SAVE RADLEY LAKES

Report No. SRL/FP/002.2

Pollution Risks Associated with the Deposition of PFA Slurry into the Radley Lakes

by

D M M Guyoncourt, B J B Crowley

and

R M G Eeles

POLLUTION RISK REPORT

commissioned by

Save Radley Lakes

(Reissued with minor revisions only)

April 2006

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RWE npower's proposal would lead to unnecessary pollution of the environment due to the continued discharge of toxic effluent into Pumney Stream and thence to the Thames itself. There is also a problem of fine windblown PFA particles.

Analysis of PFA and leachate compositions now in the Public Record, have shown that discharges into Pumney Stream frequently exceed the Environmental Quality Standards for a number of contaminants, many of which are toxic.

An average of nearly 2 Megalitres per day of supernatant PFA effluent is being discharged directly into the Thames. One would have thought that effective and careful monitoring and control of this discharge would be being carried out, by both the Power Station and the Environment Agency, particularly in view of the expected variability of its content. We see little evidence that this is happening.

This report raises serious concerns about this method of PFA disposal, based upon our understanding of the nature of PFA, monitoring data supplied by the Environmental Agency and eyewitness accounts of actual pollution events.

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EXECUTIVE SUMMARY

The main points which the Save Radley Lakes Action Group wishes to make are summarised below:

1. The quantity of toxic metals and metalloids discharged into the Thames is significant and adds up to a daily total of over six kilograms.
2. The vast amount of potentially polluting material locked up in a bunded lake represents a long-term hazard, particularly as many of the dangerous substances contained in it are bio-accumulative and can, over time, become concentrated in the biological environment.
3. The Environment Agency currently applies the lower quality Environmental Quality Standard (EQS 2) to the Pumney Stream discharge. Discharge records for July 99 to March 05 show that even this standard has been breached for boron, copper and vanadium. However we believe that the environmental quality of the Thames, as a potentially a salmonate river, should meet the higher standard and it is strongly recommended that this higher standard should also be applied to the Pumney Brook.
4. Serious pollution incidents are known to have occurred. In April 1998, pH levels in the discharge from Lake G to to the Pumney Stream reached dangerously high levels of alkalinity. This resulted in the Environment Agency temporarily withdrawing the discharge consent until effective measures were implemented to maintain the pH below a strict limit. Nevertheless problems with maintaining an adequately low level of alkalinity persisted throughout 1998. A severe pollution incident, witnessed by one of the authors but otherwise unsubstantiated, is alleged to have occurred in June 1998. In February 2001, there was a release of a substantial quantity of cenospheres into the Pumney

Stream. In recent years, no fish have been observed in the stream, which now appears to be biologically depleted. Bivalve molluscs are also notable by their almost complete absence and the stream bottom is now silty rather than gravely as previously.

5. There have been incidents of airborne fly-ash causing serious problems for local residents. Lakes E and F are less than 400 metres residential housing off Audlett Drive in Abingdon, and less than 100 metres from houses at Thrupp Farm. Potential problems of dust from the PFA are therefore very real.

6. We believe that monitoring of the discharges is insufficiently frequent to provide an accurate assessment of discharge levels, particularly in view of the variability of the composition of the fuel ash due to variations in the source and type of coal. This means that there is a significant risk of serious pollution occurring without it being detected at source.

INTRODUCTION

Pulverised Fuel Ash (PFA) is the residue from the burning of powdered coal at Power Stations. It is composed mainly of silica, alumina, iron and calcium in the form of silicaceous particles about 10 microns in diameter. It also contains a wide range of other elements such as arsenic, boron, cadmium, chromium, copper, vanadium and zinc most of which are toxic to humans and to wildlife at quite low concentrations. The ash particles are collected in electrostatic precipitators while the residual gases flow to the stack. The burning temperature is 1100 to 1700^0 C and at such temperatures many constituents are vaporised, however, many metal compounds re-condense on the surfaces of more refractory particles before entering the precipitator. These surface components are often water soluble and are not locked into the silicaceous material and therefore dissolve readily in water subsequently. It has been shown that most soluble material will dissolves within 5 minutes.

For transport from Didcot A Power Station to Radley Lakes, the ash is mixed with water to form a slurry containing 30% by weight of solids. This is pumped via an 8km pipeline to the Lakes. After the coarse PFA particles have settled out, the excess water is pumped to a treatment pond where alkalinity is reduced using CO_2 gas before discharging to the Thames via Pumney Stream. For every tonne of ash delivered, 2.3 cubic metres of leachate* is discharged to the Thames.

The composition of the PFA is monitored quarterly at Didcot A Power Station, and the leachate is monitored by the Environment Agency at the discharge point nominally on a monthly basis. However there was a period of almost three years (2000 to 2003) during which only one analysis was made. The pH of the leachate is monitored by the Power Station, but this record is not in the Public Domain.

A small component of PFA is in the form of hollow spheres (cenospheres). These have very low density and are harvested from the lake surface by RWE npower and are a valuable commodity with many industrial applications. They form a scum on the surface of the supernatant leachate, and can be blown across the water surface. When this material dries out, the cenospheres become readily airborne and can be blown long distances. The material is easily crushed and the resultant ultra-fine particles can enter the lungs and are potentially carcinogenic. There is also a radiological hazard from breathing or

* In this report, the term "leachate" is used to describe aqueous discharges that have been in direct contact with PFA. It is applied to all types of discharge: supernatant flow into watercourses as well leaching into groundwater.

ingesting PFA particles since they are likely to contain significantly elevated levels of natural radionuclides.

BIO-CONCENTRATION OF METALS

Many of the heavy metals that might be found in coal or in the resultant fuel ash are bio-accumulative, that is, they are absorbed more readily into biological tissue than they are excreted. This means that there is potential for bio concentration through take-up by successive generations of biological organisms leading to concentrations in the biological environment that are considerably in excess of the ambient concentrations that would otherwise occur. This amplification up the food-chain is most serious for predatory species, such as otters, which lie at the top.

Coal itself is fossilised plant matter, so there is already potential for bio concentration to have occurred already and to have elevated concentrations of bio-accumulative metals that were present in the environment when the coal measures were laid down. One cannot simply assume that heavy-metal contamination of coal is in line with that of surrounding rocks or soils that were not formed directly from biological matter.

Coal is sourced from different places around the world and virtually anything *could* be present in it. Therefore comprehensive analyses are needed for each coal burnt. Everything that is in the coal ends up somewhere in the environment, either in the atmospheric emissions, the ash, or the desulphurisation products.

The question of what is in the PFA is clearly closely related to the coal content. Basically the PFA is the oxidised (or partially oxidised) solid-phase remnants of the combustion of the pulverised coal that are removed from the gas stream as it enters the flue. Its main constituents are silica, alumina, iron and calcium in the form of fine silicaceous particles in the 10 micron range. If the ash particles were homogeneous then most of the metallic constituents would, in an alkaline environment, be “locked up” in the glassy silicaceous matrix. However this is not so, due to the volatilisation-condensation mechanism[1,2,3] whereby, at the combustion temperatures occurring in the boiler (1100- 1700ºC) some elements are vaporised and subsequently condense onto the surfaces of the finer particles as a highly reactive soluble glass phase. Elements that are enriched on the fine PFA particles in this way include[†] Cu, Pb, Zn, which are only harmful above threshold levels, and As, B, Be, Cd and Hg which are known to be toxic to plants and animals, even in small doses[4,5,6]. When PFA is mixed with water to form a slurry, many of these elements are rapidly released into the water, with chemical equilibrium with the ash being achieved in ~5 minutes[7]. Controlled dilution of decanted effluent is therefore required to establish concentrations below the limits set for the receiving watercourse. The solubility of many trace elements is sensitive to pH. High pH values (>9) decrease solubility of As, Cd, Cr, Cu, Ni, Hg, Pb and Zn and increase solubility of others such as Mo[8,9] (Boron?).

