Appendix 7
Waste

CONTENTS

1. Landfill

The NAEI category Landfill maps directly on to 6A1 Landfills for methane emissions. Emissions are reported from managed landfills only, as open dumps and unmanaged landfills are considered insignificant in the UK.

The UK method conforms to good practice since a first order decay (Tier 2) methodology is used based on estimates of historical data on waste quantities, composition and disposal practices over several decades.

The UK method is based on equations 4 and 5 in the Revised 1996 IPCC guidelines (IPCC, 1997) (pp 6.10-6.11) which are compatible with equations 5.1 and 5.2 in the Good Practice Guidance (IPCC, 2000). A slightly different version of equation 5.1 is used, which takes into account the fact that the model uses a finite time interval (one year). The full derivation of the equations used is given in Appendix 2 of Brown *et al* (1999).

The UK method divides the waste stream into four categories of waste: rapidly degrading, moderately degrading, slowly degrading and inert waste. These categories each have a separate decay rate. The decay rates are based on data from the Netherlands and range from 0.05 (slowly degrading waste) to 0.185 (rapidly degrading waste), which lie within the range of 0.03 to 0.2 quoted in the Good Practice Guidance.

The model extends back to 1945, which gives a time period of around 4 half lives for the slowest of the three decay rates (0.05, half life 14 years). This lies within the range of 3 to 5 half lives recommended by the Good Practice Guidance.

The model distinguishes between four separate categories of landfill site with different degrees of gas collection control:

- closed sites;
- sites with no gas collection;
- sites with limited collection;
- sites with comprehensive collection.

Each site type has different gas collection and oxidation rates. As recommended, the model attempts to take into account changes in landfill practice over past decades by altering the proportion of waste disposed of to each of these categories of site in past years, and also by modifying the gas collection rate over time where appropriate. The model also simulates retrofitting of sites, i.e. upgrading from a site with no gas control or limited gas control to one with comprehensive gas control.

The estimates of historical waste disposal and composition data are based on various data sources, described fully in Brown *et al* 1999. As recommended in the Good Practice Guidance, estimates for municipal waste are based on population where data is absent.

As recommended in the Good Practice Guidance, the estimates of waste disposal quantities include commercial and industrial waste, demolition and construction waste and sewage sludge, as well as municipal waste. For industrial and commercial waste, the data are based on national estimates from a recent survey, although the survey was incomplete at the time of finalising the model estimates. The data were extrapolated to cover past years based on employment rates in the industries concerned.

All sites in the UK are managed, and therefore have a methane correction factor of 1.0. However, as described above, differences in oxidation rates have been simulated by the practice of dividing waste disposal sites into four types as described above.

Degradable organic carbon (DOC) was estimated based on a national study, as recommended in the Good Practice Guidance. However the figures used were based on expert opinion rather than measured data.

The fraction of degradable organic carbon dissimilated (DOC_F) was assumed to be 60%. At the time when the model was set up, the IPCC recommended default value was 77%, but there were indications that this could be an overestimate, so a lower figure was used. The new IPCC recommended range quoted in the Guidance is 50-60%.

The fraction of CH_4 in landfill gas is generally taken to be 50%, which is in line with the Guidance. For old shallow sites it is taken to be 30% to reflect a higher degree of oxidation.

The fraction of methane recovered was assumed to be 85% for sites with full gas control and 40% for sites with limited gas control. The estimates are not derived from metering data, as recommended by the Guidance, as such data were not readily available at the time of the study. A panel of UK industry experts selected the figures.

The oxidation factor is assumed to be 10% for all site types. Recovered methane is subtracted before applying the oxidation factor. This is in line with the Guidance.

The emissions of pollutants from the flare stacks were not estimated but those from electricity generation and heat generation were. Emissions from electricity generation are considered under Power Stations and emissions from heat generation are included under Miscellaneous and are discussed in Appendix 1.

An estimate of NMVOC emissions from landfills was made using an emission factor of 0.01 t NMVOC/ t methane produced which is equivalent to 5.65g NMVOC/ m^3 landfill gas (Passant, 1993).

Neither the GHGI nor the NAEI reports carbon dioxide emissions from the anaerobic decay of landfilled waste since this is considered to be part of the carbon cycle and is not a net source.

The estimates include the contribution of sewage disposed of to landfill.

2. Waste Water Treatment

The NAEI category Sewage is mapped on to the IPCC category 6B2 Domestic and Commercial Wastewater. There is no estimate made of emissions from private wastewater treatment plants operated by companies prior to discharge to the public sewage system or rivers. The NAEI estimate is based on the work of Hobson *et al* (1996) who estimated emissions of methane for the years 1990-95. Subsequent years are extrapolated on the basis of population. Sewage disposed of to landfill is included in landfill emissions.

The methodology of the UK model differs in some respects from the IPCC default methodology. The main differences are that it considers wastewater and sewage together rather than separately. It also considers domestic, commercial and industrial wastewater together rather than separately. Emissions are based on empirical emission factors derived from the literature expressed in kg CH_4/tonne dry solids rather than the BOD default factors used by IPCC. The model however complies with the IPCC Good Practice Guidance as a national model (IPCC, 2000).

The basic activity data are the throughput of sewage sludge through the public system. The estimates are based on the UK population connected to the public sewers and estimates of the amount of sewage per head generated. From 1995 onwards the per capita production is a projection (Hobson *et al*, 1996). The main source of sewage activity data is the UK Sewage Survey (DOE, 1993). Emissions are calculated by disaggregating the throughput of sewage into 14 different routes. The routes consist of different treatment processes each with its own emission factor. The treatment routes and emission factors are shown in Table 1. The allocation of sludge to the treatment routes is reported for each year on the CRF tables attached to this report as a CD ROM.

The model accounts for recovery of methane and its subsequent utilization and flaring by estimating the proportion of anaerobic digester emissions that are recovered.

