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Notat

Angående Rapport om Miljøbase Vats

Vedhæftet er et resume og vurdering af de undersøgelser, der er foretaget omkring Miljøbase Vats og et overslags beregning af den luftbårne støvbelastning.

Henrik Skov

Dato: 25. juni 2014
Sagsnr.: 1

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Med venlig hilsen

Henrik Skov

Status report on the environmental impact of Miljøbase Vats

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1 Introduction

This report summarises and reviews the environmental investigations that have taken place to assess the impact of “Miljøbase Vats” on the surrounding environment. Furthermore, the report will suggest new and additional activities that might close possible knowledge gabs.

The company AF Decom Offshore runs AF Miljøbase Vats, which is a recycling facility for former offshore oil platforms. It is located in Vatsfjord (Norway). It has been in operation since 2004. The plant is operated on licenses by the Norwegian Environment Agency (Miljødirektoratet, former Klima og Forurensingsdirektoratet, KLIF) and Statens Strålevern, which allow certain emissions from the plant to the environment. The area has been studied for environmental impacts, in particular those potentially related to the recycling plant. NIVA has prepared annual reports on the state of the environment since 2010.

The report consists of 3 chapters: Chapter 1 describes investigations in relation to airborne emissions and dispersion. The concentration of dust originating from the activities at Miljøbase Vats have been estimated, based on the available information. Chapter 2 deals with pollution in other matrixes based on the available reports by NIVA. Chapter 3 contains recommendations for future activities.

2 Atmospheric Dispersion calculations

The two main sources of air pollution from AF Decom Miljøbase Vats are considered to be (1) oxy-fuel gas cutting and (2) fugitive dust blown from the site. Besides these types of air pollution there is also odour pollution as a result of decay of marine vegetation on the structures to be scrapped.

Here, we will not consider odour pollution.

The air pollution is described in the report by Proactima (2011). The considerations in that report are examined in the following.

2.1 Air pollution from oxy-fuel gas cutting

In oxy-fuel gas cutting, metal is severed or removed at high temperatures by a chemical reaction with oxygen. The necessary heat is generated by a flame that is produced by burning a gaseous fuel in oxygen.

Two main types of pollution can be expected to occur:

- Release from the coating that has been applied to the material being cut.
- Release from the material itself. This includes release from any contaminants that may be present.

Proactima (2011) discusses emission in the form of particles. It is indicated that all of the emitted particles are smaller than 2.5 µm, and that most are smaller than 0.5 µm. This implies that the particles have a very small settling velocity and will be transported like a gas.

We consider this emission of particles in the following. An open question is whether there is any significant emission in the form of gases; one might imagine that heating of the material could cause contaminants on the surface (e.g. mercury) to evaporate.

According to Proactima (2011) technical literature reports emission rates of particles spanning from less than 10mg/s to 400 mg/s for oxy-fuel gas cutting. For offshore installations emission rates of 10-80 mg/s are reported. Proactima (2011) adopts an emission rate of 45 mg/s in their calculations. We will do the same, but note that results should be multiplied by a factor of 9 if the actual emission rate corresponds to the largest one reported in literature, and that they should be divided by 4.5 if the actual rate is at the lower end of the reported range.

For the first ten months of 2011 the "reported number of hours with oxy-fuel gas cutting" was 5049 hours, corresponding to 6060 hours per year. However, the report estimates that only during 10-50 percent of the time there was actual work with cutting, and only 10-50 percent of this time a torch was in operation. The basis of these estimates is not clear to us. A clue may be found in table 3 of Proactima (2011). We interpret Table 3 in Proactima (2011) to the effect that there are three torches at the site, and that each torch is in operation 6% of the daytime working hours. A further clarification would be desirable.

Anyhow, the result is a very high uncertainty on emissions. Assuming the lowest estimate of operating time, a torch would be in operation only 0.1 x 0.1 x 6060 hours, i.e. 60 hours per year. Assuming the highest estimate of operating time a torch would be in operation 0.5 x 0.5 x 6060 hours, i.e. 1515 hours. A central estimate may be considered to be 0.25 x 0.25 x 6060 hours, i.e. 379 hours.

All of these considerations are reflected in Table 2.1. The bottom line is that a “central estimate” corresponding largely to the final estimate in Proactima (2011) is a $PM_{2.5}$ emission of 89 kg per year; the report assumes an emission on the order of 50 kg per year. However, it is apparent from the table that the uncertainty is very large – the emission may be as low as 3 kg per year or as high as 3160 kg per year.

In other words, the result we get from the “central estimate” might have to be multiplied by a number between 0.035 and 36 in order to be correct.

Table 2.1. Estimates related to yearly emission rate of $PM_{2.5}$.

Emission rate		Lower bound	Upper bound	Central estimate
Emission rate, mg/s		10	400	45
Emission rate correction factor to be applied to central estimate if the bound is correct		0.22	8.9	1
Hours with emission per year		Lower bound	Upper bound	Central estimate
Hours of operation, "work with oxygen cutting"	6060			
Actual work with cutting (fraction of hours of operation)		0.1	0.5	0.25
Torch turned on (fraction of "actual work")		0.1	0.5	0.25
Combined (fraction of hours of operation)		0.01	0.25	0.0625
Torch operation correction factor to be applied to central estimate if the bound is correct		0.16	4	1
Combined (hours)		60.6	1515	379
Total correction factor				
Total correction factor, considering uncertainties on emission rate and hours with emission		**0.0352**	**35.6**	**1**
Emission in kg per year when applying central estimate for emission rate		14	355	89
Emission in kg per year when applying extreme bounds for emission rate		**3**	**3158**	**89**

2.1.1 Dispersion calculations

The report Proactima (2011) presents some estimates on concentrations in the air and on deposition as a result of smoke from oxy-fuel gas cutting

The concentration estimates are confined to examples of concentrations in specific meteorological situations.

We have performed dispersion calculations with the Danish local-scale dispersion model OML, which is applicable to this type of problem, and which can compute concentrations on an hourly basis through one or several years. The OML model is widely used in the context of the Danish guideline air emission regulation (Miljøstyrelsens Luftvejledning, Miljøstyrelsen 2002).

The dispersion calculations should be considered as indicative only, principally because of the huge uncertainty in emission rate and in emission conditions in general. Also some other issues limit the accuracy of the calculations: we have used meteorological data from Kristiansund as a substitute for local data, we have assumed a single point source, and the calculations do not consider terrain effects. Anyhow, these calculations deliver a much more comprehensive impression of concentration contributions than those presented in Proactima (2011), which only presented results for two meteorological scenarios (wind speeds of 2 and 10 m/s)[1].

Several sets of dispersion calculations have been carried out with varying initial conditions; we report here results from a set of calculations based on the following assumptions: All release is taking place from a single point with release height 5 m; release temperature 200 °Celsius; volume flow 1 m^3/s. A larger release height will result in a shift of the largest yearly average concentrations from being close to the source (around 50 meters) to larger distances. By assuming that release takes place from a single point we will somewhat overestimate the largest concentrations.

If we consider the concentration pattern for the yearly average and assume a yearly emission of 89 kg $PM_{2.5}$ (the "central estimate"), the highest contribution is found in a distance of 60 m from the source and amounts to 0.07 $\mu g/m^3$ as a yearly average. At a distance of 1000 m the largest contribution is 0.003 $\mu g/m^3$. These results can be found in Table 2.2, which shows the results of the computations referred to.

If we adopt the most conservative estimates concerning emission rates, these numbers should be multiplied by 36, resulting in concentration contributions of, respectively, 2.5 $\mu g/m^3$ and 0.1 $\mu g/m^3$, at distances of 60 and 1000 m.