Once PFA is mixed with water, an effluent is rapidly created whose composition is, over a wide range of PFA:water ratios, largely independent of the water quantity. Once decanted off, this would generally require dilution with clean water to achieve compliance with regulatory limits. It is not clear whether Npower do this, and if so, where they take the water from. Once this effluent is discharged into a receiving watercourse, its constituents are available for uptake and bioconcentration by aquatic flora and fauna[10,11,12].

[†] For explanation of chemical symbols, see APPENDIX 3:

The uptake of metals (Cd, Cu, Ni and Zn) from PFA effluent by the Water hyacinth, *Eichhornia crassipes,* has been studied by Cordes et al[13]. they observe bioaccumulation ratios, the ratio of the concentration in the plant tissue (µg/g) divided by the concentration in the water (µg/ml) for cadmium, for example, in plant tops after 7-14 days, of between 400 in a high cadmium slurry (Ratcliffe-on-Soar power station) and 1600 in a low cadmium slurry (Indraprastha power station, India), both equating to elemental concentrations in the range 1-3 ppm w/w which is ~3 orders of magnitude greater than the concentrations in the effluent.

There is therefore considerable potential for bio-concentration of toxic metals in plants, and in animals that feed on them, both within water courses receiving the PFA effluent, and later upon the ash filled pits after restoration and planting, particularly on those where the ash is contained in bunds from which the soluble material is unable to leach out.

This is compounded by the proposed lack of significant overburden which would allow plant roots more access to dissolved material emanating from the ash.

Plants found growing on the PFA pits east of the main railway line include: Slender Centaury, *Centaurium tenuiflorum*, Annual Beard Grass, *Polypogon monspeliensis* together with species of willowherb and oraches. These have stunted growth; particularly those growing in recently deposited material (3 to 5 years old). Slender Centaury plants are often less than 2 cm in height on recently deposited PFA. Plants growing on older PFA deposits are less stunted[14]. These pits (east of the main railway line) are open to surrounding ground water so that the leachate is free to flow away. In this way, it is presumed, contaminants are gradually depleted by transport to surrounding groundwater. Transport of leachate will not occur with the pits west of the railway line where the PFA is isolated from surrounding groundwater by 1.25 m thick clay linings. It is probable that contaminants in these pits will remain for decades or even permanently.

EFFECT OF THE BUNDS

Without bunds, practically all the leachate will reach the Thames over a period of time via groundwater which flows north to south. The rate at which this occurs depends on the permeability of the PFA. A proportion also reaches the Thames initially, pumped via Pumney Stream.

With bunds again a proportion of the leachate is pumped directly to the Thames via Pumney Stream initially. There will be a contaminant residue left in the pits - probably permanently. It is likely the concentration of contaminants will increase with depth due to rainwater dilution at the surface and subsequent pumping away. Some contaminants might escape by ionic diffusion through the bund. Some will be retained at the surface for a much longer period by the bio-accumulation mechanism)

The phase II disposal process involves using clay bunds to contain the ash so as to prevent leachate entering the groundwater. From a pollution point of view this has two undesirable consequences: (1) greater volume of effluent containing both dissolved and suspended pollutants enters the River Thames and (2) retention of concentrated leachate in the environment with potential to enter the food chain, via bio-accumulative processes as described above, over a long period of time. The protection of groundwater may be desirable, though it has already been compromised by Phase I disposal operations, which used unbunded lakes.

RADIOLOGICAL HAZARDS

Conservative estimates of the radioactivity of fly ash are given in a report[15] by ENTEC, in a report commissioned by DEFRA, as being[‡] ~1 Bq/g of which, for UK sourced coal, 85% is due to K-40 and about 15% is due to actinide decays. For “multinational coal” fly ash, these proportions are given as mean values of 70% and 30% respectively. However it is questionable whether these figures are meaningful, as considerable variability between coals from different sources would be expected.

The ENTEC report[15] goes on to say that the potential for leaching of contaminants from fly ash is considered to be low, due to low water solubility overall and the alkalinity of the effluent. However this argument is questionable, since the same argument was once used in respect of all heavy metals, and, as we have noted, many of these *do* get into the leachate.

There is risk of radon emanation from PFA indicating some potential risk posed by internal doses to construction workers using these materials[16]. Presumably, members of the public engaged in recreational activities on the surface of a restored “PFA lake”, would be subject to the same risks.

The ENTEC Report[15] concludes with the following unreassuring statement:

“The radionuclides present in coal ash decay via beta, gamma and alpha mechanisms, indicating that any risks to human health may come from external or internal doses, ie, via inhalation, ingestion, direct contact or proximity to contaminated materials.”

A thorough risk assessment addressing these issues will be essential if the space above a PFA dump is to be turned into a public amenity.

No monitoring of the actinide content of PFA from Didcot, or its radioactivity is routinely carried out.

DUST CONTAINMENT

It is a condition of the Planning Consent that Npower apply adequate measures to prevent release of PFA and cenospheres as airborne material. However looking at the way things are happening on lakes H/I, for example, this is not being done and moreover the degree of containment that would be required, given the proximity of E/F to homes and businesses, appears impossible to achieve. As the lake is filled, it is inevitable that the surface will dry off and loose ash and residual cenospheres trapped in pools etc will then be able to become airborne.

Airborne fly-ash has caused serious problems for local residents. One in particular, living at Pumney Farm, had her house inundated with the substance, which required a clean-up funded by Npower. During the hotter months the surface of PFA lagoons become dry and ‘dust-devils’ lift considerable quantities of the substance into the air.

PFA LEACHATE DISCHARGED TO THE THAMES

At Didcot A Power Station, the Pulverised Fuel Ash (PFA) is mixed with water to form a slurry which is pumped via an underground pipeline to Radley Lakes, 8 km distant. The mixture contains 70% water, 30% solids by weight, hence for every tonne of PFA transferred, 2.3 cubic metres of water is pumped with it to Radley. Coarser components of

‡ 1 Bq = 1 Becquerel = 1 radioactive disintegration per second.

the ash settle out in the lakes and decanted water is pumped to a treatment pond where it is treated with CO_2 gas to reduce its pH. The main components of the ash are insoluble refractory oxides, but 2 - 5% of the PFA component is water-soluble and this passes rapidly into solution in the carrier water. Because of the presence of large quantities of $CaCO_3$, the pH of the effluent is quite alkaline (pH 10 to 12). The CO_2 treatment aims to reduce pH below 9 for discharge to the Thames via Pumney Stream.

Because of the very large quantities involved, the absolute quantities of harmful and dangerous substances, even when present at quite low concentrations, can be significant. A typical rate of dumping, over recent years, is 300,000 tonne of PFA per annum. Hence the rate of discharge of leachate to the Thames is 1,900 m^3/day or 1.9 Megalitres per day. Based on average measured concentrations of contaminants as given in table 3, the average daily discharge of toxic metals and metalloids (in dissolved form) to the Thames is

Table 1 Average absolute daily discharge rates for some of the monitored contaminants

	Arsenic	Boron	Cadmium	Chromium	Copper	Iron	Lead	Nickel	Zinc
g/day	67	5800	2.6	213	35	160	17	51	54

POLLUTION INCIDENTS IN PUMNEY STREAM

There have been reports of various pollution incidents in this Stream. In April 1998, pH levels in the discharge from Lake G to to Pumney Stream reached dangerously high levels of alkalinity. This resulted in the Environment Agency temporarily withdrawing the discharge consent until effective measures were implemented to maintain the pH below a strict limit. The temporarily adopted solution was increased dilution. Nevertheless problems with maintaining an adequately low level of alkalinity persisted throughout 1998 and beyond. The biological consequences of this event were not reported.

