CHAPTER 7

EMISSIONS OF FLUORINATED SUBSTITUTES FOR OZONE DEPLETING SUBSTANCES

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7 EMISSIONS OF FLUORINATED SUBSTITUTES FOR OZONE DEPLETING SUBSTANCES

7.1 INTRODUCTION

7.1.1 Chemicals and relevant application areas covered

Hydrofluorocarbons (HFCs) and, to a very limited extent, perfluorocarbons (PFCs), are serving as alternatives to ozone depleting substances (ODS) being phased out under the Montreal Protocol. Current and expected application areas of HFCs and PFCs include (IPCC/TEAP, 2005):

- refrigeration and air conditioning;
- fire suppression and explosion protection;
- aerosols;
- solvent cleaning;
- foam blowing; and
- other applications[1].

These major groupings of current and expected usage are referred to in this chapter as *applications* within the ODS substitutes category. This introduction (Section 7.1) provides a general framework for estimating emissions from ODS substitutes, and subsequent sections (Sections 7.2 through 7.7) provide more specialised guidance on the individual applications introduced above. Some of these applications themselves encompass products or uses with diverse emission characteristics, and countries will produce more rigorous estimates if they account for this diversity through the adoption of disaggregated assessments (higher tier). Additionally, the use of HFCs and PFCs in some applications, specifically rigid foam (typically closed-cell foam), refrigeration and fire suppression, can lead to the development of long-lived *banks* of material. The emission patterns from these uses can be particularly complex and methods employing disaggregated data sets are essential to generate accurate emissions estimates. Other applications, such as aerosols and solvent cleaning may have short-term inventories of stock but, in the context of emission estimation, can still be considered as sources of prompt emission. This statement also applies to flexible foams (typically open-cell foam).

HFCs and PFCs are not controlled by the Montreal Protocol because they do not contribute to depletion of the stratospheric ozone layer. HFCs are chemicals containing only hydrogen, carbon, and fluorine. Prior to the Montreal Protocol and the phase-out of various ODS, the only HFCs produced were HFC-152a, which is a component of the refrigerant blend R-500, and HFC-23, a low temperature refrigerant which is a by-product of HCFC-22[2] production. HFC-134a entered production in 1991 and a variety of other HFCs have since been introduced and are now being used as ODS substitutes (IPCC/TEAP, 2005) among other applications. When collecting data on HFC and PFC consumption for reporting purposes, care needs to be taken to include those HFCs in blends, but, at the same time, to avoid including those components of a blend which are not required to be reported (e.g., CFCs and HCFCs).

HFCs and PFCs have high global warming potentials (GWPs) and, in the case of PFCs, long atmospheric residence times. Table 7.1 gives an overview of the most important HFCs and PFCs (IPCC Second Assessment Report (IPCC, 1996); IPCC Third Assessment Report (IPCC, 2001); IPCC/TEAP, 2005), including their main application areas. The various HFCs and PFCs have very different potencies as greenhouse gases. PFCs have particularly high GWPs regardless of the integrated time horizon adopted because of their long atmospheric lifetimes. The consumption patterns relating to individual gases must be known, therefore, or estimated with reasonable accuracy, to achieve useful assessments for the contribution to global warming from emissions of these groups of chemicals.

[1] HFCs and PFCs may also be used as ODS substitutes in sterilisation equipment, for tobacco expansion applications, and as solvents in the manufacture of adhesives, coating and inks.

[2] HCFCs - hydrochlorofluorocarbons.

As CFCs, halons, carbon tetrachloride, methyl chloroform, and, ultimately, HCFCs are being finally phased out[3], HFCs are being selectively used as replacements. PFCs are also being used, but only to a limited extent. Even though up to 75 percent of previous application of CFC may now be covered by non fluorocarbon technologies (IPCC/TEAP, 2005), HFC use is expected to continue to grow at least in the short term.