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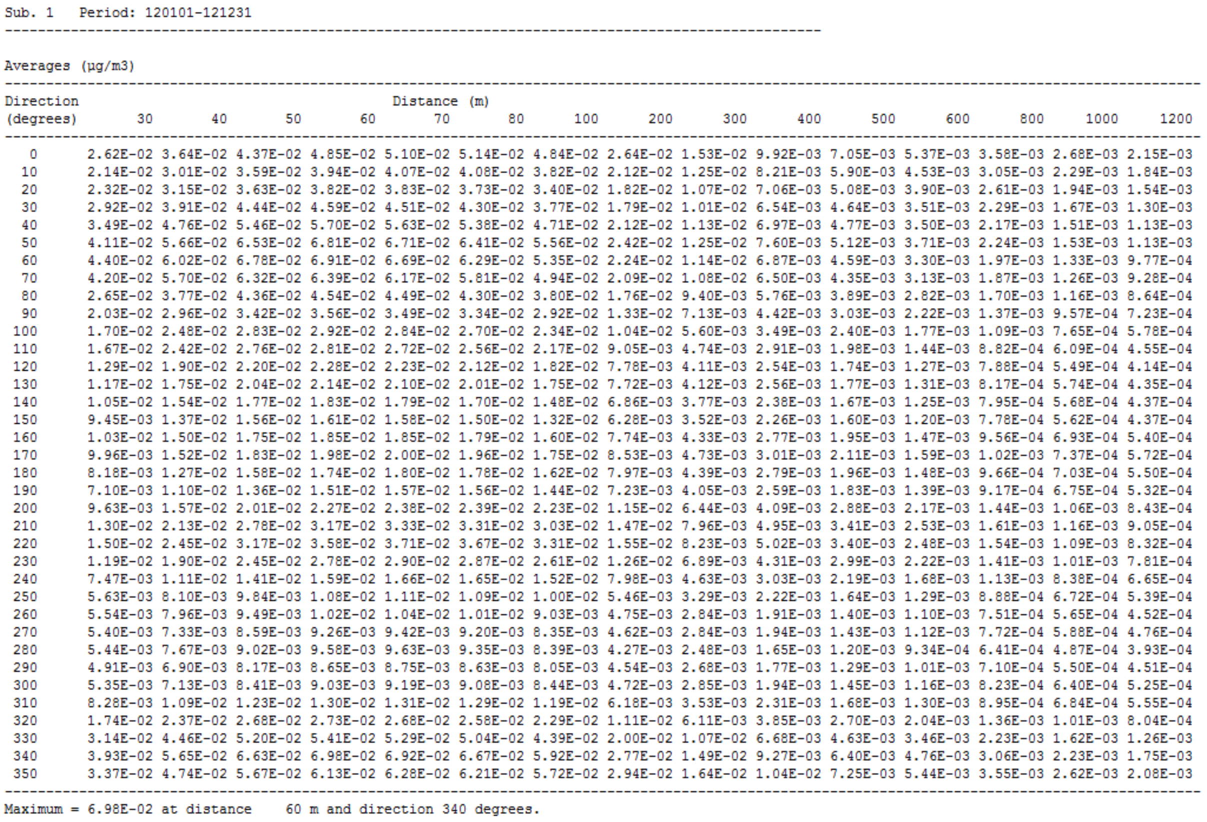
[1] The graphs in the report are too unclear to read, but there is an error in the explanation to Figure 9, where the emission rate not is 10 mg/s as written, but 1 mg/s.

Table 2.2. Results of dispersion calculations for smoke from oxy-fuel gas cutting. The table shows yearly average values for ambient air concentrations of $PM_{2.5}$ in the unit microgram/second. It assumes the "central estimate" for both emission rate and hours with emission per year.



```
Sub. 1   Period: 120101-121231
-----------------------------------------------------------------------------------------------

Averages (µg/m3)
---------------------------------------------------------------------------------------------------------------------------------------------------
Direction                                               Distance (m)
(degrees)         30        40        50        60        70        80       100       200       300       400       500       600       800      1000      1200
---------------------------------------------------------------------------------------------------------------------------------------------------
   0       2.62E-02 3.64E-02 4.37E-02 4.85E-02 5.10E-02 5.14E-02 4.84E-02 2.64E-02 1.53E-02 9.92E-03 7.05E-03 5.37E-03 3.58E-03 2.68E-03 2.15E-03
  10       2.14E-02 3.01E-02 3.59E-02 3.94E-02 4.07E-02 4.08E-02 3.82E-02 2.12E-02 1.25E-02 8.21E-03 5.90E-03 4.53E-03 3.05E-03 2.29E-03 1.84E-03
  20       2.32E-02 3.15E-02 3.63E-02 3.82E-02 3.83E-02 3.73E-02 3.40E-02 1.82E-02 1.07E-02 7.06E-03 5.08E-03 3.90E-03 2.61E-03 1.94E-03 1.54E-03
  30       2.92E-02 3.91E-02 4.44E-02 4.59E-02 4.51E-02 4.30E-02 3.77E-02 1.79E-02 1.01E-02 6.54E-03 4.64E-03 3.51E-03 2.29E-03 1.67E-03 1.30E-03
  40       3.49E-02 4.76E-02 5.46E-02 5.70E-02 5.63E-02 5.38E-02 4.71E-02 2.12E-02 1.13E-02 6.97E-03 4.77E-03 3.50E-03 2.17E-03 1.51E-03 1.13E-03
  50       4.11E-02 5.66E-02 6.53E-02 6.81E-02 6.71E-02 6.41E-02 5.56E-02 2.42E-02 1.25E-02 7.60E-03 5.12E-03 3.71E-03 2.24E-03 1.53E-03 1.13E-03
  60       4.40E-02 6.02E-02 6.78E-02 6.91E-02 6.69E-02 6.29E-02 5.35E-02 2.24E-02 1.14E-02 6.87E-03 4.59E-03 3.30E-03 1.97E-03 1.33E-03 9.77E-04
  70       4.20E-02 5.70E-02 6.32E-02 6.39E-02 6.17E-02 5.81E-02 4.94E-02 2.09E-02 1.08E-02 6.50E-03 4.35E-03 3.13E-03 1.87E-03 1.26E-03 9.28E-04
  80       2.65E-02 3.77E-02 4.36E-02 4.54E-02 4.49E-02 4.30E-02 3.80E-02 1.76E-02 9.40E-03 5.76E-03 3.89E-03 2.82E-03 1.70E-03 1.16E-03 8.64E-04
  90       2.03E-02 2.96E-02 3.42E-02 3.56E-02 3.49E-02 3.34E-02 2.92E-02 1.33E-02 7.13E-03 4.42E-03 3.03E-03 2.22E-03 1.37E-03 9.57E-04 7.23E-04
 100       1.70E-02 2.48E-02 2.83E-02 2.92E-02 2.84E-02 2.70E-02 2.34E-02 1.04E-02 5.60E-03 3.49E-03 2.40E-03 1.77E-03 1.09E-03 7.65E-04 5.78E-04
 110       1.67E-02 2.42E-02 2.76E-02 2.81E-02 2.72E-02 2.56E-02 2.17E-02 9.05E-03 4.74E-03 2.91E-03 1.98E-03 1.44E-03 8.82E-04 6.09E-04 4.55E-04
 120       1.29E-02 1.90E-02 2.20E-02 2.28E-02 2.23E-02 2.12E-02 1.82E-02 7.78E-03 4.11E-03 2.54E-03 1.74E-03 1.27E-03 7.88E-04 5.49E-04 4.14E-04
 130       1.17E-02 1.75E-02 2.04E-02 2.14E-02 2.10E-02 2.01E-02 1.75E-02 7.72E-03 4.12E-03 2.56E-03 1.77E-03 1.31E-03 8.17E-04 5.74E-04 4.35E-04
 140       1.05E-02 1.54E-02 1.77E-02 1.83E-02 1.79E-02 1.70E-02 1.48E-02 6.86E-03 3.77E-03 2.38E-03 1.67E-03 1.25E-03 7.95E-04 5.68E-04 4.37E-04
 150       9.45E-03 1.37E-02 1.56E-02 1.61E-02 1.58E-02 1.50E-02 1.32E-02 6.28E-03 3.52E-03 2.26E-03 1.60E-03 1.20E-03 7.78E-04 5.62E-04 4.37E-04
 160       1.03E-02 1.50E-02 1.75E-02 1.85E-02 1.85E-02 1.79E-02 1.60E-02 7.74E-03 4.33E-03 2.77E-03 1.95E-03 1.47E-03 9.56E-04 6.93E-04 5.40E-04
 170       9.96E-03 1.52E-02 1.83E-02 1.98E-02 2.00E-02 1.96E-02 1.75E-02 8.53E-03 4.73E-03 3.01E-03 2.11E-03 1.59E-03 1.02E-03 7.37E-04 5.72E-04
 180       8.18E-03 1.27E-02 1.58E-02 1.74E-02 1.80E-02 1.78E-02 1.62E-02 7.97E-03 4.39E-03 2.79E-03 1.96E-03 1.48E-03 9.66E-04 7.03E-04 5.50E-04
 190       7.10E-03 1.10E-02 1.36E-02 1.51E-02 1.57E-02 1.56E-02 1.44E-02 7.23E-03 4.05E-03 2.59E-03 1.83E-03 1.39E-03 9.17E-04 6.75E-04 5.32E-04
 200       9.63E-03 1.57E-02 2.01E-02 2.27E-02 2.38E-02 2.39E-02 2.23E-02 1.15E-02 6.44E-03 4.09E-03 2.88E-03 2.17E-03 1.44E-03 1.06E-03 8.43E-04
 210       1.30E-02 2.13E-02 2.78E-02 3.17E-02 3.33E-02 3.31E-02 3.03E-02 1.47E-02 7.96E-03 4.95E-03 3.41E-03 2.53E-03 1.61E-03 1.16E-03 9.05E-04
 220       1.50E-02 2.45E-02 3.17E-02 3.58E-02 3.71E-02 3.67E-02 3.31E-02 1.55E-02 8.23E-03 5.02E-03 3.40E-03 2.48E-03 1.54E-03 1.09E-03 8.32E-04
 230       1.19E-02 1.90E-02 2.45E-02 2.78E-02 2.90E-02 2.87E-02 2.61E-02 1.26E-02 6.89E-03 4.31E-03 2.99E-03 2.22E-03 1.41E-03 1.01E-03 7.81E-04
 240       7.47E-03 1.11E-02 1.41E-02 1.59E-02 1.66E-02 1.65E-02 1.52E-02 7.98E-03 4.63E-03 3.03E-03 2.19E-03 1.68E-03 1.13E-03 8.38E-04 6.65E-04
 250       5.63E-03 8.10E-03 9.84E-03 1.08E-02 1.11E-02 1.09E-02 1.00E-02 5.46E-03 3.29E-03 2.22E-03 1.64E-03 1.29E-03 8.88E-04 6.72E-04 5.39E-04
 260       5.54E-03 7.96E-03 9.49E-03 1.02E-02 1.04E-02 1.01E-02 9.03E-03 4.75E-03 2.84E-03 1.91E-03 1.40E-03 1.10E-03 7.51E-04 5.65E-04 4.52E-04
 270       5.40E-03 7.33E-03 8.59E-03 9.26E-03 9.42E-03 9.20E-03 8.35E-03 4.62E-03 2.84E-03 1.94E-03 1.43E-03 1.12E-03 7.72E-04 5.88E-04 4.76E-04
 280       5.44E-03 7.67E-03 9.02E-03 9.58E-03 9.63E-03 9.35E-03 8.39E-03 4.27E-03 2.48E-03 1.65E-03 1.20E-03 9.34E-04 6.41E-04 4.87E-04 3.93E-04
 290       4.91E-03 6.90E-03 8.17E-03 8.65E-03 8.75E-03 8.63E-03 8.05E-03 4.54E-03 2.68E-03 1.77E-03 1.29E-03 1.01E-03 7.10E-04 5.50E-04 4.51E-04
 300       5.35E-03 7.13E-03 8.41E-03 9.03E-03 9.19E-03 9.08E-03 8.44E-03 4.72E-03 2.85E-03 1.94E-03 1.45E-03 1.16E-03 8.23E-04 6.40E-04 5.25E-04
 310       8.28E-03 1.09E-02 1.23E-02 1.30E-02 1.31E-02 1.29E-02 1.19E-02 6.18E-03 3.53E-03 2.31E-03 1.68E-03 1.30E-03 8.95E-04 6.84E-04 5.55E-04
 320       1.74E-02 2.37E-02 2.68E-02 2.73E-02 2.68E-02 2.58E-02 2.29E-02 1.11E-02 6.11E-03 3.85E-03 2.70E-03 2.04E-03 1.36E-03 1.01E-03 8.04E-04
 330       3.14E-02 4.46E-02 5.20E-02 5.41E-02 5.29E-02 5.04E-02 4.39E-02 2.00E-02 1.07E-02 6.68E-03 4.63E-03 3.46E-03 2.23E-03 1.62E-03 1.26E-03
 340       3.93E-02 5.65E-02 6.63E-02 6.98E-02 6.92E-02 6.67E-02 5.92E-02 2.77E-02 1.49E-02 9.27E-03 6.40E-03 4.76E-03 3.06E-03 2.23E-03 1.75E-03
 350       3.37E-02 4.74E-02 5.67E-02 6.13E-02 6.28E-02 6.21E-02 5.72E-02 2.94E-02 1.64E-02 1.04E-02 7.25E-03 5.44E-03 3.55E-03 2.62E-03 2.08E-03
---------------------------------------------------------------------------------------------------------------------------------------------------
Maximum = 6.98E-02 at distance    60 m and direction 340 degrees.
```

