	12,1
4	0,25	1,5	15
9	0,33	1,9	15
16 *	0,21/0,19	1,5/1,6	13/18
36	0,35	2,4	14
64	0,24	2,0	12

*) parallel tests

5 EFFECT OF STABILISATION

Stabilising contaminated soil reduces the leaching of contaminants into the ground. Experiments involving the stabilisation of the sub-base material using 3.0-3.5% by weight of bitumen (MB3000) show a definite reduction in the leaching of PAH. The eluates from the leaching tests on stabilised material are also reduced in relation to eluate from stabilised material.

The effects of stabilisation vary according to the PAH compound, and the effect is greatest with the least water-soluble PAH compounds. A comparison of the leaching tests shows the following ratio between leaching from stabilised material and non-stabilised sub-base material.

Table 4 Effect of stabilising PAH-contaminated sub-base material at Fornebu (ratios show the difference between leaching from stabilised and non-stabilised soil)

PAH compound	Lowest value	10 percentile	Median
Anthrasene	2,7	3,4	7,2
Fluoranthene	0,6	4,3	4,2
Pyrene	3,3	7,4	4,7
Benzo(a)anthrasene	1,9	6,0	7,6
Benzo(a)pyrene	20,9	26,4	33,2

As an additional statistical safeguard, the lowest of the median value and 10 percentile value was used in subsequent calculations.

Stabilised material is highly suitable for constructing road foundations. This has been proved in tests carried out by the Directorate of Public Roads.

6 TOXICITY TESTS

At the request of the Directorate of Public Construction and Property (Statsbygg) DHI has carried out ecotoxicological tests on eluate from column tests on crushed sub-base material. Tests were conducted on marine crustaceans (Acartia tonsa) and freshwater algae (Pseudokirchneriella subcapitata). Tests involving marine algae (Skeletonema costatum) gave experimental problems. Among other things, a mortality rate of 100% was recorded in the blind test, which obviously could not be used. As far as marine crustaceans were concerned, the tests showed no toxicity. The freshwater algae proved to be more sensitive to the PAH compounds concerned, and data from these tests were used in subsequent analyses.

The impact assessment is based on principles for industrial wastewater in Denmark, as described in Environmental Project no. 260 (1994). All (environmental) impact assessments are based on estimates of anticipated concentrations, and these are always calculated very conservatively, i.e. with parameters based on the worst-case scenario. In this project, the concentration of discharge (Predicted Environmental Concentration – PEC) is measured in three areas in the recipient: An initial dilution zone (at the point of discharge), where effects can be accepted, and a local area (where only acute effects can be accepted). Outside the local area, neither acute nor chronic effects can be accepted.

6.1 *Results from toxicity tests*

The toxicity tests show growth inhibition (in %) with a concentration of eluate/water of 200 ml/litres, together with 50% and 10% mortality rates measured in ml/litre. The results of the algae tests are shown in the table on the next page. Figures in parentheses are 95% confidence intervals.

A growth inhibition on algae of <10% is usually considered as “no effect” and below the limit for quantification. The eluate from the column tests is not filtered or centrifuged to remove particles, as is usually the case with chemical analyses. This is because we wanted to see whether colloids in the water washed out from soil deposits had any effect on toxicity.

The results of the toxicity tests are used to estimate the concentration that is not expected to result in unacceptable effects on the environment (Predicted No Effect Concentration, PNEC). The lowest of the PNEC concentrations is divided by a safety factor. The factor depends on the quality of the set of data as regards the number of groups of organisms represented and parameters measured (acute or chronic toxicity). The two estimated values are compared by looking at the PEC/PNEC ratio. If this is lower than 1, the discharge is not expected to cause unacceptable effects in the recipient.

Table 5 Results from toxicity tests and calculated Environmental Concentrations

Material and test	PAH in soil [mg/kg]	L/S ratio	PAH in eluate [µg/l]	Growth inhibition at 200 ml/litre [%]
Crushed asphalt	10,5	0,1	0,12	10
	10,5	0,2	0,22	3
Crushed asphalt	12	0,1	0,47	10
	12	0,2	1,39	8
	12	5	2,4	4
	12	10	0,59	0
Sub-base	381	0,1	<0,1	3
Sub-base	464	0,1	5,4	6
Sub-base	1169	0,1	15	17
	1169	0,5	29	6
	1169	10	82	10
Sub-base	2273	0,1	18	17

Material and test	NOEC[1] [ml/ litre]	LOEC[2] [ml/ litre]	EC10[3] [ml/ litre]
Crushed asphalt	<200	200	>200
	300	500	>500
Crushed asphalt	<200	200	200
	10	20	186 (91-457)
	≥500	>500	>500
	≥500	>500	>500
Sub-base	<200	200	>200
Sub-base	<200	200	>200
Sub-base	<200	200	<200
	100	200	262 (232-287)
	50	100	160 (116-200)
Sub-base	<200	200	<200