At the time, this watercourse was believed to represent one of the most important fish nurseries in the district, and its biodiversity was confirmed by macroinvertebrate surveys carried out by Didcot Power Station in 1996 and 1999, which rated it as being of medium to high conservation value.

In June 1998, R Everett, and one of the authors, R M G Eeles, claim to have seen more than 1,000 dead and dying fish (i.e. those larger than about 1 inch) in the outlet to Pumney Stream, where water from the settling ponds is discharged. The number of dead fish less than 1 inch was estimated to be greatly in excess of 10,000. Only a week before, they had observed an extremely healthy, large, fish population in Pumney Brook. The Environment Agency were informed by letter and latterly by e-mail. Dr Eeles received no confirmation of the letter and the incident was apparently not acted upon. It is not recorded in the pollution registry, and, of course, since this alleged incident was never investigated, no cause can ever be established.

The effects of these incidents appear to have been transient, as fish were reported[17] to have “returned to the stream” in 1999; and the 1999 macroinvertebrate survey did not observe any adverse long-term consequences.

However, in February 2001, there was a release of a substantial number of cenospheres into Pumney Ditch coinciding with reports of dead fish by members of the public[18].

Nevertheless a site inspection, by Innogy, on 20 October 2001 reported "a tremendous amount of healthy fish" in Pumney stream[19]. This is the last time that the condition of the Pumney Stream has been commented upon in the Liaison Group minutes. Since then, ash pumping rates have increased and the stream has gone into decline.

This watercourse now appears to be 'biologically depleted' with no fish having been observed there for some years, and bivalve molluscs are virtually absent. The Pumney Stream has never recovered to its former biologically-rich state, and is no longer gravel, but instead muddy, bottomed. The once-clear water has since remained cloudy, often with a peculiar greyish-blue colouration. The EA however report a 'normal' population of invertebrates, which is not the observation of RMG Eeles who considers that the invertebrates present occur in very depleted numbers and, on the whole, comprise species of high tolerance to low water-quality habitats. They are, in the main, species such as pond skaters, which survive above, i.e., not in, the water. R Faulkner, who can verify the former state of the Pumney Stream, also observed a release of scum like substance that covered the whole Stream, probably related to the release of cenospheres into the Stream in 2001 and its possible consequences. A photograph of this incident is available.

A sample taken from the Pumney stream near to the discharge outlet in August 2005 confirms[20] that the stream has declined significantly from its former state. Water quality was very poor and the few species present were those that are characteristic of poor quality habitats.

PFA ANALYSIS

Ash analyses are carried out by Didcot Power Station and these are issued quarterly to the EA. Results for the period May 97 to November 04 (a total of 32 analyses) are presented graphically , in Appendix 1. It can be seen that the levels of some elements are relatively constant over the period, but some, such as Mg, Ca, Al, P and Ba, show wide fluctuations whilst other's such as As, Zn and Cu, exhibit transient increases (spikes).

Trigger levels (presumably to trigger corrective action) are given in the report and compared to maxima and average values in Table 2. The trigger levels have been exceeded 45 times in the 32 analyses. Phosphorus consistently exceeds the trigger level by factors of between 4 and 22. Boron and calcium are consistently very close to the trigger level, and each has exceeded their trigger levels by 49% and 141% respectively on 7 occasions. There is no evidence of corrective actions being taken.

It is suspected that trigger levels are set too high for elements such as As, Cr, Cu and V based on the incidence of exceeding of EQS levels for leachate discharged to the Thames (see below). Elements: Co, Hg, Sn and U were apparently not analysed.

Table 2 Dry PFA analyses from Didcot A Power Station May 97 - Nov 04

	trigger level mg/kg	average mg/kg	average % trigger	maximum mg/kg	maximum % trigger	number > trigger	tonne / year *
Al	130000	14270	11%	32000	25%		
Sb	300	8	3%	45	15%		2
As	200	50	25%	217.7	**109%**	**1**	15
Ba	1000	565	56%	2260	**226%**	**3**	169
B	178	151	85%	266	**149%**	**7**	45
Ca	25000	21716	87%	60170	**241%**	**7**	
Cd	6	2	28%	3	50%		1
Cl	-	-	-	-	-	-	
Cr	200	43	21%	65	33%		13
Co	-	-	-	-	-	-	
Cu	220	42	19%	259	**118%**	**1**	13
Fe	63000	18105	29%	32000	51%		
K	22000	1806	8%	13118	60%		
P	700	2887	**412%**	15541	**2220%**	**24**	
Pb	600	20	3%	67	11%		6
Mn	800	229	29%	442	55%		69
Hg	-	-	-	-	-	-	
Mo	100	11	11%	20	20%		3
Mg	12000	4620	38%	12205	**102%**	**1**	
Na	10000	766	8%	2231	22%		
Ni	300	30	10%	47	16%		9
S	5500	3343	61%	5500	**100%**	**1**	
Se	15	6	38%	9	60%		2
Si	250000	977	0%	2599	1%		
Ti	7000	885	13%	3456	49%		
Sn	-	-	-	-		-	
V	750	97	13%	135	18%		29
Zn	600	68	11%	454	76%		20
Total							**397**

The last column gives the quantity of the element based on a typical annual amount of PFA dumped at Radley. Only toxic elements with appreciable water solubility are included in this column. The total annual quantity of these elements amounts to almost 400 tonne.

ANALYSIS OF PFA LEACHATE AT PUMNEY STREAM

The PFA leachate is pumped from the lakes to a CO_2 treatment pond and thence to Pumney Stream. Samples are taken by the Environment Agency at the point of discharge (before mixing with stream water). The scheduled sampling frequency is twelve times per year and samples to be taken on random dates without prior warning. These analyses are in the Public Record at the Environment Agency and have been obtained for the period July 99 to March 05. In the event, only 32 samples were taken in the six year period (less than half the required amount) and only a single sample was taken in the period October 00 to August 03. A summary of these data, showing maximum and average values, is given in Table 3 (below) and the whole dataset is presented graphically in Appendix 2. The current Drinking Water Standard (DWS) and the Environmental Quality Standards (EQS 1 & EQS 2) are also given in the Table 3. The relevant standards for fresh water are

Table 3 Summary of analyses of leachate discharged to Pumney Stream, July 99 – March 05

	DWS (2000)	for a $CaCO_3$ content of 100 – 150 mg / l		Six year maximum			Six year average		
	μg / l	EQS 1	EQS 2	μg / l	% EQS 1	% EQS 2	μg / l	% EQS 1	% EQS 2
As	10	50	50	116	232%	232%	35	69%	69%
Dissolved As	10	50	50	80	160%	160%	33	66%	66%
B	1000	2000	2000	6340	317%	317%	3024	151%	151%
Ba		100	1000	not analysed			not analysed		
Cd	5	5	5	2.2	44%	44%	1.4	28%	28%
Dissolved Cd	5	5	5	1.8	37%	37%	1.3	25%	25%
Co		3	3	not analysed			not analysed		
Cr	50	20	200	315	1575%	158%	111	556%	56%
Dissolved Cr	50	20	200	310	1550%	155%	109	543%	54%
Cu	2000	10	10	52	524%	524%	18	181%	181%
Dissolved Cu	2000	10	10	84.4	844%	844%	18	181%	181%
Fe	200	1000	1000	230	23%	23%	83	8%	8%
Dissolved Fe	200	1000	1000	50	5%	5%	33	3%	3%
Hg		1	1	not analysed			not analysed		
Mg	50000			9000			7338		
Mn		30	30						
Ni	20	20	150	50	250%	33%	27	133%	18%
Dissolved Ni	20	20	150	50	250%	33%	24	121%	16%
Pb	25	10	125	20	200%	16%	9	89%	7%
Dissolved Pb	25	10	125	20	200%	16%	5	50%	4%
Se				not analysed			not analysed		
U				not analysed			not analysed		
V		20	20	920	4600%	4600%	207	1034%	1034%
Zn	5000	50	250	50	100%	20%	28	56%	11%
Dissolved Zn	5000	50	250	120	240%	48%	28	57%	11%
pH		9	9	9.6	107%	107%	8.4	94%	94%

DWS Drinking Water Standard revised in 2000
EQS Environmental Quality Standard for 100 – 150 mg/$CaCO_3$ / l
EQS 1: most sensitive aquatic life
EQS 2: less sensitive aquatic life

either EQS 1, for most sensitive aquatic life, or EQS 2, for less sensitive aquatic life. It is seen that:

under EQS 1 (most sensitive aquatic life):
the maximum exceeds EQS for: As, B, Cr, Cu, Ni, Pb, V, Zn
the six year average exceeds EQS for: B, Cr, Cu, Ni, V

under EQS 2 (less sensitive aquatic life):
the maximum exceeds EQS for: As, B, Cr, Cu, V
the six year average exceeds EQS for: B, Cu, V

It is seen that even under the most lax standard that could be applied, it is breached for boron, copper and vanadium.