If we consider the concentration pattern for the maximum hourly concentrations – that is the highest concentration that occurs during any hour of the year, assuming that we can rely on the hour-by-hour meteorological data from Kristiansund – the maximum is found at a distance of 40 m from the source. Assuming the "central estimate" for emission rate during effective operation of the torch (45 mg/s) we get a concentration of 35 µg/m^3 at 40 meters distance. At a distance of 200 meters the maximum hourly concentration is 10 µg/m^3, and at a distance of 1000 meters it is 1.6 µg/m^3. So far we assumed the "central estimate" for emission rate during effective operation. If we adopt the most conservative estimate, the values should be multiplied by 9, i.e. the maximum hourly concentration at 200 m distance would be 315 µg/m^3.

Note, however, that this discussion does not refer not to an average, but to the maximum concentration occurring for the worst hour of the year. For cumulative dosage the average is most relevant.

2.1.2 Deposition estimates

The report Proactima (2011) presents some deposition estimates based on various somewhat arbitrary assumptions.

Use of the OML dispersion model enables us to make a better quantification of deposition. The newest version of the OML model permits a user to produce such estimates; however, in this context we have had to apply Danish meteorological data (a ten year series of data from Aalborg Airport). This fact is not considered crucial for results.

Table 2.3 indicates dry deposition velocities from literature. As it appears, dry deposition velocities vary greatly according to surface. The size of the particles resulting from oxy-fuel gas cutting is believed to be quite small – generally less than 2 µm. As a relatively conservative estimate for dry deposition velocities we have assumed an overall dry deposition velocity of 1 cm/s. For wet deposition we have assumed a scavenging coefficient of 0.0001 per second, and a yearly rainfall of 1500 mm. Wet deposition, however, is only of minor importance compared to dry deposition.

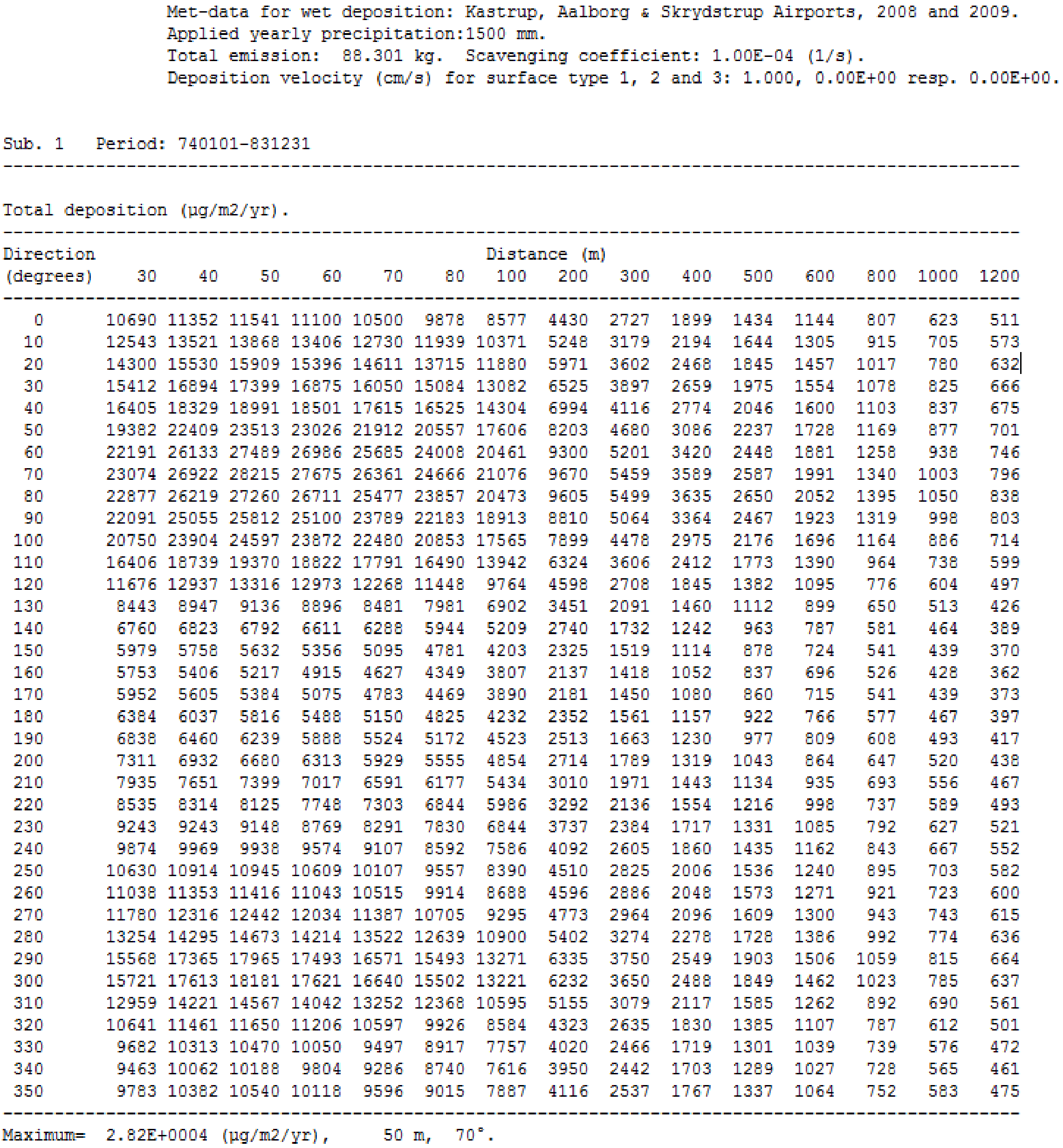
Table 2.3. Dry deposition velocities (cm/s)