Table 1 Specific Methane Emission Factors for Sludge Handling kg Ch_4/Mg dry solids, Hobson *et al* (1996)

Sludge Handling System	Gravity Thick-ening[1]	Long term storage	Anaerobic Digestion[2]	Agricul - tural Land	Landfill
Anaerobic digestion to agriculture	0.72		143	5	
Digestion, drying, agriculture	0.72		143	5	
Raw sludge, dried to agriculture	0.72			20	
Raw sludge, long term storage (3m) ,agriculture	0.72	36		20	
Raw sludge, dewatered to cake, to agriculture	0.72			20	
Digestion, to incinerator	0.72		143		
Raw sludge, to incinerator	0.72				
Digestion , to landfill	0.72		143		0
Compost, to agriculture	0.72			5	
Lime raw sludge, to agriculture	0.72			20	
Raw Sludge , to landfill	0.72				0
Digestion , to sea disposal	0.72		143		
Raw sludge to sea disposal	0.72				
Digestion to beneficial use(e.g. land reclamation)	0.72		143	5	

1 An emission factor of 1 kg/tonne is used for gravity thickening, Around 72% of sludge is gravity thickened hence an aggregate factor of 0.72 kg CH_4/Mg is used.

2 The factor refers to methane production, however it is assumed that 121.5 kg CH_4/Mg is recovered or flared

Nitrous oxide emissions from the treatment of human sewage are based on the IPCC (1997c) default methodology. The average protein consumption per person is based on the National Food Survey (MAFF, 2000). These range from 22.7 to 23.7 g protein/person/day. The food survey is based on household consumption of food and so may give a low estimate.

3. Waste Incineration

The NAEI estimates emissions from the categories MSW incineration and sewage incineration. Included in the inventory for the first time are the categories clinical incineration and cremation. However the coverage of these new sources is incomplete due to a lack of emission factor data. The waste incineration categories are mapped onto the single NAEI category 6C Waste Incineration. The emission factors used are shown in Table 3. The emission factors for N_2O have been revised in the new inventory based on IPCC (2000).

Table 3 Emission Factors for Waste Incineration (kg/t waste)

		C[1]	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
MSW(old)	kg/t	75[a]	0.0008[d]	0.03[f]	1.8[c]	0.709[c]	0.0231[d]	1.36[c]
MSW(new)	kg/t	75[a]	0.0008[d]	0.03[f]	1.37[g]	0.197[g]	0.0308[g]	0.076[g]
Cremation	kg/body	0	NE	NE	0.308[h]	0.141[h]	0.013[h]	0.0544[h]
Clinical	kg/t	NE	NE	NE	1.78[h]	1.48[h]	NE	1.09[h]
Sewage	kg/t	0	0.39[b]	0.8[f]	2.5[b]	15.5[b]	0.84[b]	2.3[e]

1 Emission factor as kg carbon/ t waste
a Royal Commission on Environmental Pollution (1993)
b EMEP/CORINAIR (1996).
c Clayton *et al.* (1991)
d Estimated from THC data in CRI (Environment Agency, 1997) assuming 3.3% methane split given in EMEP/CORINAIR (1996)
e EMEP/CORINAIR (1996). A factor of 14 kt/Mt is used prior to 1996.
f IPCC (2000)
g Emission factor for 1999, Environment Agency (2000)
h EMEP/CORINAIR (1999)

The arisings of waste and their method of disposal are not known with any reliability. The estimates of municipal solid waste disposed of to incinerators are based on incinerator capacity (Patel *et al.*, 2000). The amounts of sewage sludge incinerated are reported in DETR (2001). Data on cremations are published by the Cremation Society of Great Britain (CSGB, 2000). Under IPCC guidelines, incineration refers only to plant that do not generate electricity. From the end of 1996, MSW incinerators in the UK had to meet new standards. As a result, many incinerators closed down, were renovated or new ones built. From 1997 onwards all MSW incinerators generated electricity and are classified as power stations so no emissions are reported under Incineration: MSW. Emission factors for modern incinerators based on 1999 data are reported as MSW (new) for comparison with the emission factors used for old incinerators. The emission factors given for MSW (old) pertain to old incinerators prior to 1993. Emission factors for the years 1993-1999 were derived from the Pollution Inventory (Environment Agency, 2000). Only those emissions of carbon dioxide deriving from recently photosynthesised carbon are estimated. It was assumed that the proportion of recently photosynthesised carbon was 25% of the total carbon content of the waste (Brown, 1995) and this assumption is reflected in the factors in Table 3.

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Appendix 8 Uncertainties

CONTENTS

1. Estimation of Uncertainty by Simulation

Quantitative estimates of the uncertainties in the emissions were calculated using direct simulation, a technique similar to Monte Carlo Simulation. This corresponds to the IPCC Tier 2 approach discussed in the Good Practice Guidance (IPCC, 2000). This work is described in detail by Eggleston *et al* (1998) though the estimates reported here have been revised to reflect changes in the 1999 Inventory. This section gives a brief summary of the methodology, assumptions and results of the simulation.

The general computational procedure was:

- An uncertainty distribution was allocated to each emission factor and activity rate. The distributions used were either normal, log-normal or uniform. The parameters of the distributions were set by analysing the available data on emission factors and activity data or expert judgement.
- A calculation was set up to estimate the emission of each gas, carbon dioxide sink, and the global warming potential for the years 1990 and 1999. Using the software tool @RISK™, each uncertainty distribution was sampled 20000 times and the emission calculations performed to formulate a converged output distribution.
- It was assumed that the distribution of errors in the parameter values was normal. The quoted range of possible error of uncertainty is taken as 2s, where s is the standard deviation. If the expected value of a parameter is E and the standard deviation is s, then the uncertainty is quoted is 2s/E expressed as a percentage. For a normal distribution the probability of the parameter being less than E-2s is 0.025 and the probability of the emission being less than E+2s is 0.975.
- For methane and nitrous oxide, it was assumed that there was no correlation between emission factors for the same fuels applied to different sources. For CO_2 emission factors for natural gas, gas oil, kerosene, fuel oil, motor gasoline, LPG, OPG, MSW and aviation fuel were correlated with those for the same fuel used in different sources. Activity data were not correlated with each other.
- The uncertainty in the trend between 1990 and 1999 was also estimated. This will be influenced by the degree of correlation of activity data and emission factors between 1990 and 1999. Generally it was assumed that activity data were not correlated, but certain emission factors were. These correlations are discussed in subsequent sections.
- To simplify the calculations the uncertainties for total halocarbon and SF_6 emissions were taken from Eggleston *et al* (1998).