The concentrations of contaminants (largely in dissolved form) measured in the discharge over the six year period, July 99 – March 05 ,are shown in table 4.

The two alternative Environmental Quality Standards EQS 1 and EQS 2 are also shown in the table and are those for a calcium carbonate concentration of 100 to 150 mg/l. It should be noted that these standards are applied as annual averages, not peak amounts.

Table 4: Average discharge concentrations for the period July 99 – March 05

		Arsenic	Boron	Cadmium	Chromium	Copper	Lead	Nickel	Vanadium	Zinc
Avg	µg/l	35	3024	1.4	111	18	9	27	207	28
Max	µg/l	116	6340	2.2	315	84	20	50	920	120
EQS1	µg/l	50	2000	5	20	10	10	20	20	15
EQS2	µg/l	50	2000	5	200	10	125	150	20	250

This shows that, over this period, the effluent discharged into Pumney Stream has exceeded the Environmental Quality Standard (EQS2) applied by the Environment Agency for two contaminants, notably Boron and Vanadium, while individual samples frequently exceed these standards by significant margins..

Because the Thames is potentially a salmonate river, and indeed meets the higher EQS standard as noted below, it is strongly recommended that the higher standard (EQS 1) be applied to RWE npower's effluent discharge. In addition to the elements already noted, discharges of chromium, nickel and zinc fail to meet this standard and lead would be close to its limit.

THAMES WATER QUALITY

The present water quality of the Thames is very relevant in deciding whether EQS 1 or EQS 2 should apply. Table 5 provides analyses of Thames water, taken from Npower's current IPPC application, at the intake to Didcot Power Station. It is seen that these meet the higher EQS 1 standard for all elements (except for Sn on one occasion: July 03).

Table 5 Quality of Thames water at CW intake at Didcot Power Station

	Jul-02 µg/l	Dec '02 µg/l	Jul '03 µg/l	Nov '03 µg/l	Jul '04 µg/l	Oct '04 µg/l	Average µg/l	EQS 1 µg/l	EQS 2 µg/l
As	<0.8	<0.8	<0.8	<0.8	0.8	0.8	<0.8	50	50
Ba	80	13	11	28	11	13	26		
Be	< 1	< 1	< 1	< 1	< 1	< 1	<1		
B	182	175	136	140	121	90	141	2000	2000
Cd	<0.1	0.2	<0.1	< 0.1	0.1	0.1	0.1	5	5
Cr	0.5	<0.4	2.2	< 0.4	0.5	0.4	< 0.7	20	200
Co	<10	<10	<10	< 10	< 10	< 10	< 10	3	3
Cu	<4	6	<4	<4	<4	<4	< 4	10	10
Hg	0.7	< 0.005	0.141	0.005	0.002	0.008	0.144	1	1
Mo	7	<5	43	< 5	< 5	< 5	< 12		
Ni	2	<2	3	< 2	2	2	2	150	150
Pb	< 1	< 1	< 1	< 1	< 1	< 1	< 1	10	125
Sb	< 0.3	< 0.3	0.7	< 0.3	0.4	0.3	0.4		
Se	<1	<1	<1	<1	<1	<1	<1		
Tl	<20	<20	<2	<2	<2	<1	<2		
Th	-	-	<50	<10	<10	<10	<10		
Sn	<8.0	<8.0	38	<8.0	<8.0	<8.0	8	25	25
Ti	4	<2	66	4	<2	2	13		
U	<20	<20	<2.0	<2.0	2	-	2		
V	2	2	5	2	2	2	2.5	20	20
Zn	56	7	7	33	9	50	27	75	250
pH	8.11	7.84	8.18	7.89	8.11	8.05	8.03	6 - 9	6 - 9

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The EA appear to have set the lower EQS 2 standard for discharges to the Thames and have assumed a calcium carbonate ($CaCO_3$) content of >250 mg/l. This is the *lowest possible* standard and seems inappropriate, since the water quality meets the higher standard, and the presence, in the Thames, of trout and occasional salmon, would seem to require the higher water quality standard.

TOXICITY TO AQUATIC LIFE

Arsenic Arsenic appears not to be very toxic to fish but affects molluscs at 10 µg/l level. It is bio-accumulative in both fish and molluscs.

Boron Many fish appear to be tolerant of boron, but aquatic plants are less so. Duckweed *Lemna minor*, 'population changes' were noted at concentrations between 0.2 - 20 µg/l. Waterweed *Elodes Canadensis* has an average toxic dose of 1000 µg/l. Water milfoil *Myriophyllum alterniflorum* has an average toxic dose of 2000 -5000 µg/l.

Cadmium is readily bio-accumulated by aquatic plants and animals[10,11,12,13], such as, and particularly, molluscs. It is also readily adsorbed by organic matter in soil. As a result, cadmium is highly persistent in the environment. Susceptibility to cadmium by aquatic organisms is very variable, with freshwater organisms generally being more susceptible than saltwater ones. Toxicity to animals depends upon amounts of Zn present, with elevated levels generally providing some degree of protection. A concentration of 1 μg/l in freshwater, of hardness above 100 mg/l $CaCO_3$, is considered harmful to aquatic life by the US EBI. The LC50 for rainbow trout is given as 30 μg/l. Because of its high toxicity, and environmental persistence, more precise and sensitive monitoring of Cadmium is required than of most other elements. Given that the principal source of Cadmium in the environment is from the residues of the burning of fossil fuels, this would seem more than desirable in this instance.

Chromium Certain species of fish and aquatic invertebrates are sensitive to chromium[21], showing reduced survival or growth at Cr(VI) concentrations >10 μg/l. In general, aquatic invertebrates are more susceptible to chromium than are fish[23]. The more toxic hexavalent form of chromium Cr(VI) is known to occur in PFA[22] in proportions of around 10% .

Copper 1 μg/l of copper is sufficient to cause mortality of 6% of juvenile trout and 5 μg/l caused 6 to 13% mortality of five species of toad[23]. Defects in juvenile trout are reported to occurr at concentrations between 1 and 5 μg/l.

Mercury is a significant threat to animals such as otters. Mercury poisoning is the single most significant factor that has caused the major decline in numbers of this species since the 1950's. Otters lie at the top of the food chain and have the consequent disadvantage of accumulating several orders of magnitude more mercury than organisms lower down the food chain. A lethal dose is something in the region of only 33 ppm (in the livers) in otters[24]. Older otters are of course more vulnerable. Despite the high toxicity of Mercury, and the likelihood of its occurrence as a reactive component of PFA, it is not monitored.

Vanadium The lethal concentration of vanadium (7day) to Rainbow Trout is reported by Sprauge, Holdway *et al*[25] as 2400 to 5600 μg/l and the threshold for chronic toxicity is judged to be 80 μg/l. For very young fry of the American flagfish *Jordanell floridae*, the 28 day LC50 is given as 900 to 1000 μg/l. In chronic exposures of flagfish, the egg-fry stage was the most sensitive one in the life cycle and mortality of such fry was the most obvious effect. At 170 μg/l of V, there were marginal effects on second generation fry, but no observed sublethal effects on older fish.