Substance	Water	Grass	Forest
Particles, 10 µm	2.0	2.0	4.0
Particles, 2 µm	0.2	0.7	1.4
Particles < 2 µm	0.005-0.2	0.05-0.7	0.1-1.4

We have conducted dispersion calculations corresponding to those illustrated in Table 2.2, but with meteorological data from Aalborg in Denmark. With the facilities in the OML model we have produced a table of deposition estimates shown in Table 2.4. The methods applied in OML provide somewhat conservative estimates, i.e., they do not underpredict deposition (however, this statement disregards the uncertainty in the underlying emission estimates).

The maximum deposition is 28.2 mg/m^2 per year at a distance of 30 meters from the source. At a distance of 100 meters the largest deposition is around 21 mg/m^2 per year, while at 1000 meter distance it is around 1 mg/m^2 per year. The uncertainty in emission rates imply that in the most extreme case the values in the table would have to be multiplied by a factor of 36, resulting in a maximum deposition of 1000 mg/m^2 per year at 30 meter distance from the source.

Table 2.4. Deposition estimates for smoke from oxy-fuel gas cutting. The table shows yearly average values and assumes the "central estimate" for both emission rate and hours with emission per year. The maximum is 28.2 microgram/m²/year.



```
                Met-data for wet deposition: Kastrup, Aalborg & Skrydstrup Airports, 2008 and 2009.
                Applied yearly precipitation:1500 mm.
                Total emission:  88.301 kg.  Scavenging coefficient: 1.00E-04 (1/s).
                Deposition velocity (cm/s) for surface type 1, 2 and 3: 1.000, 0.00E+00 resp. 0.00E+00.


Sub. 1   Period: 740101-831231
---------------------------------------------------------------------------------------------------

Total deposition (µg/m2/yr).
---------------------------------------------------------------------------------------------------
Direction                                      Distance (m)
(degrees)    30    40    50    60    70    80   100   200   300   400   500   600   800  1000  1200
---------------------------------------------------------------------------------------------------
    0     10690 11352 11541 11100 10500  9878  8577  4430  2727  1899  1434  1144   807   623   511
   10     12543 13521 13868 13406 12730 11939 10371  5248  3179  2194  1644  1305   915   705   573
   20     14300 15530 15909 15396 14611 13715 11880  5971  3602  2468  1845  1457  1017   780   632
   30     15412 16894 17399 16875 16050 15084 13082  6525  3897  2659  1975  1554  1078   825   666
   40     16405 18329 18991 18501 17615 16525 14304  6994  4116  2774  2046  1600  1103   837   675
   50     19382 22409 23513 23026 21912 20557 17606  8203  4680  3086  2237  1728  1169   877   701
   60     22191 26133 27489 26986 25685 24008 20461  9300  5201  3420  2448  1881  1258   938   746
   70     23074 26922 28215 27675 26361 24666 21076  9670  5459  3589  2587  1991  1340  1003   796
   80     22877 26219 27260 26711 25477 23857 20473  9605  5499  3635  2650  2052  1395  1050   838
   90     22091 25055 25812 25100 23789 22183 18913  8810  5064  3364  2467  1923  1319   998   803
  100     20750 23904 24597 23872 22480 20853 17565  7899  4478  2975  2176  1696  1164   886   714
  110     16406 18739 19370 18822 17791 16490 13942  6324  3606  2412  1773  1390   964   738   599
  120     11676 12937 13316 12973 12268 11448  9764  4598  2708  1845  1382  1095   776   604   497
  130      8443  8947  9136  8896  8481  7981  6902  3451  2091  1460  1112   899   650   513   426
  140      6760  6823  6792  6611  6288  5944  5209  2740  1732  1242   963   787   581   464   389
  150      5979  5758  5632  5356  5095  4781  4203  2325  1519  1114   878   724   541   439   370
  160      5753  5406  5217  4915  4627  4349  3807  2137  1418  1052   837   696   526   428   362
  170      5952  5605  5384  5075  4783  4469  3890  2181  1450  1080   860   715   541   439   373
  180      6384  6037  5816  5488  5150  4825  4232  2352  1561  1157   922   766   577   467   397
  190      6838  6460  6239  5888  5524  5172  4523  2513  1663  1230   977   809   608   493   417
  200      7311  6932  6680  6313  5929  5555  4854  2714  1789  1319  1043   864   647   520   438
  210      7935  7651  7399  7017  6591  6177  5434  3010  1971  1443  1134   935   693   556   467
  220      8535  8314  8125  7748  7303  6844  5986  3292  2136  1554  1216   998   737   589   493
  230      9243  9243  9148  8769  8291  7830  6844  3737  2384  1717  1331  1085   792   627   521
  240      9874  9969  9938  9574  9107  8592  7586  4092  2605  1860  1435  1162   843   667   552
  250     10630 10914 10945 10609 10107  9557  8390  4510  2825  2006  1536  1240   895   703   582
  260     11038 11353 11416 11043 10515  9914  8688  4596  2886  2048  1573  1271   921   723   600
  270     11780 12316 12442 12034 11387 10705  9295  4773  2964  2096  1609  1300   943   743   615
  280     13254 14295 14673 14214 13522 12639 10900  5402  3274  2278  1728  1386   992   774   636
  290     15568 17365 17965 17493 16571 15493 13271  6335  3750  2549  1903  1506  1059   815   664
  300     15721 17613 18181 17621 16640 15502 13221  6232  3650  2488  1849  1462  1023   785   637
  310     12959 14221 14567 14042 13252 12368 10595  5155  3079  2117  1585  1262   892   690   561
  320     10641 11461 11650 11206 10597  9926  8584  4323  2635  1830  1385  1107   787   612   501
  330      9682 10313 10470 10050  9497  8917  7757  4020  2466  1719  1301  1039   739   576   472
  340      9463 10062 10188  9804  9286  8740  7616  3950  2442  1703  1289  1027   728   565   461
  350      9783 10382 10540 10118  9596  9015  7887  4116  2537  1767  1337  1064   752   583   475
---------------------------------------------------------------------------------------------------
Maximum=  2.82E+0004 (µg/m2/yr),     50 m,  70°.
```

2.2 Fugitive dust from the site

A relatively large fraction of the scrapped material (1-10% of the total weight) ends as "oppsop": cement and stone dust, small metal bites, paint flakes etc. The report Proactima (2011) refers to it as coarse particles, larger than 10 µm. It seems likely that it also includes finer particles and that there can be episodes where particles are blown from the site.

With the information at hand we are not able to make estimates on the effect of this, but it is potentially a very important source which deserves further investigation.

2.3 Conclusion

2.3.1 oxy-fuel cutting

The process of oxy-fuel cutting is examined guided by the input provided by Proactima (2011). According to this, there is a release of $PM_{2.5}$ amounting to somewhere between 3 and 3200 kg per year, with 89 kg as a "central estimate". The results presented in the following are only indicative, because they refer to a certain set of assumptions concerning the release.