TABLE 7.1
MAIN APPLICATION AREAS FOR HFCS AND PFCS AS ODS SUBSTITUTES [1]

Chemical	Refrigeration and Air Conditioning	Fire Suppression and Explosion Protection	Aerosols		Solvent Cleaning	Foam Blowing	Other Applications[2]
			Propellants	Solvents			
HFC-23	X	X					
HFC-32	X						
HFC-125	X	X					
HFC-134a	X	X	X			X	X
HFC-143a	X						
HFC-152a	X		X			X	
HFC-227ea	X	X	X			X	X
HFC-236fa	X	X					
HFC-245fa				X		X	
HFC-365mfc				X	X	X	
HFC-43-10mee				X	X		
PFC-14[3] (CF_4)		X					
PFC-116 (C_2F_6)							X
PFC-218 (C_3F_8)							
PFC-31-10 (C_4F_{10})		X					
PFC-51-14[4] (C_6F_{14})					X		

[1] Several applications use HFCs and PFCs as components of blends. The other components of these blends are sometimes ODSs and/or non-greenhouse gases. Several HFCs, PFCs and blends are sold under various trade names; only generic designations are used in this chapter.

[2] Other applications include sterilisation equipment, tobacco expansion applications, plasma etching of electronic chips (PFC-116) and as solvents in the manufacture of adhesive coatings and inks (Kroeze, 1995; U.S. EPA, 1992a).

[3] PFC-14 (chemically CF_4) is used as a minor component of a proprietary blend. Its main use is for semiconductor etching.

[4] PFC-51-14 is an inert material, which has little or nil ability to dissolve soils. It can be used as a carrier for other solvents or to dissolve and deposit disk drive lubricants. PFCs are also used to test that sealed components are hermetically sealed.