1.1 CARBON DIOXIDE EMISSION UNCERTAINTIES

It was necessary to estimate the uncertainties in the activity data and the emission factors for the main sources and then combine them.

The uncertainties in the fuel activity data were estimated from the statistical differences data in DTI (1996). These are effectively the residuals when a mass balance is performed on the

production, imports, exports and consumption of fuels. For solid and liquid fuels both positive and negative results are obtained indicating that these are uncertainties rather than losses. For gaseous fuels these figures include losses and tended to be negative. For natural gas, a correction was made to take account of leakage from the gas transmission system but for other gases this was not possible. The other uncertainties for minor fuels (colliery methane, orimulsion, SSF, petroleum coke) and non-fuels (limestone, dolomite and clinker) were estimated based on judgements based on their relative uncertainty compared with the known fuels. The high uncertainty in the aviation fuel consumption reflects the uncertainty in the split between domestic and international aviation fuel consumption.

The uncertainties in the emission factors were based largely on expert judgement. It was possible to compare the coal emission factors used in the inventory with some recent measurements (Fynes, 1994). Also Transco (1998) data allowed an estimate of the uncertainty in the carbon content of natural gas. The time series data of the gross calorific value of fuels used in the UK (DTI, 1996) would also give *some indication* of the relative variability in the carbon contents. Thus the uncertainties in the fuel emission factors were based on judgements on whether they were likely to be similar or less than those of coal or natural gas.

In the case of non-fuel sources, the uncertainty depended on the purity of limestone or the lime content of clinker so the uncertainties estimated were speculative.

The uncertainties in certain sources were estimated directly. Flaring uncertainties were estimated by comparing the 1996 GHGI estimate to that of the SCOPEC (1997) study. Uncertainties in the land use change sources were recalculated (Milne, 1999) for the revised source categories in the IPCC 1996 Guidelines using data from Eggleston *et al* (1998). The overall uncertainty was estimated as around 2.6% in 1990 and 2.1% in 1999. The reduction in uncertainty from the 1998 inventory is due to the revision downwards of the land use change and forestry estimates.

The uncertainty in the trend between 1990 and 1999 was also estimated. In running this simulation it was necessary to make assumptions about the degree of correlation between sources in 1990 and 1999. If source emission factors are correlated this will have the effect of reducing the trend uncertainty. The assumptions were:

- Activity data are uncorrelated
- Emission factors of similar fuels are correlated (i.e. gas oil with gas oil, coke with coke etc)
- Land Use Change and forestry emissions are correlated (i.e. 5A with 5A etc)
- Offshore emissions are not correlated since they are based on separate studies using emission factors appropriate for the time.
- Process emissions from blast furnaces, coke ovens and ammonia plant were not correlated.

The trend was found to range between -8.3% and -10.6%

Table 1 Estimated Uncertainties in Carbon Dioxide Inventory[1]

Source	Activity Uncertainty %	Emission Factor Uncertainty %	Uncertainty in Emission %
Coal (including derived gases)	1.2	6	‡
Coke	5.6	3	‡
Petroleum Coke	5	3	‡
SSF	3	3	‡
Burning Oil	6	2	‡
Fuel Oil	4	2	‡
Gas Oil/Diesel Oil	1.4	2	‡
Motor Spirit	0.8	2	‡
Orimulsion	1	2	‡
Aviation Fuel (Domestic)	50	2	‡
Lubricants	25	5	‡
Natural Gas	2.4	1	‡
Colliery Methane	5	5	‡
LPG	24	3	‡
OPG	1.1	3	‡
Scrap Tyres	15	10	‡
Waste Oils	15	5	‡
Ammonia Production	-	-	5
Cement	1	2	‡
Lime/Limestone/Dolomite	1	5	‡
Soda Ash Use	15	2	‡
Flaring	-	-	28
Other Offshore	-	-	28
Natural Gas (offshore)	2.4	10	‡
Iron & Steel Processes	1	20	‡
Aluminium Production	1	5	‡
Waste Incineration	7	20	21
5A Forest Biomass Change[2]	-	-	30
5D Soils[2]	-	-	60
5E Other[2]	-	-	50

1 Expressed as 2s/E
2 Uniform distribution used
‡ Input parameters were uncertainties of activity data and emission factors.

1.2 METHANE EMISSION UNCERTAINTIES

In the methane inventory, combustion sources are a minor source of emissions. The uncertainty in methane combustion emission factors will outweigh the activity errors so an uncertainty of 50% was assumed for combustion sources as a whole. The errors in the major sources are listed in Table 2. These are mainly derived from the source documents for the estimates or from the Watt Committee Report (Williams, 1993). The uncertainty in offshore emissions is based on a

comparison of the source data (UKOOA, 1993) and another study on offshore emissions (Woodhill Engineering, 1993)

Table 2 Estimated Uncertainties in the Methane Inventory

Source	Reference	Source Uncertainty %
Fuel Combustion	‡	50
Field Burning	‡	50
Landfill	Brown *et al* 1999	~48[1]
Livestock: enteric	Williams, 1993	20
Livestock: wastes	Williams, 1993	30
Coal Mining	Bennett *et al*, 1995	13
Gas Leakage	Williams, 1993	17-75[2]
Offshore	‡	28
Sewage Sludge	Hobson *et al*, 1996	50

1 Skewed distribution
2 Various uncertainties for different types of main and service
‡ See text

The sources quoted in Table 2 are assumed to have normal distributions of uncertainties with the exception of landfills. Brown et al (1999) estimated the uncertainty distribution for landfill emissions using Monte Carlo analysis and found it to be skewed. For normal distributions there is always a probability of negative values of the emission factors arising. For narrow distributions this probability is negligible, however with wide distributions the probability is higher. In the original work (Eggleston *et al*, 1998) this problem was avoided by using truncated distributions. However, it was found that this refinement made very little difference to the final estimates, so in these estimates normal distributions were used rather than truncated normal.

The total emission of methane in 1999 was estimated as 2632 Gg. The Monte Carlo analysis suggested that 95% of trials were between 2299 Gg and 3459 Gg. The uncertainty was around 20%. The emission of methane in 1990 was estimated as 3670 Gg. The Monte Carlo analysis suggested that 95% of trials were between 3081 Gg and 4421 Gg. The uncertainty was around 18%.