As a *yearly average*, the contribution to $PM_{2.5}$ concentrations is small, amounting to 0.07 $\mu g/m^3$ at a distance of 70 m from the source and smaller than that everywhere else. By adopting the most extreme assumptions concerning emission this value should be multiplied by 36, resulting in 2.5 $\mu g/m^3$ at the most exposed location. The EU limit value for $PM_{2.5}$ in ambient air is 25 $\mu g/m^3$.

These numbers are yearly averages. The maximum during a single hour of the year has also been calculated – and is of course much larger – but is of less interest in the context of dosage.

However, there are some questions related to the interpretation of the above results:

- How toxic is the material released? Is it relevant to consider limit values of other components than $PM_{2.5}$?
- Are significant amounts of material released which we do not take into account? As a specific example, it could be that mercury evaporation takes place as a result of heating of the material to be cut.
- Is the estimated operation time reasonable? According to the assumptions, the number of hours with a torch in actual operation is only a small fraction (1-25%) of the number of reported hours with burning ("oppgitt antal timer med brenning") and the reasoning behind this is not clear to us.

In addition to concentration calculations we have carried out indicative deposition estimates. According to these the maximum deposition of $PM_{2.5}$ from oxy-fuel gas cutting is 28 $\mu g/m^2$ annually, and this maximum is found 30 meters from the source. Again, a proper interpretation of this result requires some information on the toxicity of the $PM_{2.5}$ in question.

2.3.2 Deposition of fugitive dust

Besides pollution from oxy-fuel gas cutting another source of emission is present, namely dust blown from the site. We would suspect that this latter source is more important for deposition of polluting substances in the surrounding environment.

Based on existing information we are not able to quantify the effect of this source, but we find that it deserves further investigation.

2.4 Reference

Proactima, 2011: Mulige tiltak for å redusere utslipp til luft. Report on behalf of AF Miljøbase Vats.

3 Environmental monitoring

In this chapter the existing knowledge has been reviewed published in the two most recent NIVA reports on levels and trends in selected samples of fish, water, sediments and mosses.

3.1 Material for review

NIVA report on environmental monitoring 2012:
Årsrapport for miljøovervåking rundt AF Miljøbase Vats for 2012. Rapport L.NR. 6456-2012.
Authors: Astri J.S. Kvassness, Anders Hobæk, Gunhild Borgersen, Janne Gitmark, Torbjørn M. Johnsen

a) Water quality of streams
b) Treated process water emitted to the fjord
c) Fish and shellfish
d) Soil samples
e) Groundwater pollution
f) Monitoring around the piers by Remotely Operated Vehicle (ROV)
g) Diversity of the fjord bed fauna
h) Sediment chemistry
i) Sediment ecotoxicology
j) Naturally occurring radioactive elements
k) Metals in mountain fern moss *(Hylocomium splendens)*
l) Conclusions and recommendations

NIVA report on environmental monitoring 2013:
Årsrapport for miljøovervåking rundt AF Miljøbase Vats for 2013. Rapport L.NR. 6673-2014.
Authors: Jonny Beyer, Astri J.S. Kvassnes, Anders Hobæk, Bjørnar A. Beylich, Torbjørn M. Johnson
a) Treated process water emitted to the fjord
b) Fish and shellfish
c) Groundwater pollution
d) Naturally occurring radioactive elements
e) Metals in mountain fern moss *(Hylocomium splendens)*

3.2 Reviewers' comments

3.2.1 NIVA report on environmental monitoring 2012

a) Water quality of streams

The main parameters analysed in this sub-study were

- Metals and other elements
- Nitrogen compounds
- Water quality parameters (Conductivity, turbidity, pH, total organic carbon)

The sampling was performed by staff of AF Miljøbase Vats, after demonstration by NIVA staff.

Regarding comparisons of upstream and downstream situations, the measurements showed an increased concentration of metals/elements, higher pH and higher concentration of suspended particulate matter at the downstream stations, although not consistently, i.e. not for all four streams.

The downstream measurements in the streams were classified according to water quality criteria laid down by KLIF:

- Raueselva: One parameter was categorized as “bad” (turbidity), the others were “moderate” or better.
- Bekk Sør: Two parameters were categorized as “bad” (pH, Zn), the others were “good” or better. [pH did not change category from upstream to downstream measurement.]
- Bekk Midt: One parameter was categorized as “bad” (turbidity), the others were “moderate” or better.
- Bekk Nor: Three parameters were categorized as “bad” or “very bad” (Turbidity, Cu, Zn).

In summary, **particle concentrations and elevated levels of Cu and Zn** can be an issue.

Regarding temporal trends, most elements showed decreasing concentrations since the previous measurements, with the exception of Zn, Hg (two streams, concentrations close to detection limits and thus uncertain), Cd (two streams) and Pb.

It was discussed in this section that the plant design should avoid the emission of polluted water to the streams. Obviously, this had not quite succeeded. Potential reasons (as discussed in the report) were lack of equilibrium after construction work in 2009 and dust spreading. The authors confirmed issues with particles, Cu and Zn, but highlighted the overall decreasing trend of Cu.

Uranium (U), barium (Ba) and molybdenum (Mo) were mentioned in the report as well, but not assessed with regard to high or low levels.

b) Treated process water emitted to the fjord

Process water and rainwater collected in the plant area is supposed to be treated on-site prior to emission to the fjord. KLIF and Statens Strålevern had issued a license according to which some emissions were allowed. The pollutant content of the wastewater was monitored by cumulative sampling over three months.

Parameters that were monitored included

- Metals and other elements
- Organic contaminants
- Water quality parameters (Conductivity, turbidity, pH, total organic carbon)

The results for metals and water quality parameters were consistent with those in the streams, i.e. indicating **high particle concentrations and elevated levels of Cu and Zn**.

Furthermore, Cr and Ni had concentrations that classified water quality as "moderate", according to KLIF's water quality categories. Some samples exceeded the Environmental Quality Standards (EQS) of the EU Water Framework Directive (WFD) for Hg. It was also remarked that the cumulative **emission of Hg had increased** compared with previous measurements.

In the discussion, the authors did not consider these concentrations to cause effects in the environment because of the dilution in the fjord.

Regarding the organic contaminants, a large suite of compounds was analysed, which were considered priority compounds in the license and which should not be present. Ten of these parameters were not detected in the process water. It has to be noted that some detection limits were relatively high (i.e. higher than state-of-the-art trace analysis can achieve).

Further ten compounds were discussed in the report, which generally were detected with varying frequencies and at varying concentrations. Where possible, the results were compared with EQS values of the WFD. These comparisons indicate concentrations close to or above annual average EQS values for **octylphenols, nonylphenols and perfluorosulfonic acid (PFOS)**. PFOS could be of particular concern because concentrations were found to be increasing. Concentrations of perfluorooctanoic acid (PFOA) were comparable to those of PFOS (but could not be compared with an EQS value). [It should also be noted that the authors compared PFOS to an incorrect AA-EQS, however, the conclusion of concentrations exceeding the EQS was still correct.]

Other organic contaminants detected in the process water (including previous samples) were organotin compounds, chlorophenols, dioxins/furans, bisphenol A, alkyl ethoxylates and siloxanes. In general, the data material showed a large variation between samples.

Like for the metals/elements, the authors did not expect any effects on the environment because of the large dilution after emission to the fjord.

c) Fish and shellfish

Metals and organic contaminants were analysed in blue mussels, crab and cod from stations in the Vatsfjorden and – for crab and cod – in the Ykrefjorden. The results were compared to KLIF's categories for environmental quality.

Regarding the metals in mussels, a "moderate pollution" was found for **As, Cr and Hg**. The concentrations were given on a dry weight basis and the reviewers were unable to find the wet weight concentrations in the annex. Assuming a dry matter content of 20%, the Hg concentrations would exceed the EU WFD EQS of 20 µg/kg wet weight in biota, also at the station which is classified as being of "good" quality.

The relatively high concentrations of As had not been indicated by the measurements in the streams or in the process water.

It was noted that the **Hg concentrations had increased** compared with previous measurements.

Regarding the organic contaminants in mussels, PCBs (as PCB_7) were undetectable at detection limits of 10 µg/kg for individual PCB congeners. Assuming that these are wet weight concentrations, the detection limits have to be considered high, for example in comparison with OSPAR assessment concentrations. The detection limits that have to be met for PCBs in mussels in the Danish environmental monitoring programme are 0.05 – 0.5 µg/kg wet weight for individual congeners (Bekendtgørelse om kvalitetskrav til miljømålinger, BEK nr. 900 af 17/08/2011; https://www.retsinformation.dk/Forms/R0710.aspx?id=160496). The mean concentration of PCB_7 in mussels in the Norwegian environmental monitoring programme was 1.16 µg/kg wet weight (Green & Knutzen, 2003). Considering these concentrations, a detection limit of 10 µg/kg seems inappropriately high.