MONITORING OF PUMNEY STREAM

These records are very incomplete. In fact, for almost three years, between October 2000 and August 2003, only one sample was taken. This period was one of particularly intense dumping of PFA by RWE npower into Lakes G and H/I. In the years 01, 02 and 03, respectively 309, 125 and 312 thousand tonnes of PFA were dumped at Radley. *Ipso facto*, approximately 1.74 million cubic metres of leachate will have been discharged to the Thames, virtually totally unmonitored during that period. There are indications, from analyses at the beginning and end of the unmonitored period that there may have been high levels of As, B, Cr and V during that period. Recent EA tests since August 03 have omitted elements such as B and V and earlier records missed Cd. Elements known to be toxic and likely to be present in PFA, such as Mercury, Barium, Manganese and Uranium were never included in tests during the last six years. The fact that such a high proportion of the analysed elements exceed the standards indicates that many such breaches may have occurred un-noticed during the last six years.

RESIDUAL POLLUTION

Based on the analysis of raw PFA, it is estimated that about 1000 tonnes of toxic elements would be present in the quantity of PFA that could be contained within lakes E and F, less than 1% of which would be detected as leaving in the effluent. The bulk of the pollutants remain in the bunded lakes, where it is intended they should remain. This represents a potential long-term pollution problem, since this toxic material will leach out over time and will be taken up and bio-accumulated by plants growing in the PFA and by animals that feed on them. Unlike the situation with unbunded lakes, which cause greater pollution of groundwater in the early stages, this problem does not go away with time. The pollutants in a bunded lake are retained semi-permanently, unless and until the containment is breached.

CONCLUSIONS

Our main conclusions of are summarised as follows:

1. The quantity of toxic metals and metalloids deposited into the Thames as PFA leachate adds up to a total of over six kilograms per day. A much greater proportion of Thames water will be supplied to consumers in the future, if the Abingdon Reservoir is built. This will take water from the Thames downstream of Radley, so this disposal method may be creating risks for the future.
2. The vast amount of potentially polluting material that remains "locked up" in a bunded lake (~ 1000 tonnes) represents a long-term hazard, particularly as many of the dangerous substances contained in it are bio-accumulative and can, over time, become concentrated in the biological environment.
3. The effluent is discharged into Pumney Stream, which used to be an important spawning site for fish in this part of the Thames, and was of medium-high conservation value for macroinvertebrates. Pollution incidents were recorded in this watercourse in 1998 and 2001. Since then, during a period of lax monitoring and high ash pumping rates, the stream has gone into decline. This watercourse now appears to be 'biologically depleted' as no fish have been observed there for several years. The Environment Agency applies EQS 2 to this discharge. The table above shows that the average concentration over the six year period exceeds this standard for three elements: x1.5 for boron, x1.8 for copper and **x10 for vanadium**. **Vanadium is particularly toxic to fish fry.**
4. The Thames is potentially a salmonate river; indeed analyses of river water meet this higher standard. It is strongly recommended that the higher standard (EQS 1) be applied to RWE npower's effluent discharge. Were this to be applied, the additional elements: chromium, nickel and zinc would exceed the prescribed limits and lead would be close to its limit.
5. With the previously filled lakes, airborne fly-ash has caused serious problems for local residents. One in particular, living at Pumney Farm, had her house inundated with the substance, which required a clean-up funded by Npower. During the hotter months the surface of PFA lagoons become dry and 'dust-devils' lift considerable quantities of the substance into the air. Lakes E and F are less than 400 metres from the housing estate off Audlett Drive in Abingdon

an less than 100 metres from houses at Thrupp Farm. Potential problems of dust from the PFA are therefore very real..

6. Contaminants known to be at high levels in the original PFA and the leachate include: As, B, Cr, Cu, V. Chromium levels have exceeded the permitted level of 100µg/litre, but the EA's response was to raise, or consider raising, the permitted levels to the Environmental Quality Standard (EQS) value of 250µg/litre averaged over a year. This is the highest EQS level they could set and is that for non-salmonate (cyprinid) water with > 250 mg/l $CaCO_3$. We question whether this is an appropriate level for the Thames.

7. Some possible contaminants, such as mercury and cadmium, even though they may be present at quite low levels, are both highly toxic and highly bio-accumulative. For these reasons, much more stringent controls apply to these substances, which therefore need to be monitored much more carefully than the evidence suggests they are being.

8. Perhaps the biggest worry is the inadequacy of the monitoring. Given the potential risks and the day-to-day variability of the coal being burnt, one would have expected rigorous monitoring of the discharges. *Even when carried out correctly*, the frequency of monitoring is inadequate to measure, to any reasonable accuracy, what is being discharged, and with, as we understand it, discharge limits set at an annual average, rather than spot values, there is even more scope for serious pollution to occur.

APPENDIX 1: PFA Analyses

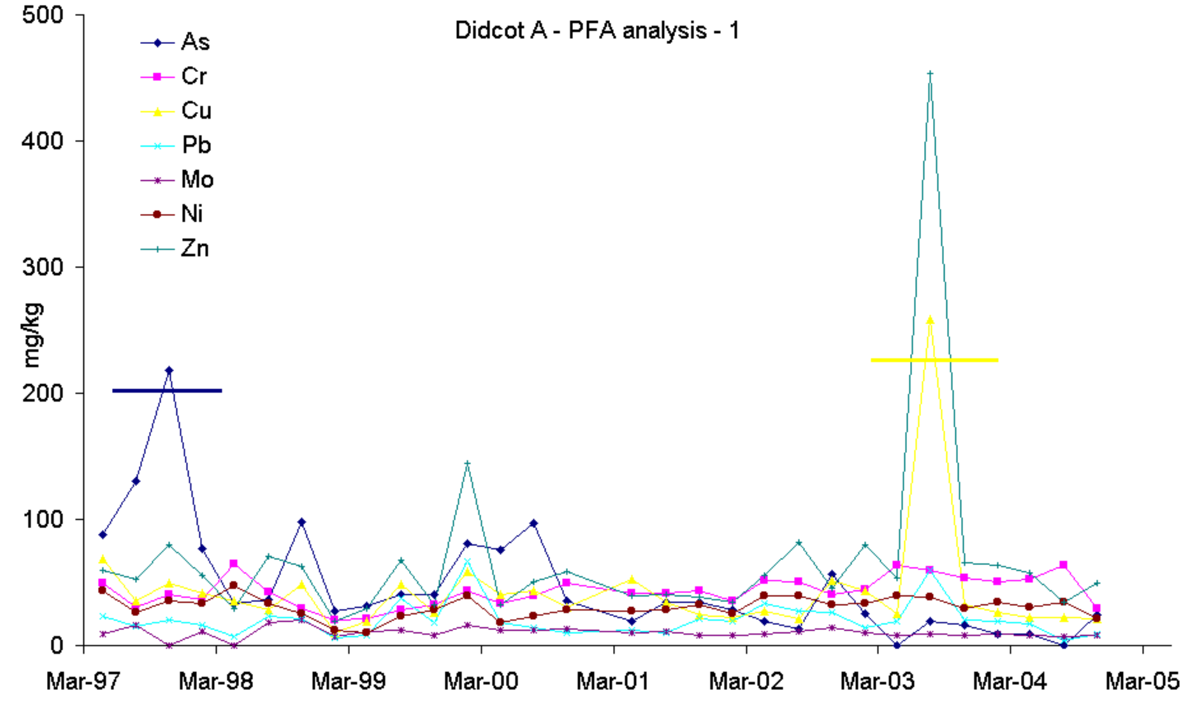

Figure A1.1 Analyses of PFA made at Didcot A Power Station (trigger levels indicated)

