Tier 3b Method – Smelter-specific relationship between emissions and operating parameters based on field measurements

This method uses periodic measurements to establish a smelter-specific relationship between operating parameters (i.e. frequency and duration of anode effects or Anode Effect Overvoltage) and emissions of CF_4 and C_2F_6. Once established, the relationship can be used along with process data collected on an on-going basis, to estimate emissions factors over time. These emission factors are multiplied by smelter-specific production (tonnes) to estimate smelter emissions. Emissions estimates will be aggregated across smelters to estimate national emissions.

The following estimation relationships can be used:

Slope Method: This method uses a linear least squares relationship between anode effect (AE) minutes per cellday[17] and emissions, expressed as an emission factor (EF):

EQUATION 3.10

$$EF \text{ (kg } CF_4 \text{ or } C_2F_6 \text{ per tonne of Al)} = Slope \bullet AE \text{ min / cellday}$$

To develop an accurate estimate of the slope, simultaneous measurements of emissions and collection of anode effect data over an appropriate period of time are required. The Slope Method is a variant of the **Tabereaux approach** described in the *IPCC Guidelines*:

BOX 3.3
TABEREAUX APPROACH

$$Slope = 1.698 \bullet (p / CE) \quad \text{and} \quad AE \text{ min / cellday} = AEF \bullet AED$$

Where:

p = Average fraction of CF_4 in the cell gas during anode effects for the CF_4 slope
or
Average fraction of C_2F_6 in the cell gas during anode effects for the C_2F_6 slope

CE = Current Efficiency for the aluminium production process, expressed as a fraction rather than as a percentage

AEF = Number of anode effects per cellday

AED = Anode effect duration in minutes

Pechiney Overvoltage Method: This method uses the Anode Effect Overvoltage as the relevant process parameter. The Anode Effect Overvoltage is the extra cell voltage, above 8V, caused by anode effects, when averaged over a 24-hour period (mV/day). The correlation formula was derived from measurements of PFC generation at smelters with Pechiney technology, expressed as an emission factor (EF):

EQUATION 3.11

$$EF \text{ (kg } CF_4 \text{ or } C_2F_6 \text{ per tonne of Al)} = \text{Over-Voltage Coefficient} \bullet AEO / CE$$

Where:

AEO = Anode effect over-voltage in mV/cellday

CE = Aluminium production process current efficiency expressed in percent

[17] The 'cellday' term really means 'the number of cells operating multiplied by the number of days of operation'. At a smelter this would more usually be calculated (for a certain period of time, e.g. a month or a year) using 'the average number of cells operating across the smelter over a certain period of days multiplied by the number of days in the period'.

Tier 2 Method – smelter-specific relationship between emissions & operating parameters based on default technology-based slope and over-voltage coefficients

If measurement data are not available to determine smelter-specific Slope or Overvoltage coefficients, default coefficients may be used together with smelter-specific operating parameters. *Good practice* default coefficients are listed in Table 3.9, Default Coefficients for the Calculation of PFC Emissions from Aluminium Production (Tier 2 Methods).

Tier 1 Method – Production-based emission factors

The simplest estimation method is to multiply default emission factors by aluminium production. When the only smelter-specific activity data available are metal production statistics, it is *good practice* to use default emission factors (see Choice of Emission Factors).

Default slope coefficients (Tier 2 method) and emission factors (Tier 1 method) were developed using available data from International Primary Aluminum Institute (IPAI) surveys and other field measurement data (Bouzat e*t al.*, 1996, Leber *et al.*, 1998, Marks, 1998, Roberts *et al.*, 1994a and 1994b, Kimmerle *et al.*, 1998, Marks *et al.*, 2000). The limited information available for some data required expert judgement regarding the suitability of some measurement sets. As an example, the Tier 1 Method Horizontal Stud Søderberg (HSS) default emission factors were calculated using 1991 data, rather than 1990 data.

When possible, the consistency of available measurement data surveyed over different time periods and at different smelters should be used to confirm a significant degree of confidence about the magnitude and trend of the emission factors and coefficients.

CHOICE OF EMISSION FACTORS

Tier 3b Method

For this method, it is *good practice* to determine the coefficients of the models by using *smelter-specific measurements.* The smelter-specific coefficients should be based on comprehensive measurements of CF_4 and C_2F_6 emissions with simultaneous collection of process data. This means that emission factors should reflect the specific conditions of a plant and the technologies involved. Emission factors are to be measured over a period of time that reflects the variability of the process and accounts for both emissions captured by the fume collection system and fugitive emissions (if this sub-source category is significant, compared with emissions captured by the fume control system). Box 3.2, Direct Measurement Techniques, gives guidance on some aspects of direct measurement techniques. It is *good practice* to follow these approaches in implementing a sampling and measurement program.[18]

Tier 2 Method

If smelter-specific measurements are unavailable, default coefficients may be used. Default coefficients are provided by technology type in Table 3.9, Default Coefficients for the Calculation of PFC Emissions from Aluminium Production (Tier 2 Methods).[19] The default coefficients must be applied by technology type within each smelter. If more than one technology type is being used at a smelter, the appropriate default coefficients must be applied separately for each technology segment.