7.1.2 General methodological issues for all ODS substitute applications

7.1.2.1 OVERVIEW OF ODS SUBSTITUTE ISSUES

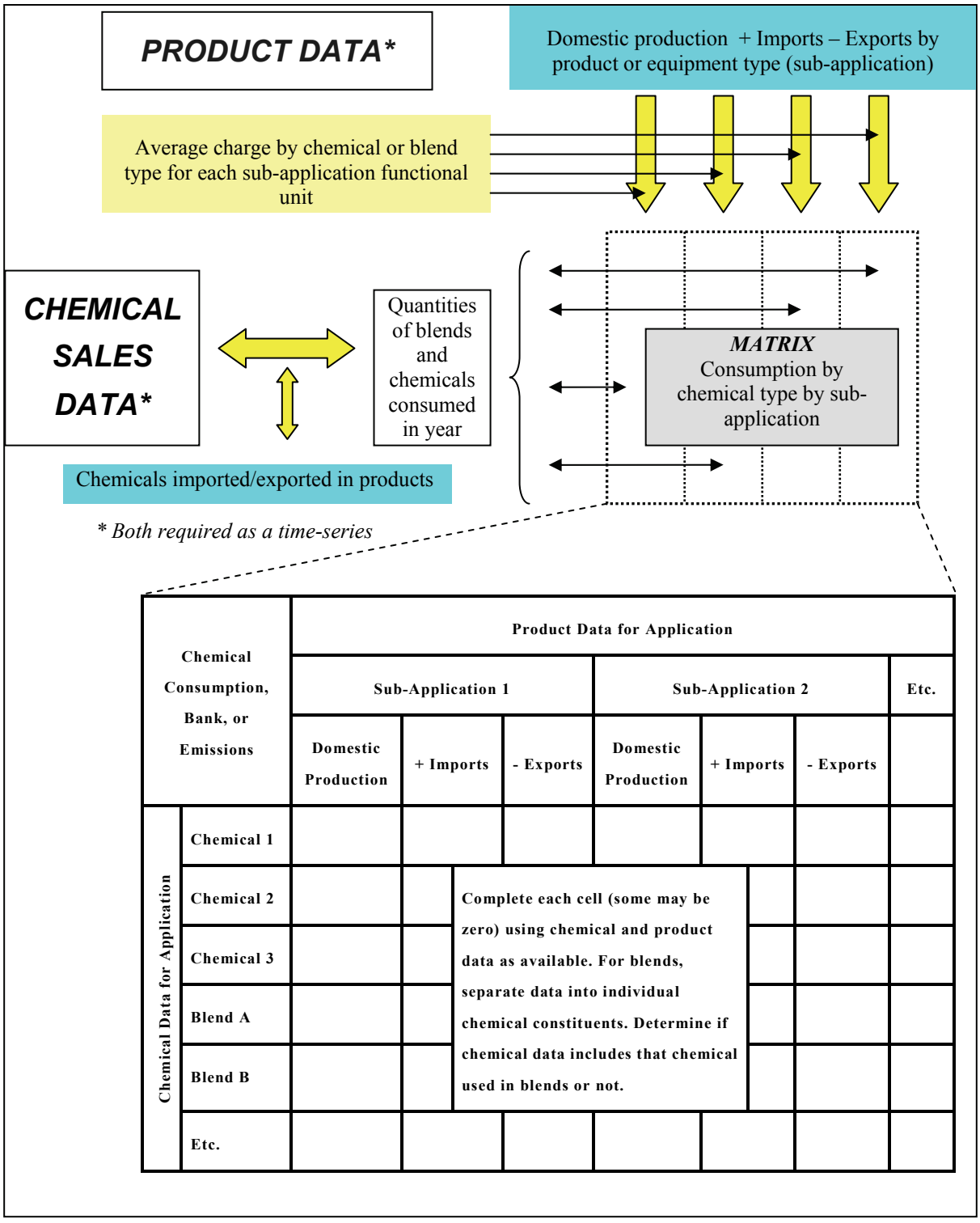
LEVELS OF DATA AGGREGATION

Each application discussed above can be divided into sub-applications. When selecting a method for estimating emissions, it is *good practice* to consider the number and relevance of sub-applications, the data availability, and the emission patterns. Applications with a high number of sub-applications (refrigeration has six major sub-applications; foam has even more) will generally benefit from a higher level of disaggregation in their data sets, owing to the differences between the sub-applications. Accordingly, for rigorous emissions estimates, inventory compilers are likely to favour estimating emissions for each sub-application separately. In this chapter, such an

[3] Refer to http://hq.unep.org/ozone/ for the phaseout schedules dictated under the Montreal Protocol.

approach defines a Tier 2 method, whereas methods based on datasets aggregated at the application level are all classified as Tier 1. Even if few sub-applications exist, estimating emissions by sub-application may still be most appropriate owing to the differences in emission patterns, chemical use, data gathering methodologies, and/or data availability. Fire protection, for example, has only two major sub-applications, but each has unique emission characteristics and a disaggregated (Tier 2) method will produce better emission estimates. On the other hand, if emission patterns of sub-applications are similar and if data are difficult to collect in disaggregated form, estimating emissions at an aggregated application level (Tier 1) can be an appropriate approach to produce reliable emission estimates. For example, although several sub-applications exist within the aerosol propellants application, because the emission patterns and chemicals used are similar, estimating emissions at an application level may be sufficient to yield good results.

Figure 7.1 Disaggregation of chemical data across an application



Chemical Consumption, Bank, or Emissions		Product Data for Application						
		Sub-Application 1			Sub-Application 2			Etc.
		Domestic Production	+ Imports	- Exports	Domestic Production	+ Imports	- Exports	
Chemical Data for Application	Chemical 1							
	Chemical 2			Complete each cell (some may be zero) using chemical and product data as available. For blends, separate data into individual chemical constituents. Determine if chemical data includes that chemical used in blends or not.				
	Chemical 3							
	Blend A							
	Blend B							
	Etc.							