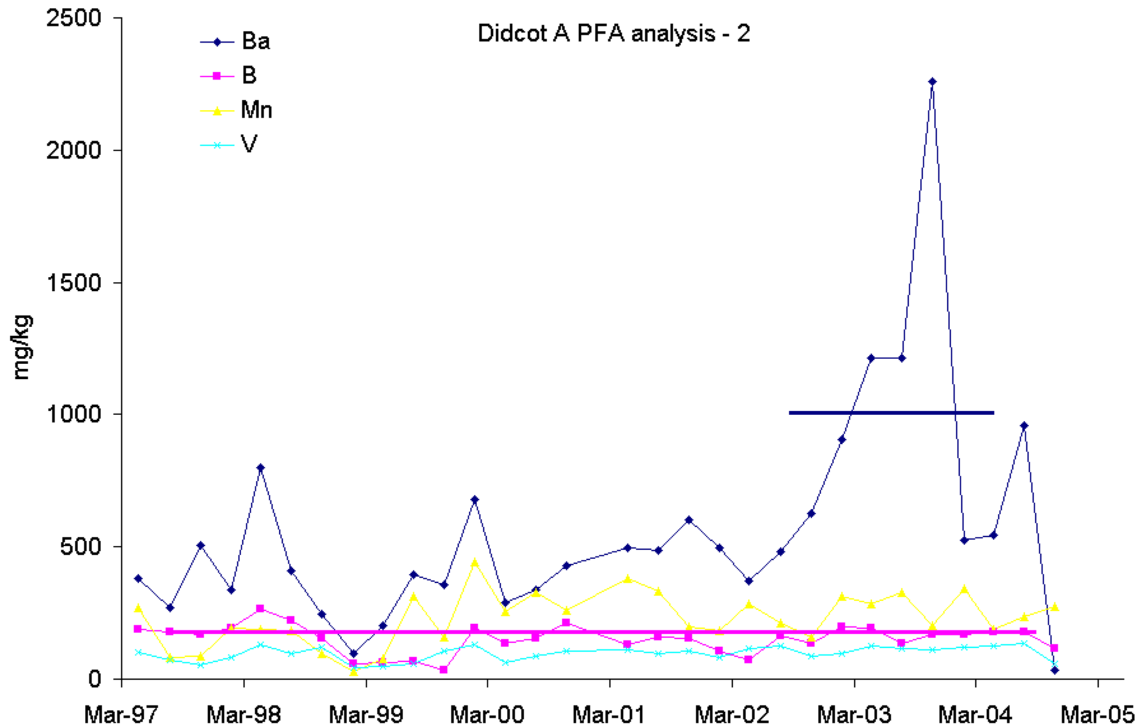

Figure A1.2 Analyses of PFA made at Didcot A Power Station (trigger levels indicated)

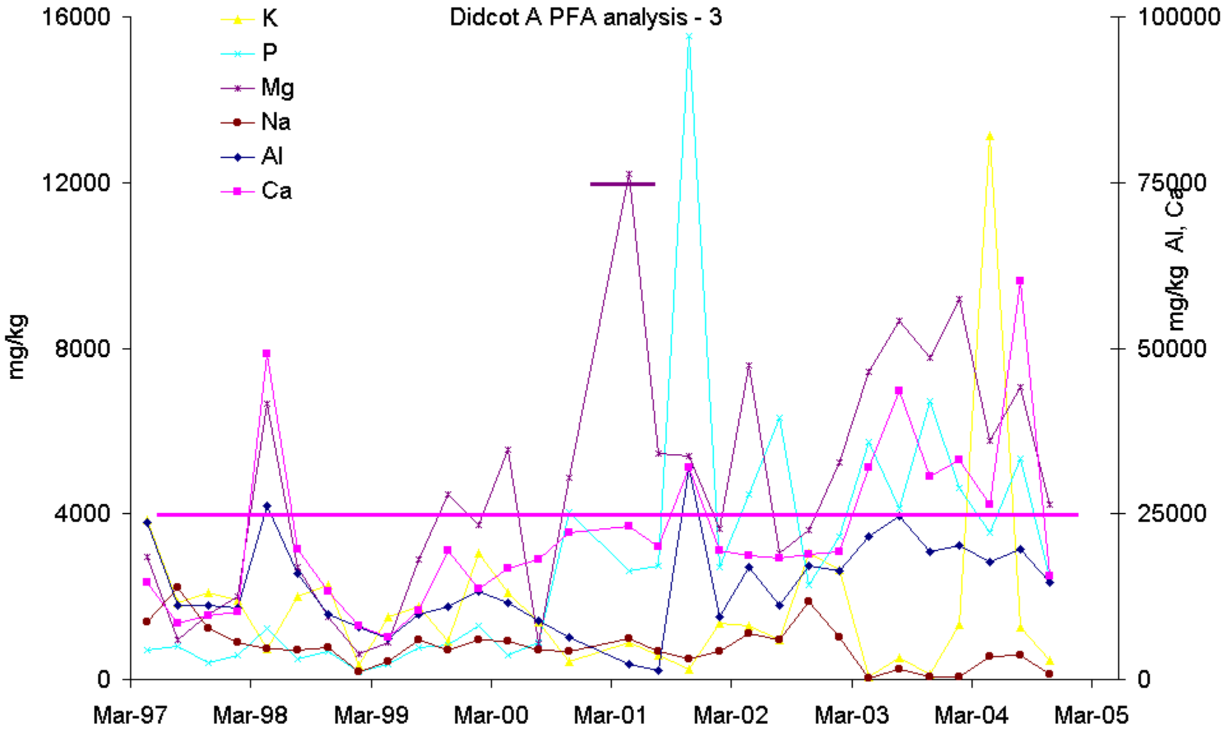

Figure A1.3 Analyses of PFA made at Didcot A Power Station (trigger levels indicated)