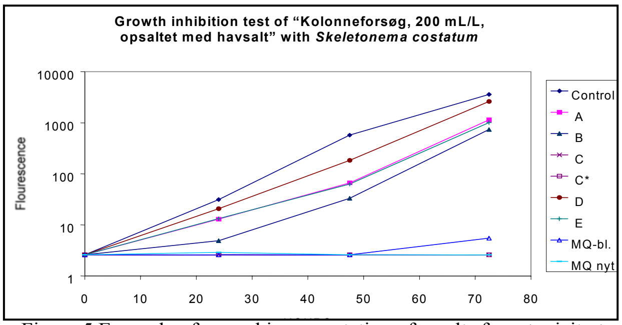

Figure 5 Example of a graphic presentation of results from toxicity tests

[1] NOEC – No Observed Effect Concentration. The greatest concentration or amount of a substance that causes no detectable harmful effect on organisms in a chronic exposure test.
[2] LOEC – Lowest observed effect concentration. The lowest concentration or amount of a substance that in toxicity tests has a detectable effect on the test organisms.
[3] EC10: The concentration (C) of a substance that gives a 10% reduction in growth of a test organism such as algae.

6.2 *Environmental impact assessment for eluates from the toxicity tests*

The impact assessment is based on the premise that there will be no acute or chronic impact on the shoreline around Fornebu as a result of PAH leaching via the groundwater. The dimensioning dilution from the new road "Ny Snarøyvei Section 2" is calculated at 156.

Thus, PEC is 1000 ml/L/156 = 6,4 ml/litre

For an impact assessment based on the results of acute tests on two groups of organisms (in this case: algae and crustaceans), one would normally start with the LC/EC50 value and a safety factor of 100 to estimate PNECacute and a safety factor of 200 for PNECchronic. With tests on a minimum of 3 groups of organisms, safety factors of 10 and 20 can be used. In this instance, the EC10 value has to be used as there are no LC/EC50 values (>500 ml/litre). However, using a safety factor of 200 to estimate PNECchronic on an EC10 value would overestimate the toxicity and give a far too conservative PNEC estimate. In this case, therefore, it is more realistic to use the factors 10 and 20 on the EC10 values.

Based on these two conditions, the PNEC rates are as follows:

PNECacute sub-base = 160 ml/litre / 10 = 16,0 ml/litre
PNECchronic sub-base = 160 ml/litre / 20 = 8,0 ml/litre

The respective PEC/PNEC risk coefficients are:
Acute: PEC/PNEC= 6,4 ml/litre / 16,0 ml/litre = 0,40
Chronic: PEC/PNEC= 6,4 ml/litre / 8,0 ml/litre = 0,80

Even the highest PAH concentrations give a PEC/PNEC coefficient of less than 1, and the water that drains out from the PAH-contaminated sub-base under the road will therefore not have any toxic effect on the recipient.

The test is carried out on sub-base material with a PAH concentration of up to 2273 mg/kg. In theory, an acceptable concentration of PAH would thus be (2273/0,8) 2840 mg/kg.

This acceptable concentration is based on EC10 values and not EC50 values, which is more usual. There is therefore a very high degree of safety built into the criteria.

For crushed asphalt the EC10 values are roughly the same as for sub-base material, and could therefore be re-used in the same way based on an environmental impact assessment.

6.3 *Recommended acceptance criteria - PAH*

Based on the previous results, the following acceptance criteria were calculated.

Table 6 Recommended acceptance criteria for the re-use of PAH-contaminated soil as the sub-base for roads at Fornebu

Material All figures in mg/kg TS	Original acceptance criteria	Hazardous waste criteria	Toxicity test	New acceptance criteria
Anthracene	75			
Fluoranthene	155			
Pyrene	105			
B(a)a	170			
B(a)P	140	100		100
SUM: Fluoranthene, Benzo(a)anthracene, Kryzene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenz(a,h)anthracene and Indeno(1,2,3-c,d)pyrene		1000		1000

Material All figures in mg/kg TS	Original acceptance criteria	Hazardous waste criteria	Toxicity test	New acceptance criteria
SUM PAH			2840	2000 *)

*) Material with a PAH concentration of between 1000 and 2000 mg/kg must not be allowed to come into direct contact with skin.

6.4 *Recommended acceptance criteria for PCB*

After the discovery of PCB in part of the asphalt and sub-base material, the eluates from the leaching tests were also analysed for PCB. No PCB was detected in any of the eluates. It may be concluded therefore that the PCB contaminant found in the asphalt and sub-base material at Fornebu is extremely immobile. This is also in accordance with the results from Veritas' preliminary tests and ongoing environmental monitoring.

In order to determine acceptance criteria, the factor that determines solubility (Kd) must be calculated based on the analysis' detection limit of 0,01 mg/l. Kd varies within an interval of 7260 and 21450. Applying the "better to be safe than sorry" principle and allowing only 50% of the lowest theoretical Kd value, this will correspond to a doubling in relation to the risk model, cf. the table below.