TYPES OF DATA

It is important early on in the estimation process to decide about how and from where data is to be collected. Data on chemical sales (sometimes referred to as *top-down* data) typically comes on a substance-by-substance basis, although even this can be complicated by the use of blends. Data on markets (sometimes referred to as *bottom-up* data) will tend to come in the form of equipment or product sales at the sub-application level, although this data will typically be influenced by the existence of imports and exports of such equipment or products. This data often need to be accompanied by an estimate of the share of the market that uses a particular technology. For example, different chemicals (including some not subject to reporting) may be used in the same sub-application. Additionally, the average amount of chemical used by each product type within the sub-application may vary. The two routes (chemicals and products) represent the two axes of a matrix and a disaggregated approach requires completion (or near completion) of that matrix (Figure 7.1). Completing this matrix is typically accomplished by using combinations of both types of data (i.e., both *top-down* and *bottom-up* data), comparing the results, and adjusting as appropriate.

DATA AVAILABILITY

There are often difficulties in collecting data for both Tier 1 and Tier 2 methods if chemical suppliers at the national level believe that there are confidentiality implications arising from disclosure of information. In practice, this has been one of the major barriers to reliable emissions estimates at the national level.

In order to overcome some of these constraints, there has, in recent years, been an effort to develop global and regional databases which provide information on historic and current activity (chemical consumption) data at the country level for specific applications and sub-applications. The value of this approach is that these data can be validated against chemical sales at regional, or even global, level and thereby avoids breeching confidentiality restrictions required by the suppliers. As these databases have developed, (for example, those developed under the oversight of the relevant UNEP Technical Options Committees under the Montreal Protocol) they have become increasingly sophisticated in their analyses of use patterns which are often well-understood at the sub-application level (see Box 7.1). This means that the two axes of the matrix described earlier can be addressed from these datasets and Tier 2 methods can be facilitated at a country level without a massive investment of resource. This activity data can then be combined with default emission factors or with country-specific emission factor data, if this is available, to derive appropriate emissions estimates. Of course, it is important to exercise care in making use of such databases and it is important to choose reputable well-documented sources. Nonetheless, the use of globally or regionally derived data of this type can deliver reliable estimates. An alternative strategy could be to use information generated from such a database to benchmark information collected nationally.

In either case, it is important that data is generated in a form that will fit with relevant reporting requirements (e.g., the Common Reporting Format of the United Nations Framework Convention on Climate Change (UNFCCC)). These requirements may vary with time during the lifetime of these *Guidelines*. Accordingly, the structuring of activity datasets should be sufficiently flexible to deal with such changes.

In some instances the complexity of the chemical and equipment supply chain can create additional challenges regarding data availability. As highlighted in Section 7.5, there are a range of containers that can be used to supply the mobile air conditioning market, from semi-bulk containers for OEMs; to intermediate containers for the average vehicle servicing centre (10-15kg); to small 300-500g cans for the do-it-yourself market. Since wastage levels will vary substantially between these differing supply-chain approaches, inventory compilers need to consider how to assess these losses in practice. The use of containers is not only limited to mobile air conditioning, but is often prevalent in other sectors of the refrigerant market, aerosols and in fire suppression. Inventory compilers could consider treating the supply of ODS substitutes as a separate element of the inventory. However, even if this route is taken, it will require detailed knowledge of the sub-applications to understand the range of sizes used and proportion of each. Accordingly, it is viewed as most appropriate to evaluate container losses (often termed *heels*) within each application and sub-application, although it would be *good practice* to compare estimated losses within different applications and sub-applications using the similar sized containers to ensure some uniformity of approach.

BOX 7.1
GLOBAL AND REGIONAL DATABASES FOR ODS SUBSTITUTES

Global and regional databases are typically developed for specific applications by experts in the field. These experts often have good professional contacts with industry sources, and are familiar with access to relevant market studies and other reports that shed light onto the consumption patterns of regions and countries. From this knowledge base it is possible to cross-reference product data, either at regional level or even at global level, with chemical consumption data. It is common for such databases to predict future consumption as well as to assess current consumption. This makes them valuable also as a policy development tool. However, it is important that such databases are properly maintained and are regularly cross-checked with actual chemical consumption data whenever it becomes available in order to be assured that any new trends or other sources of discrepancy are accounted for and fully reconciled wherever possible.