Polycyclic aromatic hydrocarbons (PAHs) were found at concentrations classified as "moderate" to "marked" pollution, the latter concerning the sum of potentially carcinogenic PAHs. It was noted that PAH **concentrations had increased considerably** since the previous measurements.

Regarding the metals in cod and crab, Hg was again highlighted as causing "moderate" pollution. All Hg concentrations exceeded the EU WFD EQS of 20 µg/kg wet weight, also at stations classified as being of "good" quality according to the KLIF assessment criteria. As and Cr were not evaluated in relation to the environmental quality classes.

PCB_7 gave concentrations of 434 – 647 µg/kg wet weight in cod liver, leading to "good" or "moderate" environmental status. These concentrations were in the higher end of what has been reported from the Norwegian environmental monitoring programme (Green & Knutzen, 2003). Concentrations of DDT and hexachlorobenzene (HCB) in cod liver were described as "low concentrations" by the authors. The DDT concentrations were similar to mean concentrations of the Norwegian environmental monitoring programme, while HCB was about half the mean concentration (Green & Knutzen, 2003).

PAHs were also analysed in cod although most fish do no accumulate PAHs and are less suitable for determining PAH concentrations in the environment (OSPAR, 1999).

In summary, the analyses in fish and shellfish raised some methodological questions. High and partly increasing concentrations were noted for As, Cr, Hg and PAHs.

d) Soil samples

The soil samples were taken from a station where elevated levels of Hg had previously been found, plus additional stations.

Hg concentrations led to a classification of one station (according to KLIF's categories of environmental quality) as "bad" environmental status, while other stations were classified as "good" or "moderate". The **concentration of Hg had been increasing**, from a formerly "very good" to a "bad" classification.

Concentrations of Zn and PAHs were elevated as well and the environmental status was classified as "good" or "moderate". The concentrations had increased compared with 2009, but were lower than in 2010.

The authors recommended a more detailed mapping of Hg concentrations in the area, also to understand transport patterns and spreading mechanisms.

In summary, the findings of **elevated levels of Hg, Zn and PAHs** support the results discussed so far as these were also identified as problematic in one or several of the other sub-studies. The increasing concentrations indicate that emissions are not entirely under control.

e) Groundwater pollution

A membrane was installed below the tarmac on the pier to avoid percolation of potentially polluted water to the groundwater. According to the license issued by KLIF (see above) the groundwater must not be affected by the plant.

The measurement programme included oil, metals and some water chemistry parameters. Hg, which was found in elevated concentrations in some of the other sub-studies, had a concentration of 2 ng/L (or below), which is relatively low. OSPAR EACs for marine water are 5-50 ng/L (OSPAR, 2004). Background levels reported in the different OSPAR regions varied from 0.05-2 ng/L.

The authors noted higher pH and conductivity than usually found for groundwater, but attributed these to inflowing saltwater.

f) Monitoring around the piers by Remotely Operated Vehicle (ROV)

The objective of this sub-study was to scan the fauna and flora of the sea floor and to register litter in the areas close to the piers.

The two areas Raunesvika and Grønavika were studied. With regard to the presence of litter, more metal items and car tires were observed at Raunesvika. The amount of litter was smaller than in previous scans in 2004 and 2009, but the areas had also been cleaned in 2009. The authors concluded that new material had been found.

The fauna and flora did not show obvious major changes compared with former studies. It was not quite clear to the reviewers what fauna and flora would be considered normal or good environmental status and whether or not the present situation deviated from this. The fauna was analysed in more detail in the following sub-study.

g) Diversity of fjord bed fauna

Sediment samples were collected from six stations and based on their fauna, diversity indexes and sensitivity indexes were calculated. The results varied with regard to ecological status. It seemed that water depth was an important factor, even more so than distance from AF Miljøbase Vats.

For three stations, the overall results showed “very good” status, for the others, the status was “good” or “moderate”. The classification as “moderate” was mainly based on the presence of species tolerable to pollution.

Except for one station, the biodiversity and sensitivity indexes had improved since 2009. The only station with decreasing quality was that at Grønavika closest to AF Miljøbase Vats and only 41 m deep. However, the station classified as “moderate” was in the inner Vatsfjord at 38 m depth.

h) Sediment chemistry

It was mentioned in this part of the report that the pier extension in 2009 had led to encapsulation of areas of TBT and PAH contamination (classified as “very bad” environmental quality). Furthermore, a pollution incident occurring in 2004/2005 was mentioned which led to emissions of Hg at the time.

The samples were the same as those for study on sediment fauna and an additional station at Raunesvika.

The results showed **elevated levels of Cu, Pb, tributyltin (TBT) and PAHs**, leading to classifications as classes II to IV. On the other hand, all stations were classified as “background” (class I) with regard to Hg concentrations. It was noted, however, that **Hg concentrations had increased** since 2009 at most stations.

The stations identified as the most problematic ones with regard to sediment fauna were not distinctly different from other stations with regard to sediment chemistry. In fact, the station Grønavika with decreasing biodiversity was classified as “background” for all parameters, and none of them increased from 2009 to 2012.

It was also remarked that **concentrations of Zn increased** at some stations although they were classified as “background”. In addition, **Hg, Cu, TBT and PAHs increased** from 2009 to 2012.

In summary, TBT seemed to remain an issue, in accordance with previous measurements. Potential problems with Zn, Hg and PAHs were identified in some of the other measurements and seemed to be confirmed here. It is unclear whether increasing concentrations in themselves were considered problematic although the concentrations stayed within class I (“background”).

i) Sediment ecotoxicology

Using an algae growth inhibition test, the same samples as in the previous two sections were analyzed for ecotoxicological effects. Station VA6, which was most problematic with regard to biodiversity, was not included in this ecotoxicological study because of insufficient sample material.

The results were evaluated in relation to each other and in relation to values from 2009. It was not possible to find a consistent improvement since 2009.

The station with the highest ecotoxicological effects had the lowest biodiversity in 2009, but had improved in 2011. The station with the second highest ecotoxicological effects was that with decreasing biodiversity. Thus, there is some internal consistency between the tests.

The conclusion of no potential toxicity that can be related to emissions from AF Miljøbase Vats did not seem quite as obvious to the reviewers.

j) Naturally occurring radioactive elements

This part of the study was related to the license issued by Statens Strålevern with regard to treatment and storage of radioactive waste.

The same sediment samples as described above were used for analyses of a range of radioactive elements (with the exception of VA7 in Yrkefjord for which there was not sufficient material). Furthermore, crabs and wastewater were analyzed.

Two sediment stations (VA4 and VA5) showed **activities of ^{226}Ra and ^{210}Pb that were higher than in 2009**. VA4 was the station with decreasing biodiversity and it was among the stations with ecotoxicological impacts. These parameters were not obvious at VA5.

The authors noted **unusually high activities of ^{40}K** at sediment station VA1, which is relatively deep (300m) and located at the merger of Vatsfjorden and Yrkefjorden. This station had also shown elevated levels of Cu, Pb and PAHs in the studies discussed above. It is also highest for ^{137}Cs and ^{228}Th.

The wastewater samples showed **increased levels of ^{238}U, ^{235}U, ^{210}Po and ^{210}Pb** compared with measurements in 2011 or before.

In summary, the report showed that some stations had elevated levels of some radioactive elements in sediment, but it remained unclear whether these originated from AF Miljøbase Vats. No other sources were discussed. Natural levels were not discussed either, but the increases observed for ^{226}Ra, ^{210}Pb, ^{238}U, ^{235}U and others did not support a high natural background.

k) Metals in mountain fern moss *(Hylocomium splendens)*

The purpose of this study was to study potential airborne metal pollution from AF Miljøbase Vats. There were no pollution categories (Tilstandsklasser) for this matrix, which means that the results were mainly compared with stations considered as reference stations. The samples collected in early 2012 represented growth since 2011.

Station 12 was highest for all metals (i.e. As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Zn, Ba and V) except Mn and Sn. This station was described as "AF Miljøbase Vats, directly opposite the plant, in the forest (west)". The authors described that there were higher concentrations near the plant than at distance and that beyond a radius of 500 m, background levels were measured.