The uncertainty in the trend between 1990 and 1999 was also estimated. In running this simulation it was necessary to make assumptions about the degree of correlation between sources in 1990 and 1999. If source emission factors are correlated this will have the effect of reducing the emissions. The assumptions were:

- Activity data are uncorrelated
- Emission factors used for animals are correlated between the same species.
- Landfill emissions were partly correlated in the simulation. It is likely that the emission factors used in the model will be correlated, and also the historical estimates of waste arisings will be correlated since they are estimated by extrapolation from the year of the study. However, the reduction in emissions is due to flaring and utilisation systems installed since 1990 and this is unlikely to be correlated. As a crude estimate it was assumed that the degree of correlation should reflect the reduction. Emissions have reduced by 36% hence the degree of correlation was 64%.

- Offshore emissions are not correlated since they are based on separate studies using emission factors that reflected the processes in use at the time.
- Gas leakage emissions were correlated.
- Emissions from deep mines were not correlated as they were based on different studies, and a different selection of mines. Open cast and coal storage and transport were correlated since they are based on default emission factors.

The trend was found to range between -15% and -38%

1.3 NITROUS OXIDE EMISSION UNCERTAINTIES

The analysis of the uncertainties in the nitrous oxide emissions is particularly difficult because emissions arise from a diverse collection of sources and little data are available to form an assessment of the uncertainties in each source. Emission factor data for the combustion sources are scarce and for some fuels are not available. The parameter uncertainties are shown in Table 3. The uncertainty assumed for agricultural soils uses a lognormal distribution since it is so high. Here it is assumed that the 97.5 percentile is greater by a factor of 100 than the 2.5 percentile based on advice from MAFF.

The uncertainty distribution of the calculated emission was heavily skewed with a mean emission of 138 Gg in 1999 within a range of 33 Gg to 532 Gg.

The uncertainty in the trend between 1990 and 1999 was also estimated. In running this simulation it was necessary to make assumptions about the degree of correlation between sources in 1990 and 1999. If sources are correlated this will have the effect of reducing the emissions. The assumptions were:

- Activity data are uncorrelated
- Emissions from agricultural soils were correlated
- The emission factor used for sewage treatment was assumed to be correlated, though the protein consumption data used as activity data were assumed not to be correlated.
- Nitric acid production emission factors were assumed to be correlated.
- Adipic acid emissions were assumed not to be correlated because of the large reduction in emissions due to the installation of abatement plant in 1998.

The trend was found to range between -13% and -72%

Table 3: Estimated Uncertainties in the Nitrous Oxide Emissions[1]

	Emission Factor Uncertainty %	Activity Rate Uncertainty %
Agricultural Soils	Log-normal[2]	0
Wastewater Treatment	Log-normal[2]	10
Adipic Acid	15	0.5
Nitric Acid	230	10
Coal	195	1.2
Anthracite	387	1.2
Coke	118	5.6
Patent Fuel	118	3
Burning Oil	140	6
Gas Oil	140	1.4
Fuel Oil	140	4
Gasoline	170	0.8
Auto Diesel	170	1.4
Orimulsion	140	1
LPG	110	24
OPG	110	1.1
Aviation Fuel (domestic)	170	50
Natural Gas	110	2.4
Colliery Methane	110	5
Lubricants	140	25
Biogas	110	5
Offshore Sources	110	1
Field burning	230	25
Poultry Litter	230	7
Scrap Tyres, Waste Oils	140	15
Sewage and MSW Incineration	230	7
Wood	230	30
Straw	230	50

1 Expressed as 2s/E
2 With 97.5 percentile 100 times the 2.5 percentile

1.4 HALOCARBONS AND SF6

The uncertainties in the emissions of HFCs, PFCs and SF_6 were taken from Eggleston *et al* (1998). The uncertainties were estimated as 25% for HFCs, 19% for PFCs and 13% for SF_6 in 1990. Trend uncertainties are reported in Table 4

1.5 GWP WEIGHTED EMISSIONS

The uncertainty in the combined GWP weighted emission of all the greenhouse gases in 1999 was estimated as 16.5% and in 1990, 13.9%. The trend in the total GWP is -14.4% within the range -12% and -16%. The uncertainty estimates for all gases are summarised in Table 4. The source which makes the major contribution to the overall uncertainty is 4D Agricultural Soils. This source shows little change over the years, but other sources have fallen since 1990. Hence the increase in uncertainty since 1990.

Table 4: Summary of Tier 2 Uncertainty Estimates

A	B	C	D	E	F	G	H	I	J
IPCC Source Category	Gas	1990 Emissions	1999 Emissions	Uncertainty in 1999 emissions as % of emissions in category		Uncertainty Introduced in national total in 1999[a]	% change in emissions between 1999 and base year	Range of likely % change between 1999 and 1990	
				2.5 percentile	97.5 percentile			2.5 percentile	97.5 percentile
		Gg CO_2 equivalent	Gg CO_2 equivalent	Gg CO_2 equivalent	Gg CO_2 equivalent	%	%	%	%
TOTAL	CO_2	592270	536261	525420	547340	2%	-9.5%	-10.6%	-8.3%
	CH_4	77075	55266	48270	72650	20%	-28%	-38%	-15%
	N_2O	66949	42890	10274	165070	b	-36%	-72%	-13%
	HFC	11374	6206	4680	7697	25%	-45%	-62%	-22%
	PFC	2281	678	551	806	19%	-70%	-77%	-62%
	SF_6	724	1314	1148	1480	13%	81%	52%	118%
	All	750673	642615	604640	763650	17%	-14%	-16%	-12%

a Calculated as 2s/E where s is the standard deviation and E is the mean, calculated in the simulation.
b Not quoted because distribution is highly skewed.