APPENDIX 2: Analyses of Leachate from Pumney Stream

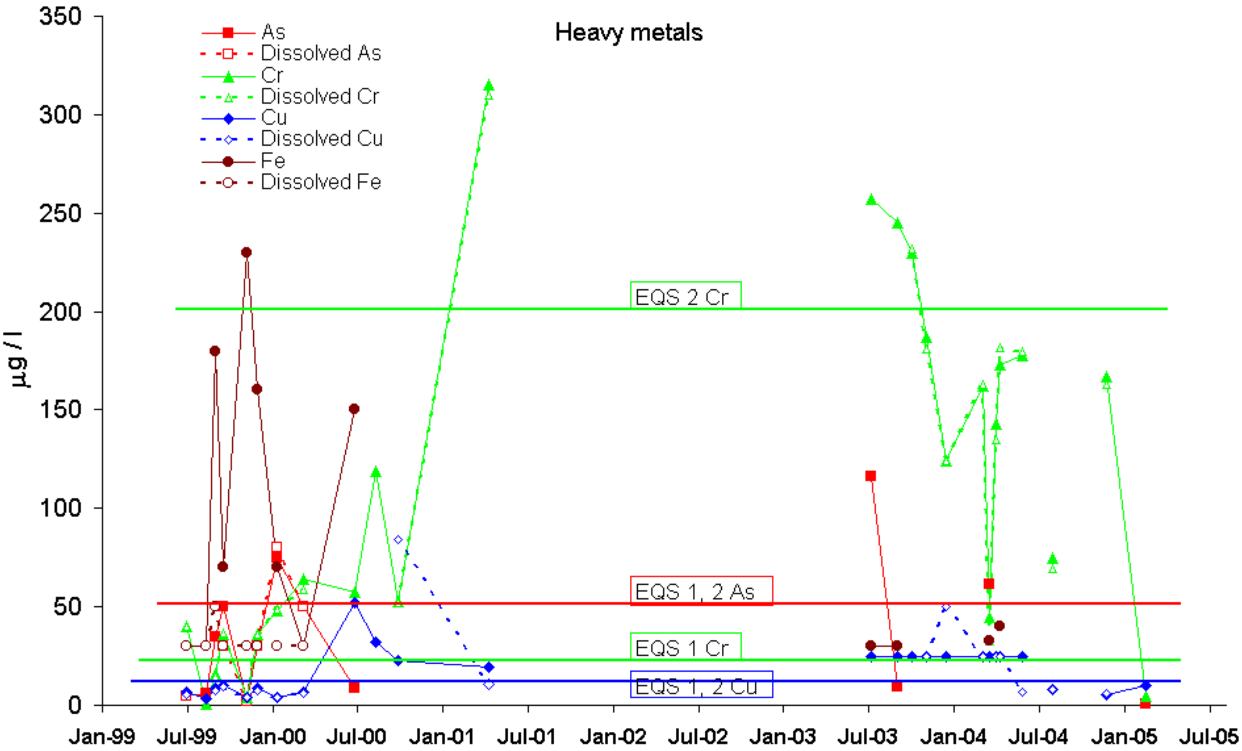

Figure A 2.1 Analysis of leachate – arsenic, chromium, copper, iron (EQS levels indicated)
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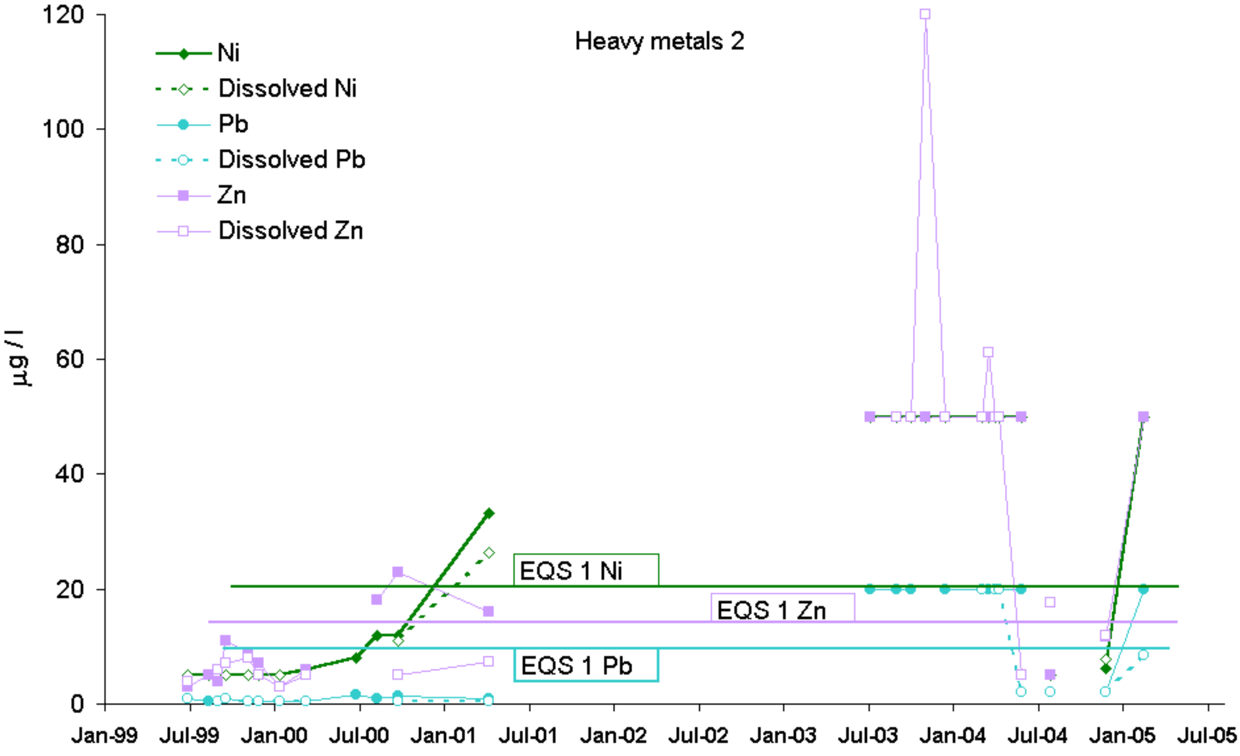

Figure A 2.2 Analysis of leachate – nickel, lead, zinc (EQS levels indicated)
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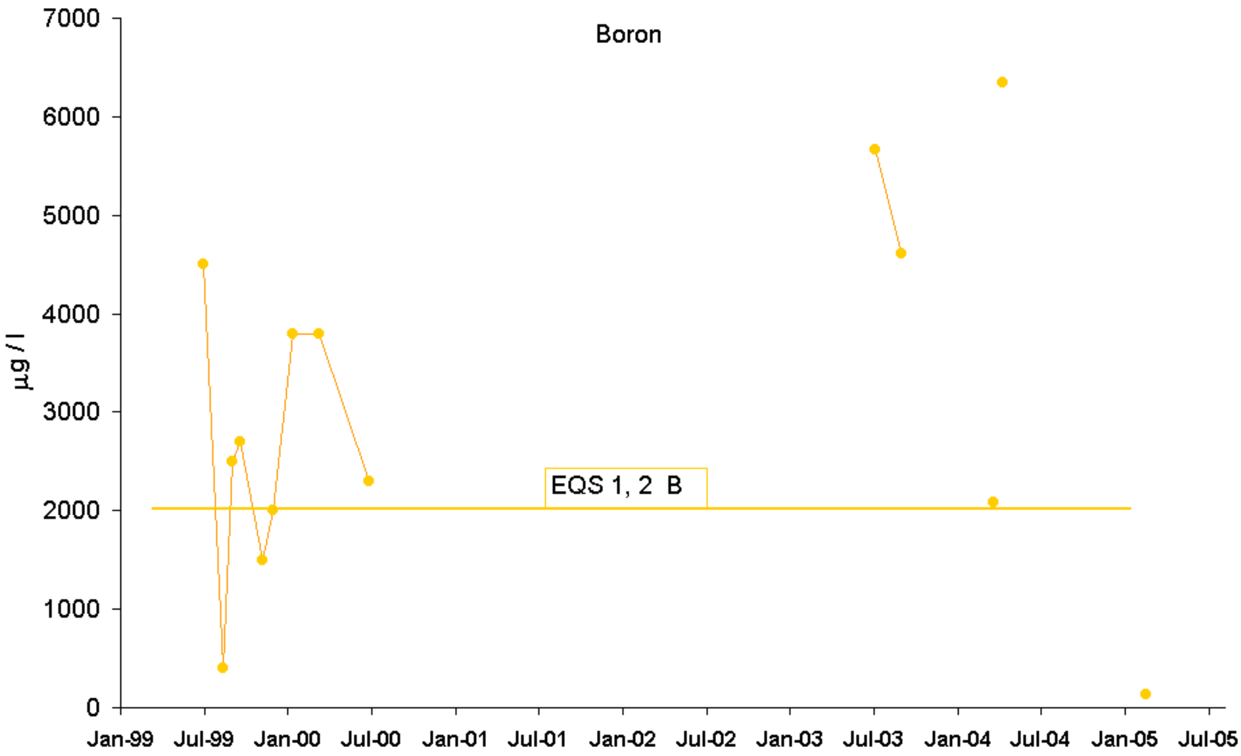