Soil samples from the same stations supported these results. Station 12 had the highest concentrations of all metals measured, except for V. Station 14 had similarly high levels (described as "AF Miljøbase Vats, north of the rock wall, opposite the road"). However, the Hg levels in these samples were 0.71 and 0.81 mg/kg dry weight, while they reached up to 5.33 mg/kg dry weight in the soil samples analysed directly at the plant (discussed under 1d). It is unclear how these samples relate to each other, both with regard to location and pollution. Zn exceeded the levels for "moderate" pollution at station 12 and 14, however, the authors highlighted that the classification applied to mixed soil samples, and these samples were surface samples.

A comparison of the moss results with results from previous years showed **lower levels in 2012 than in 2010 and 2011, but higher than results from 2009**.

The radius affected by the plant was determined to be 500 m, which was less than in some previous years, but more than in 2008.

Correlation analyses showed correlations of Cd, Cr, Hg, Cu, Ni, Zn, Ba og V, while Mn and Sn did not follow the other metals. The authors mentioned that the **pattern of metals in the moss and soil samples was the same as that in dust on the pier.**

l) Conclusions and recommendations

This section summarized the main findings of the sub-studies 1a) to 1k). Consistently with the description and discussion of the results in the individual sections, the main conclusions were about the environmental classification (Tilstandsklasser) as well as the temporal development.

With regard to Hg in mussels, the authors compared the results with EU limits in seafood. In addition, it would be relevant to compare with WFD EQS values.

The conclusions from the ROV study did not mention marine litter although this was highlighted in the specific section of the report.

This section only contained two specific recommendations, i.e.
- further monitoring in soil and studies into the distribution mechanisms of Hg (related to sub-study 1d)
- further sampling of floor moss and further efforts to reduce emissions from the pier area (related to sub-study 1k).

3.2.2 NIVA report on environmental monitoring 2012

a) Treated process water emitted to the fjord

The purpose of this sub-study was the same as described in section 1b). It was specified here that the process water was pre-treated. Following this step, it was combined with rain water for treatment in a sand filter and subsequently emitted to the fjord at a depth of 23 m.

The measuring programme was the same as in 1b). The same results were found with regard to high particle loads and high conductivity, possibly caused by inflowing saltwater.

With regard to metals, the results also agreed with those of 1b), in terms of **elevated levels of Cu, Zn, Cr and Ni**, i.e. concentrations above the “good” environmental quality class defined by KLIF. In addition, **levels of As** were elevated in one of the quarterly samples.

Cu was compared with EU WFD EQS values. Both annual average and maximum allowable concentrations of the WFD were exceeded for Cu by all four quarterly samples.

Although not commented on the report, **levels of V** were up to 10 times higher levels than in the previous report.

Regarding the organic contaminants, the previous results are confirmed, in terms of high concentrations of **alkylphenols, alkyl ethoxylates and perfluorinated alkylated substances (here: PFOS and PFOA)**. The first two compound groups had higher concentrations than in the previous report. For PFOS and PFOA, this was difficult to say because of a large variation among the quarterly samples. However, the authors noted that PFOS had increased over the measurement period.

Other organic compounds that were detected, but did not show increasing levels were organotins, dichlorophenols and dioxins/furans. In addition, PAHs were detected for the first time, but only in two of the four samples.

None of the inorganic parameters exceeded the levels of emissions accepted by KLIF. These levels had been reduced compared with those in the previous report. This led to increases in the relative emission loads (percentage of acceptable emission), while the absolute emission loads were largely unchanged.

b) Fish and shellfish

The measurement programme had been extended compared with the previous report, with additional species and stations.

Regarding the metals in mussels, previous results of **elevated levels of As, Cr and Hg** were confirmed. Hg concentrations at two of the three stations were classified as “marked pollution” (which had been “moderate” previously). The Hg values exceeded the WFD EQS for biota at all three stations. The authors suggested sampling from additional stations close to the plant, maybe with additional caged mussels.

Regarding the organic contaminants in mussels, the high detection limit described for PCBs in section 1c) has become considerably lower, i.e. reduced from 10 µg/kg to 0.05 µg/kg. Consequently, PCBs could be detected in all samples, however, concentrations were low (< 1 µg/kg wet weight).

While HCB and DDT were comparable to levels in the previous report, PAHs in blue mussels were lower by a factor of 3-4.

Regarding the analysis of cod, Hg was now classified as “good”. However, the concentrations exceeded the EU WFD EQS of 20 µg/kg wet weight. PCBs could now be detected in cod fillet and liver, because of lower detection limits. Surprisingly, the PCB concentrations in cod liver were 10 times lower than in the previous report, while HCB and DDT were found to occur at the same level.

Although not discussed in the report, there might still be some methodological issues, which affect comparability between the 2012 and 2013 analyses.

The remaining analyses in biota were in line with the results for mussels and cods, in terms of elevated levels of Hg. HCB was elevated in flatfish from one station, i.e. 10 times higher than at the other stations. Cd had surprisingly high levels in crab claws from one station.

In summary, the methodological issues of too high detection limits had apparently been resolved. However, there seemed to be inconsistencies for PAH and PCB concentrations between the two years of sampling.

c) Groundwater pollution

The purpose and design of this sub-study was the same as described under 1e). The results also were similar to the previous report although Hg concentrations were slightly higher (i.e. up to 9 ng/L). One sample had a concentration of Fe, which was 5 times higher than the second highest concentration (2 and 0.4 mg/L), but not discussed further.

d) Naturally occurring radioactive elements

This study was different from the one in the previous year as it did not include sediment analyses. Perhaps sediment was not analyzed on a yearly basis because of low sedimentation. This means that some observations of elevated activity in the previous report were not studied further.

While the wastewater samples of the previous study showed increased levels of ^{238}U, ^{235}U, ^{210}Po and ^{210}Pb, only ^{226}Ra, ^{228}Ra and ^{210}Pb were analyzed in the present study. The results were described as low, typical of water in contact with natural minerals.

In summary, there was not full consistency between the studies in 2012 and 2013. The reasons for a slightly different approach were not given in the report. This sub-study was not performed by NIVA (except for providing crab samples).

e) Metals in mountain fern moss *(Hylocomium splendens)*

This sub-study had been designed and conducted in the same way as previously, i.e. metals were analysed in moss and accompanying soil samples. It was highlighted that the license by Miljødirektoratet (former KLIF) now also regulated the amount of settleable dust emitted by the plant. The metal levels in the moss reflected uptake the previous year.

The results agree with those in the previous report. **Stations 12 and 14 were again highest for all metals.** There were tendencies of increasing concentrations, although not for all parameters at all stations. More specifically this means:

- Hg and Zn were lower than in 2010/2011, but higher than in 2009.
- Ba had increased from 2010 to 2011 and has since been approx. constant.
- Ni, Cu, Cr, and V had highest concentrations in 2013.
- For Cu, Cr and Ni, concentrations had increased steadily from 2009 to 2013.

The radius affected by the plant was again determined to be 500 m, in accordance with the previous year.

The results were again supported by the soil samples, which also showed **elevated Hg and Zn levels** at the stations 12 and 14, in terms of concentrations exceeding the "very good" environmental quality. As was elevated at stations 17 and 19, which the authors related to naturally occurring As.

f) Conclusions and recommendations

This section summarized the main findings of the sub-studies 2a) to 2e). With regard to the sub-study on process water, the authors concluded that Cu, Zn, PFOS, oktylphenol as well as octyl and nonyl ethoxylates required some attention. However, they considered it unlikely that the emission presented a risk for the environmental status of Vatsfjorden.

With regard to the fish and shellfish, the conclusion was that the plant had not contributed to a significant pollution of fish and shellfish in Vatsforden, with a possible exception of Hg in mussels from the inner fjord.

With regard to the groundwater samples, it was concluded that only Hg was slightly elevated, but still representing "good" environmental quality (Tilstandsklasse II).

With regard to the floor moss measurements, it was concluded that the radius affected by the plant was smaller than in 2010/2011. Other results, e.g. those of increasing concentrations over time, were not included in this section.

In summary, the authors concluded that the plant was operated in a satisfactory way and within the requirements set by the environmental authorities. No recommendations were given.

3.3 Reviewers' conclusions

1. Assessments

The reports present extensive and thorough studies of the area around AF Miljøbase Vats, based on various indicators of pollution. The main objective of the report published in 2013 was to assess the state of the environment and potential impacts from the plant. For the assessment, most measurements were compared to environmental quality classes (Tilstandsklasser) laid down by the Norwegian Environment Agency (Miljødirektoratet, former KLIF). However, it was not quite clear to the reviewers which category was the target, i.e. whether all measurements were expected to fall into the “Background” or “Very good” category. It was not entirely clear either what had been pre-defined as acceptable in terms of potential environmental impacts.