2. Estimation of Uncertainties using a Tier 1 Approach

The IPCC Good Practice Guidance (IPCC, 2000) defines Tier 1 and Tier 2 approaches to estimating uncertainties in national greenhouse gas inventories. The Monte Carlo approach described above corresponds to Tier 2 whilst Tier 1 provides for a simplified calculation method based on the error propagation equations. The results of the Tier 1 approach are shown in Table 5. In the Tier 1 approach the emission sources are aggregated up to a level broadly similar to the IPCC Summary Table 7A. Uncertainties are then estimated for these categories. The uncertainties used in the Tier 2 approach are not exactly the same as those used in the Monte Carlo Simulation since the Tier 1 source categorisation is far less detailed. However, the values used were chosen to agree approximately with those used in the Monte Carlo Simulation. The Tier 2 approach is only able to model normal distributions. This presented a problem in how to estimate a normal distribution approximation of the lognormal distribution used for agricultural soils and wastewater treatment. The approach adopted was to use a normal distribution with the same mean as the lognormal distribution. The standard deviation was then estimated as (97.5 percentile –mean)/2.

The Tier 1 approach suggests an uncertainty of 18% in the combined GWP total emission in 1999. The analysis also estimates an uncertainty of 2% in the trend between 1990 and 1999.

Table 5: Tier 1 Uncertainty Calculation and Reporting

	Source Category	Gas	Base year emissions 1990	Year Y emissions 1999	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty	Combined uncertainty range as % of national total in year t	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced trend in total emissions by source category
			Gg CO2 equiv	Gg CO2 equiv	%	%	%	%	%	%	%	%	%
	A	B	C	D	E	F	G	H	I	J	K	L	M
1A	Coal	CO2	237791	123943	1.2	6	6.119	1.180155	-0.105727	0.165109	-0.634363	0.280199	0.693490
1A(stationary)	Oil	CO2	91799	62333	2	2	2.828	0.274356	-0.021623	0.083037	-0.043246	0.234863	0.238811
1A	Natural Gas	CO2	110249	201206	2.4	1	2.600	0.814075	0.142100	0.268034	0.142100	0.909739	0.920770
1A	Other (waste)	CO2	134	859	7	20	21.190	0.028316	0.000991	0.001144	0.019819	0.011324	0.022826
1A3a	Aviation Fuel	CO2	2158	2822	50	2	50.040	0.219757	0.001298	0.003759	0.002596	0.265833	0.266846
1A3b	Auto Fuel	CO2	109039	114660	0.8	2	2.154	0.384010	0.028223	0.152610	0.056447	0.172659	0.181651
1A3d	Marine Fuel	CO2	3461	2710	1.4	2	2.441	0.010295	-0.000837	0.003610	-0.000673	0.007148	0.007179
1A3	Other Diesel	CO2	1923	1483	1.4	2	2.441	0.005635	-0.000217	0.001976	-0.000433	0.003912	0.003935
1B	Solid Fuel Transformation	CO2	3000	2242	1.2	6	6.119	0.021344	-0.000436	0.002986	-0.002612	0.005068	0.005701
1B	Oil & Natural Gas	CO2	9138	5891	1	14	14.036	0.128660	-0.002573	0.007847	-0.036021	0.011097	0.037692
2A1	Cement Production	CO2	6829	6113	1	2	2.236	0.021272	0.000356	0.008144	0.000713	0.011517	0.011539
2A2	Lime Production	CO2	1192	1574	1	5	5.099	0.012488	0.000739	0.002097	0.003689	0.002965	0.004733
2A3	Limestone & Dolomite use	CO2	1369	1325	1	5	5.099	0.010517	0.000204	0.001766	0.001019	0.002497	0.002697
2A4	Soda Ash Use	CO2	166	123	15	2	15.133	0.002900	-0.000024	0.000164	-0.000048	0.003480	0.003480
2B	Ammonia Production	CO2	1368	1108	10	1	10.050	0.017320	-0.000074	0.001475	-0.000074	0.020865	0.020865
2C1	Iron&Steel Production	CO2	3210	3237	1.2	6	6.119	0.030819	0.000651	0.004312	0.003905	0.007317	0.008294
5A	5A LUCF	CO2	-9456	-10439	1	30	30.017	-0.487608	-0.003123	-0.013906	-0.093684	-0.019666	0.095725
5D	5D LUCF	CO2	15439	12663	1	60	60.009	1.182491	-0.000738	0.016869	-0.044257	0.023656	0.050277
5E	5E LUCF	CO2	2808	2508	1	50	50.010	0.195179	0.000139	0.003341	0.006827	0.004725	0.008385
6C	MSW Incineration	CO2	663	0	7	20	21.190	0.000000	-0.000756	0.000000	-0.015129	0.000000	0.015129
		CO2 Total	592270	586261									
1A	All Fuel	CH4	1889.97953	1894.071919	1.2	50	50.014	0.147415	0.000368	0.002523	0.018393	0.004282	0.018885
1A3a	Aviation Fuel	CH4	2.49515897	3.016944003	50	50	70.711	0.000332	0.000001	0.000004	0.000059	0.000284	0.000290
1A3b	Auto Fuel	CH4	614.636986	377.3906455	0.8	50	50.006	0.029367	-0.000196	0.000503	-0.009809	0.000569	0.009825
1A3d	Marine Fuel	CH4	6.664896	5.219424	1.4	50	50.020	0.000406	-0.000001	0.000007	-0.000032	0.000014	0.000035
1A3	Other Diesel	CH4	1.4575115	1.303047071	1.4	50	50.020	0.000102	0.000000	0.000002	0.000004	0.000003	0.000005
1B1	Coal Mining	CH4	17202.706	6528.367	1.2	13	13.055	0.132629	-0.010818	0.008997	-0.141939	0.014759	0.142704
	Solid Fuel Transformation	CH4	0.530	0.110	1.2	50	50.014	0.000009	0.000000	0.000000	-0.000023	0.000000	0.000023
1B2	Natural Gas Transmission	CH4	8942.561	8198.962	1	15	15.033	0.191806	0.000724	0.010922	0.010862	0.015446	0.018883
	Offshore Oil& Gas	CH4	2418.801	1349.695	1	28	28.018	0.058846	-0.000960	0.001798	-0.026883	0.002543	0.027003
2B	Chemical Industry	CH4	1.882	1.882	1	20	20.025	0.001232	0.000008	0.000053	0.000152	0.000074	0.000169
2C	Iron & Steel Production	CH4	16.361	15.501	1.2	50	50.014	0.001206	0.000002	0.000021	0.000100	0.000035	0.000105
4A	Enteric Fermentation	CH4	19176.992	18767.892	0.1	20	20.000	0.583800	0.003118	0.024988	0.062360	0.003534	0.062460
4B	Manure Management	CH4	2338.244	2301.365	0.1	30	30.000	0.107438	0.000399	0.003066	0.011977	0.000434	0.011985
4F	Field Burning	CH4	266.045	0.000	25	50	55.902	0.000000	-0.000903	0.000000	-0.015170	0.000000	0.015170
6A	Solid Waste Disposal	CH4	23457.000	15036.000	15	46	48.394	1.132094	-0.006718	0.020030	-0.309015	0.424901	0.525396
6B	Wastewater Handling	CH4	701.022	756.336	1	50	50.010	0.058860	0.000208	0.001008	0.010406	0.001425	0.010503
6C	Waste Incineration	CH4	0.655	1.712	7	50	50.488	0.000134	0.000002	0.000002	0.000077	0.000023	0.000080
		CH4 total	77075	55266									