Table 4 Calculated acceptance criteria for PCB based on various discharge areas at Fornebu

Area	Comp	PNEC µg/l	Dilution	Source conc. µg/l	Kd [1)] l/kg TS	Acceptance criteria mg/kg
Area A + B:						
	PCB	0,002	180	0,36	3272	1,18
Area C:						
	PCB	0,002	88	0,18	3272	0,58
Area D+E:						
	PCB	0,002	45	0,09	3272	0,29
Area F+G+H:						
	PCB	0,002	137	0,27	3272	0,90
Area I+J+K+L+M+N:						
	PCB	0,002	226	0,45	3272	1,48
Area O:						
	PCB	0,002	156	0,31	3272	1,02

1) Kd value from the risk model is 1636.

7 RE-USE OF MATERIAL

7.1 *Implementation*

As regards road construction, a stone size is used that forms up to 2/3 of the thickness of the sub-layer. Where requirements for humus and fine material content in stone fill are concerned, the same requirements apply as for reinforcing layers, cf. Manual 018 item 522.1.

The fill material is spread out and consolidated to avoid unacceptable deformation post-construction, with the greatest possible homogeneity in a horizontal direction. The latter is particularly important with transitions between stabilised and non-stabilised material, where the fill is built up with separate horizontal layers or with grading between the different materials in order to achieve highest quality of evenness, cf. Manual 018 figures 260.1 and 266.1.

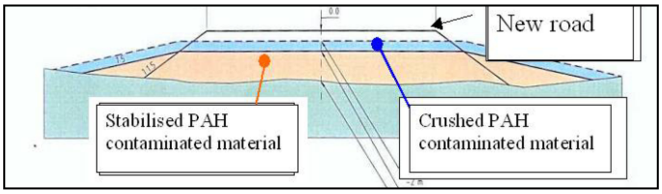

Figure 6 Principle drawing for re-use of PAH-contaminated material in road construction

The compression requirement for filling is 97% of Standard Proctor in accordance with Manual 018, figure 203.2 and Manual 176, figure 1.2. The layers are consolidated using a minmum of 10 passes with a vibrating roller with a minimum mass of 10 tonnes.

The contractor is responsible for controlling the work in accordance with Manual 018 chap. 269, Manual 176, items 1.3 and 3.5 and the Process Code figures 25.2 and 25.3. This covers inspection, measuring, field tests and analysis of core extractions.

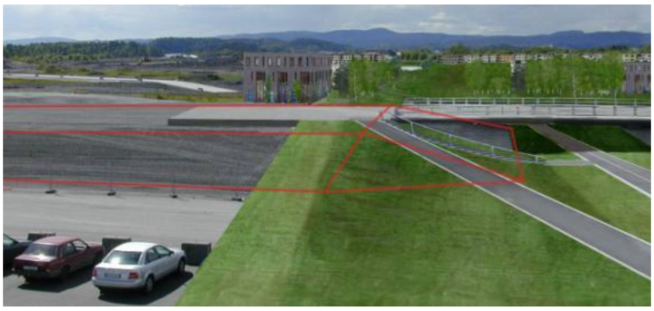

Figure 7 Use of PAH-contaminated soil in road construction at Fornebu, present situation (top) and future situation (bottom)

7.2 *Post-construction control – leaching of PAH*

To verify the assumptions on which the calculations of leaching from the soil were based, further leaching tests were carried out on the material used in the construction of the new road "Indre Ringvei".

The documentation comprises 4 different tests.

1. Supplementary toxicity tests on eluates from leaching tests. The report includes all the tests carried out before construction, and the conclusion concerning criteria for re-using the soil in road construction is not changed as a result of the new tests. The report concludes that there is a good safety margin in the scheme's acceptance criteria.
2. A supplementary assessment of leaching from stabilised material, based on whether leaching occurs as diffusion or is steered by other processes. The conclusion is that the leaching process is controlled by diffusion, and that

planned re-use of stabilised material will not impact on the respective recipients.

3. Supplementary tank tests on material used in the construction of Indre Ringvei. The results show that leaching from the material under Indre Ringvei is of the same magnitude as that indicated in preliminary tests. The time-scale is also in accordance with the assumptions.
4. Supplementary leaching tests to look at the possible effect of road salt. Test were carried out using water containing 0.5% and 5% of salt to see whether road salting could results in increased leaching of PAH. The tests show that road salt does not result in increased leaching of PAH. In fact, it appears as though the PAH concentration diminishes somewhat, but this is within the margin of uncertainty with such tests. Once again, the increasing LS ratio indicates a longer duration.

8 CONCLUSION

Of a total of 200 000 m^3 of PAH-contaminated material:

- Stabilised material: 20 000 tonnes is re-used as fill under Indre Ringvei.
- Non-stabilised material: 80 000 tonnes re-used as fill under Indre Ringvei.
- Some 60 000 m^3 of PAH-contaminated material re-used in Ny Snarøyvei Section 2

In addition, 80 000 m3 is used in building up new terrain on Storøya and only 15 000 m3 had to be sent to the disposal facility at NOAH Langøya as hazardous waste.

The solutions chosen for the re-use of PAH-contaminated material have proven to be socio-economically beneficial, with low costs and high utilisation of waste products. The solutions chosen at Fornebu also mean less strain on limited storage facilities.

Before final completion, the re-use ratio of excavated material is 96%, which is far higher than the target figure of 75%.

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