[18] Other methods may incorporate an explicit factor representing a contribution from newly started cells. The smelter-specific slope coefficients developed under Tier 3b will incorporate these emissions.

[19] Current measurement programs are improving the quantity and quality of available data. These data should be available by early 2000, and may supersede the values provided in Table 3.9.

TABLE 3.9
DEFAULT COEFFICIENTS FOR THE CALCULATION OF PFC EMISSIONS FROM ALUMINIUM PRODUCTION (TIER 2 METHODS)

Technology[a]	Slope[b,d] [(kg $_{PFC}/t_{Al}$) / (AE-Minutes/cellday)]				Overvoltage coefficient[b] [(kg $_{PFC}/t_{Al}$) / (mV/cellday)]	
	CF_4	Uncertainty	C_2F_6	Uncertainty	CF_4	C_2F_6
CWPB	0.14	±0.009	0.018	±0.004	1.9	NA
SWPB	0.29	±0.02	0.029 [c]	±0.01	1.9	NA
VSS	0.068 [g]	±0.02	0.003 [g]	±0.001	See note e	–
HSS	0.18 [f]		0.018		–	–

[a] Centre Worked Prebaked (CWPB), Side Worked Prebaked (SWPB), Vertical Stud Søderberg (VSS), Horizontal Stud Søderberg (HSS).
[b] Source: IPAI, EPA field measurements, and other company measurement data.
[c] There is inadequate data for establishing a slope coefficient for C_2F_6 emissions from SWPB cells based on measurement data; therefore a default of one-tenth of the CF_4 coefficient is *good practice*, consistent with the *IPCC Guidelines*.
[d] Embedded in each Slope coefficient is an assumed emissions collection efficiency as follows: CWPB 95%, SWPB 90%, VSS 85%, HSS 90%. These collection efficiencies have been assumed based on expert opinion. While collection efficiency for HSS cells may vary, the company measurement data used for calculation of these coefficients are consistent with a collection efficiency of at least 90%.
[e] Overvoltage coefficients are not relevant to VSS and HSS technologies.
[f] The HSS Slope coefficients are based on 1991 IPAI survey data.
[g] Further work on emission measurement and uncertainty analysis should be pursued for VSS. These default coefficients are based on a small number of data, and it is expected that the uncertainty might be higher than for other coefficients (Bjerke, 1999a, and Bjerke *et al*., 1999b).
NA = not available.

Tier 1 Method

The simplest method is to multiply default emission factors by aluminium production. Default emission factors by technology-type are available in the *IPCC Guidelines*. It is *good practice* to base these factors on recently updated measurements, and revised default emission factors and associated uncertainty ranges are presented in Table 3.10, Default Emission Factors and Uncertainty Ranges for the Calculation of PFC Emissions from Aluminium Production (by Technology Type), below. As the Tier 1 method is the most uncertain of the three approaches, it is *good practice* to use default emission factors as a method of last resort, when only metal production statistics are available.

TABLE 3.10
DEFAULT EMISSION FACTORS AND UNCERTAINTY RANGES FOR THE CALCULATION OF PFC EMISSIONS FROM ALUMINIUM PRODUCTION (BY TECHNOLOGY TYPE)

Technology	CF_4		C_2F_6	
	kg/tonne Al[e]	Uncertainty Range[a]	kg/tonne Al[e]	Uncertainty Range[a]
CWPB	0.31	0.0003-1.3	0.04	0.00004-0.2
SWPB	1.7	0.8-3.8	0.17 [b]	0.08-0.4
VSS	0.61 [c]	0.4-1.1	0.061 [c]	0.04-0.1
HSS	0.6 [d]	0.0006-1.4	0.06 [d]	0.00006-0.13

[a] Uncertainty was estimated by the IPCC Washington expert meeting group to a 95% confidence interval on the basis of the variance of anode effect minute data from IPAI Survey Data for 1990 (or 1991 for HSS) for each technology type.
[b] There are inadequate data for establishing an emission factor for C_2F_6 emissions from SWPB cells based on measurement data; therefore a default of one-tenth of the CF_4 coefficient is *good practice*, consistent with the *IPCC Guidelines*.
[c] The VSS default emission factors are based on IPAI, EPA field measurements, and other 1990 company measurement data. These default factors are based on a small number of data, and it is expected that the uncertainty might be higher than for other factors (Bjerke, 1999a, and Bjerke *et al*., 1999b).
[d] The HSS default emission factors are based on 1991 IPAI survey data.
[e] Source: IPAI, EPA field measurements, and other 1990 company measurement data, except for HSS that is based on 1991 data (Bjerke, 1999a, and Bjerke *et al*., 1999b).

It is *good practice* to apply the default emission factors that are based on 1990 (or 1991 for HSS) median anode effect frequency and duration data, for all years for which there are no process (anode effect) data unless it can be demonstrated otherwise.