Table 5: Tier 1 Uncertainty Calculation and Reporting (Continued)

	Source Category	Gas	Base year emissions 1990	Year Y emissions 1999	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty	Combined uncertainty range as % of national total in year t	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced trend in total emissions by source category
			Gg CO2 equiv	Gg CO2 equiv	%	%	%	%	%	%	%	%	%
	A	B	C	D	E	F	G	H	I	J	K	L	M
1A2&1A2&1A4&1A5	Other Combustion	N2O	4084.218	3927.247	1.2	195	195.004	1.191737	0.000574	0.005232	0.111940	0.008878	0.112291
1A3a	Aviation Fuel	N2O	21.238	27.767	50	170	177.200	0.007657	0.000013	0.000037	0.002171	0.002616	0.003399
1A3b	Auto Fuel	N2O	965.271	4294.464	0.8	170	170.002	1.136088	0.004620	0.005721	0.785397	0.006472	0.785424
1A3d	Marine Fuel	N2O	68.324	53.506	0.8	170	170.002	0.014155	-0.000007	0.000071	-0.001128	0.000081	0.001131
1A3	Other Diesel	N2O	228.177	176.384	1.4	140	140.007	0.038429	-0.000025	0.000235	-0.003534	0.000465	0.003564
1B2	Oil & Natural Gas	N2O	93.559	61.784	1	110	110.005	0.010576	-0.000024	0.000082	-0.002683	0.000116	0.002685
2B	Adipic Acid Production	N2O	25136.353	660.920	0.5	15	15.008	0.015436	-0.027775	0.000880	-0.416628	0.000623	0.416628
2B	Nitric Acid Production	N2O	4133.725	2984.969	10	230	230.217	1.069367	-0.000738	0.003976	-0.169643	0.056235	0.178721
2C	Iron & Steel	N2O	11.106	9.451	1.2	118	118.006	0.001735	0.000000	0.000013	-0.000009	0.000021	0.000023
4B	Manure Management	N2O	1582.764	1596.494	1	419	419.001	1.040954	0.000322	0.002127	0.134832	0.003008	0.134865
4D	Agricultural Soils	N2O	29472.053	27975.166	1	419	419.001	18.240519	0.003656	0.037267	1.531889	0.052703	1.532795
4F	Field Burning	N2O	77.762	0.000	25	230	231.355	0.000000	-0.000089	0.000000	-0.020396	0.000000	0.020396
6B	Wastewater Handling	N2O	1033.301	1069.588	10	401	401.125	0.667644	0.000246	0.001425	0.098839	0.020150	0.100872
6C	Waste Incineration	N2O	41.033	51.832	7	230	230.106	0.018560	0.000022	0.000069	0.005119	0.000684	0.005164
		N2O Total	66949	42890									
2	Industrial Processes	HFC	11374	6206	1	25	25.020	0.241611	-0.004703	0.008267	-0.117578	0.011691	0.118158
2	Industrial Processes	PFC	2281	678	1	19	19.026	0.020080	-0.001698	0.000903	-0.032256	0.001278	0.032282
2	Industrial Processes	SF6	724	1314	1	13	13.038	0.026664	0.000925	0.001751	0.012023	0.002476	0.012275
		Halocarbon & SF6 Total	14379	8198									
	TOTALS	GWP	750673	642615									
	Total Uncertainties%							18.5					2.24

3. Key Source Analysis

The Good Practice Guidance (2000) requires that a key source analysis be made to identify the key source categories in the inventory. The results of the analysis are reported in Table 6. The analysis is based on the Tier 2 level analysis and trend analysis. The key source analysis was performed on the data shown in Table 5 using the same categorisation and the same estimates of uncertainty. The table indicates whether a key source arises from the level assessment or the trend assessment. The factors which make a source a key source are:

- A high contribution to the total
- A high contribution to the trend
- High uncertainty.

For example: auto oil combustion is a key source of carbon dioxide because it is large; landfill methane is key because it is large, has a high uncertainty and shows a significant trend.