The main objective of the report published in 2014 was to check compliance with the standards and requirements set by the Norwegian Environment Agency in the license for the plant operation. In this context, it is unclear for the reviewers how the occurrence of certain organic pollutants in the process water was evaluated, given that the requirement is described as “The water must not be polluted with priority compounds”.

In some cases, but not consistently, EU WFD EQS values were used for comparisons. It was not clear to the reviewers whether the primary target was to meet WFD EQS values or Norwegian environmental quality classes or the lowest of both. The authors did not compare with OSPAR Environmental Assessment Criteria (EAC), which are available for metals and organic parameters in several marine media.

The authors also assessed the temporal development, i.e. environmental quality was generally expected to improve with time. Also in this case, the discussion of potential environmental impacts would have been clearer if specific criteria had been set with regard to the expected improvement. Several parameters increased in concentration over time (see e.g. 2e), but this did not give rise to recommendations for further study or specific actions.

Thus, the reports include an impressive amount of data, but they are of descriptive character. In the reviewers’ view, the reports would benefit from clear assessment criteria / environmental targets and possibly a risk assessment section. The reviewers are aware that this might not have been NIVA’s task in this connection.

2. Methodological issues

In the report published in 2013, some detection limits appeared relatively high. For example, the detection limits of individual congeners of polychlorinated biphenyls (PCBs) were 10 µg/kg. The reviewers assume that this was based on fresh weight, which would lead to higher numbers on a dry weight basis. OSPAR EAC for mussels ranges between 1.0 and 1790 µg/kg dry weight for PCBs (OSPAR, 2009). The current assessment criteria in use are between 1.2 and 80 µg/kg dry weight. Background assessment concentrations (BAC) for mussels are 0.60 – 0.75 µg/kg dry weight (OSPAR, 2009; 2013). Detection limits to be met for analysis of fish and shellfish in the Danish environmental monitoring programme range between 0.05 and 0.5 µg/kg wet weight (Bekendtgørelse om kvalitetskrav til miljømålinger, BEK nr. 900 af 17/08/2011; https://www.retsinformation.dk/Forms/R0710.aspx?id=160496).

Based on the detection limits used in the older report, comparisons with BAC are meaningless. For comparions with OSPAR EACs, the detection limit should be at least 3 times below the EACs to ensure good analytical quality of the results at or above the EAC value. Only for PCB-153 (with an EAC of 80 µg/kg dry weight), the detection limit would be sufficient.

In the report published in 2014, the detection limits of PCBs were lower, i.e. at the level required for the Danish environmental monitoring programme. Cod liver was the only biological sample with PCB concentrations above detection limits in both reports. However, there is a striking difference of roughly a factor 10 between the PCB concentrations in the two reports. The spatial variation (i.e. between stations) is similar in the two years. The reviewers were surprised about this large temporal variation and suggest verification.

From a methodological point of view, it is questionable to analyse polycyclic aromatic hydrocarbons (PAHs) in fish as they are likely to be degraded (OSPAR, 1999). Analyzing PAHs in fish might create a bias towards non-detects. The reviewers looked for the reasoning behind the PAH analysis in fish and found that potential health risks should be assessed (2014 report, page 21). However, it says on the same page that NIVA would not assess whether these samples were eatable as these assessments are the responsibility of the food authority. The reviewers suggest clarifying this approach, perhaps with a focus on environmental assessments.

As the data material is very large and covers several sub-studies, it would be interesting to combine the data sets. Multivariate statistical methods could be applied to derive potential patterns in the data and to analyse whether there is a typical “chemical fingerprint” of AF Miljøbase Vats.

The report published in 2013 included a recommendation by NIVA of a more detailed mapping of Hg concentrations in the area of the plant, also to understand transport patterns and spreading mechanisms. This recommended study had apparently not been performed by the time of the 2014 publication.

3. Environmental issues

The data material presented and discussed in this report had some recurring themes. The reviewers identify these as

- high particle loads
- elevated levels of Cu, Zn and Hg
- increasing levels of Hg
- possibly elevated levels of Cr, Ni and As, where As might have natural causes
- organic contaminants, in particular PAHs and perfluoroalkyl substances (such as PFOS and PFOA), alkylphenols and alkyl ethoxylates.
- increasing levels of PFOS (and potentially other perfluoroalkyl substances)
- elevated levels of PAH
- potentially continuing issues with organotins
- litter close to the pier.

3.4 References

Green, N.W.; Knutzen, J. (2003) Organohalogens and metals in marine fish and mussels and some relationships to biological variables at reference localities in Norway. Marine Pollution Bulletin 46, 362-377.

OSPAR (1999) JAMP Guidelines for Monitoring Contaminants in Biota. Ref. no. 1999-2. www.ospar.org

OSPAR (2004) OSPAR/ICES Workshop on the evaluation and update of background reference cocnentrations (B/RCs) and ecotoxicological assessment criteria (EACs) and how these assessment tools should be used in assessing contaminants in water, sediment and biota. Hazardous Substances Series. Wiorkshop on BRC-EAC 9-13/02/2004. ISBN 978-1-907390-08-1.

OSPAR (2009) Background Document on CEMP Assessment Criteria for QSR 2010. Monitoring and Assessment Series. Publication no. 461/2009. ISBN 1-904426-52-2.

OSPAR (2013) Levels and trends in marine contaminants and their biological effects – CEMP Assessment Report 2012. Monitoring and Assessment Series. Publication no. 596/2013. ISBN 978-1-909159-29-7.

4 Reviewers' recommendations with regard to follow-up studies that could be made

Very little is known about the contribution of fugitive dust from Miljøbase Vats to the surrounding air. Also, it is not clear whether mercury is released to the air in any significant amount, either through evaporation or by dust releases.

It is possible to address these questions in an indicative manner by conducting measurements of certain pollutants, e.g at the veranda of the Fish farm. Local meteorological data are essential in order to interpret such data, alongside with some information on activities going on at Miljøbase Vats. Relevant pollutants are Hg^o, PM_{20}, $PM_{10,}$ $PM_{2.5}$, PM_1, CO and bulk sampling of heavy metals.

An analysis of such data would provide information on the level of atmospheric pollution, and to what extent it is associated with releases from Miljøbase Vats.

Detailed dispersion modelling may be considered in case the measurements point to a need for it but such detailed modelling would involve severe difficulties in regard to estimating the source term. Furthermore, the fact that dispersion takes place in a very hilly terrain with complex flows would make detailed dispersion modelling quite resource demanding.

4.1 Specific recommendations

We therefore have the following recommendation for future activities. We have to outline that there is not any guarantee for significant result from the proposed activities. The measurement point is located next to Miljøbase Vats and it will be difficult to pick out "positive" observations independent of the matrix.

1. Atmospheric compounds relevant for assessing pollutants from Miljøbase Vats should be measured at the veranda at the Fish Farm:
    - Hg^o, PM_{20}, $PM_{10,}$ $PM_{2.5}$, and PM_1, CO, Bulk sampling of heavy metals
    - Meteorological data (using a sonic anemometer)
    - Webcam
2. Multivariate analysis of existing data across years and sub-studies (based on the NIVA reports) should be made to reveal potential patterns in the data. The method can also be used to analyse to which extent the chemical pattern can be related to certain emission sources.
3. New systematic measurements of organic contaminants and metals in biological samples. As a minimum, these should include PCBs (to verify former and present levels. If sample material from 2012 still exists, this could be included for re-analysis), perfluoroalkyl substances (to study accumulation of potentially emitted PFOS and related compounds), PAHs (shellfish only), organotins (shellfish only) and metals. Stations should be identical with the NIVA approach, possibly with additional stations closer to the plants. Primary samples should be cod and

blue mussels, additional samples of dab could be considered in (Green & Knutzen, 2003). Sampling and analysis should follow OSPAR guidelines.

4. Measurements of organic contaminants and metals in sediment cores. As a minimum, these should include alkylphenols, alkyl ethoxylates, PAHs, organotins and metals. The stations should present a gradient from the process water outlet into the fjord. From a cost-benefit point of view, it might be most relevant to analyze a full sediment core of the closest and most distant sample, and surface sediment of the samples in between. Sampling and analysis should follow OSPAR guidelines.
5. Measurements of some WFD priority substances in water. The EU WFD has set environmental quality standards (maximum allowable concentrations and annual averages) for a range of priority substances (organic contaminants and metals) in surface water, including coastal waters. Because of the varying concentrations in water a time-integrating method, i.e. passive sampling, might be most beneficial, with focus on metals and hydrophobic compounds. These measurements can be supported by spot samples of water.