Figure A 2.3 Analysis of leachate – boron (EQS levels indicated)
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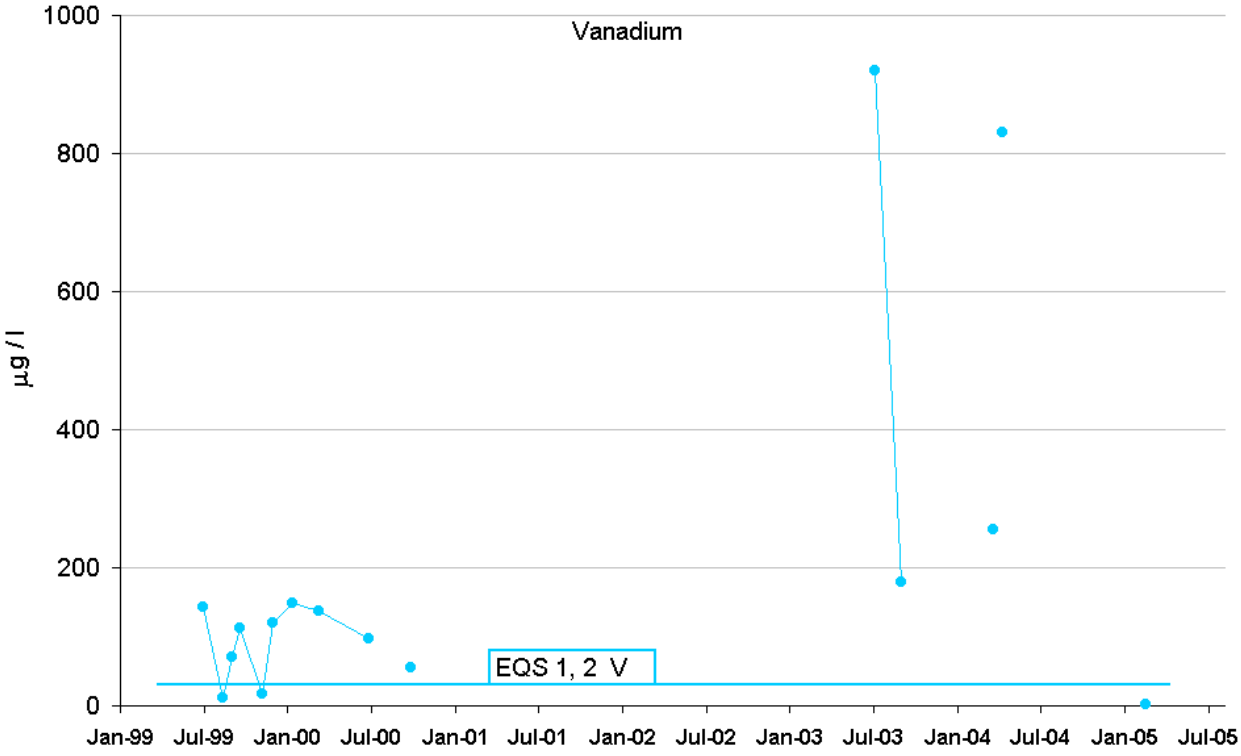

Figure A 2.4 Analysis of leachate – vanadium (EQS levels indicated)
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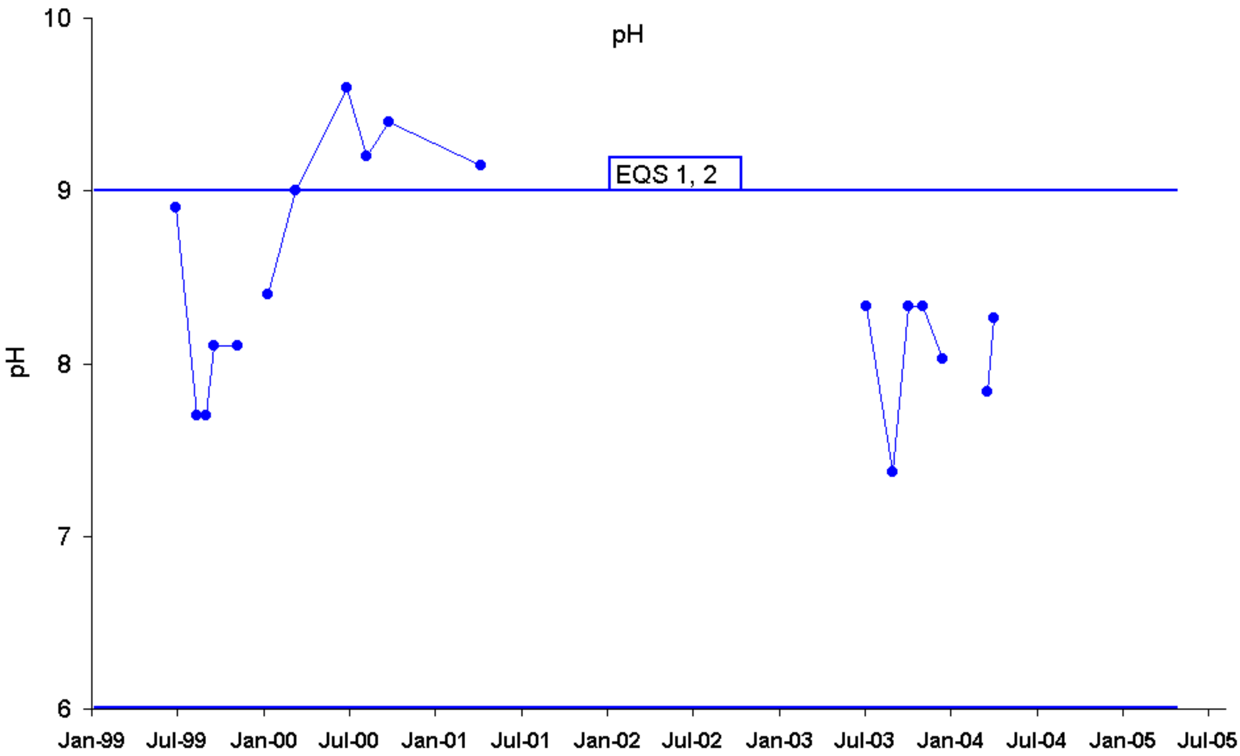

Figure A 2.5 Analysis of leachate – pH (EQS levels indicated)
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APPENDIX 3: Chemical Symbols

This report makes frequent use of standard symbols to refer to the chemical elements. The following table gives a list of chemical symbols representing a selection of substances likely or known to occur in PFA, in alphabetical order, against atomic number (Z), atomic weight (A) and group (with Actinides denoted by 'C').

Table 6: Table of chemical elements

Symbol	Name	Z	A	Group
Al	Aluminium	13	27.0	IIIA
As	Arsenic	33	74.9	VA
B	Boron	5	10.8	IIIA
Be	Beryllium	4	9.0	IIA
C	Carbon	6	12.0	IVA
Ca	Calcium	20	40.1	IIA
Cd	Cadmium	48	112.4	IIB
Co	Cobalt	27	58.9	VIII
Cr	Chromium	24	52.0	VIB
Cu	Copper	29	63.5	IB
Fe	Iron	26	55.8	VIII
Hg	Mercury	80	200.6	IIB
K	Potassium	19	39.1	IA
Mg	Magnesium	12	24.3	IIA
Mn	Manganese	25	54.9	VIIB
Mo	Molybdenum	42	95.9	VIB
Na	Sodium	11	23.0	IA
Ni	Nickel	28	58.7	VIII
O	Oxygen	8	16.0	VIA
P	Phosphorus	15	31.0	VA
Pb	Lead	82	207.2	IVA
Po	Polonium	84	209.9	VIA
Rn	Radon	86	222	VIIIA
S	Sulphur	16	32.1	VIA
Sb	Antimony	51	121.8	VA

Symbol	Name	Z	A	Group
Se	Selenium	34	79.0	VIA
Si	Silicon	14	28.1	IVA
Sn	Tin	50	118.7	IVA
Th	Thorium	90	232	IIC
Ti	Titanium	22	47.9	IVB
Tl	Thallium	81	204.4	IIIA
U	Uranium	92	238	IVC
V	Vanadium	23	50.9	VB
Zn	Zinc	30	65.4	IIB

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