Table 6 Source Category Analysis Summary

Quantitive Method Used: Tier 2					
A IPCC Source Categories		B Gas	C Category Key Source Category	D If Column C is Yes, Criteria for Identification	E Comments
1A	Coal	CO2	Yes	Level	
1A(stationary)	Oil	CO2	Yes	Level	
1A	Natural Gas	CO2	Yes	Level	
1A	Other (waste)	CO2	No		
1A3a	Aviation Fuel	CO2	No		
1A3b	Auto Fuel	CO2	Yes	Level	
1A3d	Marine Fuel	CO2	No		
1A3	Other Diesel	CO2	No		
1B	Solid Fuel Transformation	CO2	No		
1B	Oil & Natural Gas	CO2	No		
2A1	Cement Production	CO2	No		
2A2	Lime Production	CO2	No		
2A3	Limestone & Dolomite use	CO2	No		
2A4	Soda Ash Use	CO2	No		
2B	Ammonia Production	CO2	No		
2C1	Iron&Steel Production	CO2	No		
5A	Land Use Change & Forestry	CO2	Yes	Level	high uncertainty
5D	Land Use Change & Forestry	CO2	Yes	Level	high uncertainty
5E	Land Use Change & Forestry	CO2	No		
6C	MSW Incineration	CO2	No		
1A	All Fuel	CH4	No		
1A3a	Aviation Fuel	CH4	No		
1A3b	Auto Fuel	CH4	No		
1A3d	Marine Fuel	CH4	No		
1A3	Other Diesel	CH4	No		
1B1	Coal Mining	CH4	No		
	Solid Fuel Transformation	CH4	No		
1B2	Natural Gas Transmission	CH4	No		
	Offshore Oil& Gas	CH4	No		
2B	Chemical Industry	CH4	No		
2C	Iron & Steel Production	CH4	No		
4A	Enteric Fermentation	CH4	Yes	Level	
4B	Manure Management	CH4	No		
4F	Field Burning	CH4	No		
6A	Solid Waste Disposal	CH4	Yes	Level, Trend	high uncertainty
6B	Wastewater Handling	CH4	No		
6C	Waste Incineration	CH4	No		
1A2&1A2&1A4&1A5	Other Combustion	N2O	Yes	Level, Trend	
1A3a	Aviation Fuel	N2O	No		
1A3b	Auto Fuel	N2O	Yes	Level, Trend	high trend
1A3d	Marine Fuel	N2O	No		
1A3	Other Diesel	N2O	No		
1B2	Oil & Natural Gas	N2O	No		
2B	Adipic Acid Production	N2O	No		
2B	Nitric Acid Production	N2O	Yes	Level, Trend	
2C	Iron & Steel	N2O	No		
4B	Manure Management	N2O	Yes	Level, Trend	high uncertainty
4D	Agricultural Soils	N2O	Yes	Level, Trend	high uncertainty
4F	Field Burning	N2O	No		
6B	Wastewater Handling	N2O	Yes	Level, Trend	high uncertainty
6C	Waste Incineration	N2O	No		
2	Industrial Processes	HFC	Yes	Level	marginally key
3	Industrial Processes	PFC	No		
4	Industrial Processes	SF6	No		

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Appendix 9
Quality Assurance and Quality Control

CONTENTS

1. Introduction

This Appendix summarizes the current QA/QC system used in the compilation of the NAEI and the UK Greenhouse Gas Inventory. The current system complies with the Tier 1 procedures outlined in the Good Practice Guidance (IPCC, 2000). Plans are underway to develop the system and extend the range of activities so that the system complies with Tier 2.

2. QA/QC System used for the UK Greenhouse Gas Inventory

2.1 DESCRIPTION OF THE CURRENT SYSTEM

The National Atmospheric Emissions Inventory and the UK Greenhouse Gas Inventory are compiled and maintained by the National Environmental Technology Centre of AEA Technology plc. Whilst significant parts of the inventory (i.e. agriculture, land use change and forestry and halocarbons and sulphur hexafluoride emissions) are compiled by other agencies and contractors, NETCEN is the *Inventory Agency* responsible for co-ordinating QA/QC activities.

The system has developed over the years. A new on-line database system was adopted for the 1997 Inventory in 1998 and since then developments have proceeded to build QA/QC procedures into the on-line system. The database consists essentially of a table of activity data and a table of emission factors for the NAEI base source categories. These are then multiplied together to produce emissions according to the IPCC and CORINAIR formats to be generated.

The Inventory has been subject to ISO 9000 since 1994 and is liable to audit by Lloyds and the AEAT internal QA auditors. The NAEI has been audited favourably by Lloyds on two occasions in the last three years. The emphasis of these audits was on authorisation of personnel to work on inventories, document control, data tracking and spreadsheet checking. As part of the Inventory management structure there is a nominated officer responsible for the QA/QC system –*the QA/QC Co-ordinator*.

The system incorporates the following activities which are carried out each year as the inventory is compiled:

1. Documentation

- Data received by NETCEN are logged, numbered and should be traceable back to their source from anywhere in the system.
- The inventory is held as an Access database of activity data and emission factors. Within the database these data fields are referenced to the data sources, or the spreadsheet used to calculate the data. For fuel consumption data, the DUKES (DTI, 2000) table numbers are identified.
- There is an on-line system of manuals, which defines timetables, procedures for updating the database, document control, checking procedures and procedures for updating the methodology manual.
- There is an on-line methodology manual which is updated as the inventory data are entered. This contains details of the methodology used, emission factor and activity data sources, discussion of the rationale for choice of methodology and emission factors.
- An annual report outlining the methodology of the inventory, data sources and changes made is produced.

2. Database

- The classification of source categories is controlled by a formatting table in the database which is used to generate emissions tabulated in the IPCC format. Other simple queries can be used to dump all emissions data contained in the database. These can be compared against the tabulated output to check that all sources are output and that the totals are correct. A consistency check between IPCC output and CORINAIR formatted output is made. Data in the CRF reporting tool are checked against the database totals.
- All fields in the database are labelled automatically with an NAEI source/fuel category, the CORINAIR SNAP code and the units used. A comment field linked to each data entry provides further description and the data source or spreadsheet used to calculate it.

3. Checking

- ISO 6000 requires that spreadsheet calculations are checked and the checks applied are described. Also the data sources used for calculations must be referenced on the spreadsheet.
- Data entry into the database is checked. It is not always possible for all data entries to be checked by a second person. However, a major proportion of the activity data are entered and checked by third persons.
- The final checks on the inventory involve a consistency check against the previous inventory for the same year. A designated auditor identifies sources where there have been significant changes or new sources. Inventory staff are required to explain these changes in the inventory to satisfy the auditor.
- A further final check is made on the inventory comparing the emissions of the latest year with those of the previous year (within the same version). A designated checker identifies sources where there have been significant changes. Inventory staff are required to explain these changes in the inventory to satisfy the checker.

4. Recalculation

- When revisions are made to the methodologies of the estimates, emissions for all previous years are recalculated as a matter of course.

5. Uncertainties

- Estimates are made of the uncertainties in the estimates according to Tier 1 and Tier 2 procedures.
- A ranking exercise is performed according to Tier 2 procedures to identify key source categories.

6. Archiving

- At the end of each reporting cycle, all the database files, spreadsheets, on-line manual, electronic source data, paper source data, output files are in effect frozen and archived. An annual report outlining the methodology if the inventory and data sources is produced.

The system outlined above complies with the Tier 1 procedures outlined in Table 8.1 of the Good Practice Guidance (IPCC,2000). However, following the release of the Good Practice Guidance a review of the QA/QC procedures has been carried out (Salway, 2001) and a QA/QC plan has been developed to extend the current procedures to comply with Tier 2. This involves extending some of the existing procedures and adopting new ones. The QA/QC plan is discussed further in Section 3.

2.2 SPECIAL QA/QC ACTIVITIES UNDERTAKEN IN 2000/2001

This section describes certain specific activities relating to QA/QC that were carried out in the last year. These will in future arise from the QA/QC plan but are not necessarily carried out on an annual basis. The activities were:

- *Halocarbons and Sulphur Hexafluoride Verification*. A study was carried out to verify the inventory of halocarbons and sulphur hexafluoride, (Salway *et al*, 2001). This entailed the collection of top down and bottom up data on the consumption of fluids by the fluid bank. The comparison with the existing inventory gave good agreement (15-20%) between major sources. Some potential anomalies were identified and will be addressed when the inventory is updated this summer.
- *QA/QC Review*. A review was carried out of the QA/QC procedures used in the Inventory and how they complied with the Good Practice Guidance, (Salway, 2001). Areas where improvements were required were identified.
- *Landfill Review*. An internal expert review of the methodology used in the estimation of landfill methane was carried out to see how it compared with the Good Practice Guidance (Salway, 2001). The review found that the methodology and model parameters were in accord with the Guidelines. The activity data and methods used to extrapolate the data were largely in accord with the Guidance, but that certain parameters were based on expert judgement rather than actual measured data.
- *Acid Plant Documentation*. Following the review of QA/QC procedures, a data collection exercise was undertaken to improve the level of supporting documentation for adipic acid and nitric acid plant. This involved requesting data on the number, type, utilisation, abatement systems, plant emission factors, and utilisation.

- *Carbon Emission Factor Review*. The Good Practice Guidance advises that carbon factors should be collected from fuel producers and industrial users. Whilst the response was rather limited, the data compared well with the petroleum factors currently in use. However, it was clear that the factors used in the oil industry for LPG (i.e. butane and propane) were significantly lower than the UK default. As a result of this comparison, the UK default has been revised based on an 80%/20% by weight mixture of propane and butane. There was some evidence that the coal factors in use do not account for the increase in the proportion of imported coal used in the UK. There is evidence to suggest that the carbon content of imported coal is higher than home produced. The possibility of a sampling and measurement project is under consideration.
- *Methane Emissions from Closed Mines*. A review was undertaken of methane emissions from closed mines, (Sage, 2001). This source is not included in the UK Inventory because it was believed to be negligible. The review concentrated on assessing the various estimates of these emissions to see whether this source should be included in the Inventory (See Appendix 3).

3. Future Development of the QA/QC System

The review discussed in the previous section identified areas where the current QA/QC system could be improved and the need for additional activities to comply with Tier 2. These developments are now included in the QA/QC plan, elements of which are described in this Section. The QA/QC plan will be included in the on-line manual system.

3.1 IMPROVEMENTS TO THE SYSTEM

3.1.1 Compliance of National Statistical Agencies

Much of the data received by NETCEN come from other government departments, agencies, research establishments or consultants. Some of these organisations (e.g. DTI, MAFF and BGS) would qualify as the *National Statistical Agencies* referred to in the Guidance. Other organisations (e.g. CEH, Enviros March) compile significant parts of the Inventory. Currently the QA/QC procedures in use at NETCEN do not extend to QA/QC procedures used at these data suppliers. The Good Practice Guidance defines as good practice that the Inventory Agency should confirm that *National Statistical Agencies* have implemented adequate QC procedures along the lines indicated in Table 8.1 of the Good Practice Guidelines. Hence, we will be contacting these organisations and inviting them to show how their systems comply with IPCC Good Practice Guidance. The QA procedures used by MAFF for agricultural data collection and archiving are outlined in Appendix 5 Agriculture and those used by the Centre for Ecology and Hydrology for preparing the land use change and forestry estimates are discussed in Appendix 6.

3.1.2 Documentation and Review

The Inventory is documented both by the on-line Manual and the Annual Report. The on-line Manual tends to include more detail which is inappropriate to the annual report. The Good

Practice Guidance highlights the need for review of methodologies during inventory compilation. Hence the on-line manual will be developed along these lines:

- *Completeness*. The manual will be extended to include material on potential emission sources, which are not estimated in the Inventory. This will include reasons for not including these sources and some assessment of their magnitude.
- *Source Review Documentation*. The manual tends to describe the methodologies in use, past revisions, emission factors and activity data sources. It is intended that the scope should be expanded to include more detail on the choice of methodology and the choice of emission factors. This will include evidence that internal review of emission sources takes place.

3.1.3 External Peer Review

Tier 2 of the Good Practice Guidance requires that key sources should be subjected to external peer review. During 2001, the UK will implement a programme of peer reviews be experts outside of the organisation responsible for the estimates. The programme for the external peer review is shown in Table 1.

Table 1. QA/QC Activities Schedule

	2000/2001[1]	2001/2002	2002/2003	2003/2004
Special Activities	QA/QC Review Halocarbon Verification Closed Mines Review	Update Halocarbon Inventory (including QA/QC procedures)		
On-going Activities	On-Going Tier 1 Activities	On-Going Tier 1 Activities	On Going Tier 1 Activities	On-Going Tier 1 Activities
	Carbon Factor Review	Carbon Factor Review(update)	Carbon Factor Review(update)	Carbon Factor Review(update)
	Acid Plant Documentation	Acid Plant Documentation (update)	Acid Plant Documentation (update)	Acid Plant Documentation (update)
		Document Completeness		
	Document Source Reviews	Document Source Reviews	Document Source Reviews	Document Source Reviews
		External Agencies QA/QC	External Agencies QA/QC follow up	
External Peer Review	National Report	UNFCCC In-Depth Review National Report Auto Fuel (CO_2, N_2O) Stationary Oil (CO_2) Natural Gas (CO_2) Other Combustion (N_2O)	National Report Agricultural Soils (N_2O) Manure Management (N_2O) Coal (CO_2) LUCF 5A & 5D (CO_2)	National Report Nitric Acid (N_2O) Enteric Fermentation (CH_4) Wastewater (N_2O) Landfill (CH_4)

1 Refers to period between inventory submission i.e. April to April

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