For example, individual members of the UNEP Technical Options Committees (TOCs) under the Montreal Protocol have prepared a number of global activity datasets that can assist countries in preparing estimates of ODS substitute emissions. Particularly relevant are the databases used to support the development of the IPCC/TEAP Special Report on Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons (IPCC/TEAP, 2005), because information on the phase-out of ozone-depleting substances is directly relevant for estimating the phase-in of substitutes. The assumptions behind these datasets have been documented in a number of summary reports which can be found at http://epa.gov/ozone/snap/emissions/index.html (e.g., Clodic D., Palandre, L., McCulloch, A., Ashford, P. and Kuijpers, L.. 'Determination of comparative HCFC and HFC emission profiles for the Foam and Refrigeration sectors until 2015.' Report for ADEME and US EPA., 2004). These existing datasets have been regularly peer-reviewed by other experts from within the relevant TOCs and have been used by the Parties to the Montreal Protocol to assess transitions in chemical markets and chemical use patterns.

If national data are difficult to obtain, countries can search the IPCC Emissions Factor Database (EFDB) for datasets such as those discussed above. All such databases should be structured to facilitate their use in inventory reporting. The EFDB is likely to become the home for a number of such global/regional databases in due course, either as additional sources for applications already covered or as new sources for applications not previously covered. Although inclusion of databases in the EFDB provides general assurance of due process, it is *good practice* for countries to ensure that all data taken from the EFDB are appropriate for their national circumstances and that peer review is sufficient for this complex area of activity.

TYPES OF EMISSION ESTIMATES

In contrast with the earlier *Guidelines*, both Tier 1 and Tier 2 methods proposed in this chapter result in estimates of *actual* emissions rather than *potential* emissions. This reflects the fact that they take into account the time lag between consumption of ODS substitutes and emission, which, as noted previously, may be considerable in application areas such as closed cell foams, refrigeration and fire extinguishing equipment. A time lag results from the fact that a chemical placed in a new product may only slowly leak out over time, often not being released until end-of-life. A household refrigerator, for example, emits little or no refrigerant through leakage during its lifetime and most of its charge is not released until its disposal, many years after production. Even then, disposal may not entail significant emissions if the refrigerant and the blowing agent in the refrigerator are both captured for recycling or destruction.

The *potential* emission method, in which emissions are assumed to equal the amount of virgin chemical consumed annually in the country minus the amount of chemical destroyed or exported in the year of consideration, is now presented only as a reference scenario in the QA/QC section. As noted above, the *potential* method does not take into account accumulation or possible delayed release[4] of chemicals in various products and equipment, which means that, over the short term (e.g., 10-15 years), estimates may become very inaccurate. Therefore, it is not considered *good practice* to use the *potential* method for national estimates.[5]

[4] Sometimes from types of equipment and products which have since converted out of halocarbon technologies.

[5] The Conference of the Parties to the UNFCCC, at its third session, affirmed '… that the actual emissions of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride should be estimated, where data are available, and used for

TIMING OF EMISSIONS AND THE SIGNIFICANCE OF BANKS

In many applications ODS substitutes such as HFCs and PFCs serve their purpose only if they are contained (e.g., refrigeration and air conditioning), while in other applications, they are meant to be emitted (e.g., as an aerosol propellant). These differences are important to understand, so that the year in which emissions occur can be accurately assessed, and hence *actual* emissions can be accurately estimated.

Where emissions occur within the first two years, they are usually referred to as *prompt* emissions. Examples of applications and sub-applications exhibiting *prompt* emissions include aerosols, aerosol solvents, open-cell foams and in some cases non-aerosol solvents. In general, emissions from applications or sub-applications exhibiting *prompt* emissions can be estimated by determining annual chemical consumption and then assuming all emissions occur within the first year or two of consumption. Thus, if chemical consumption is unknown prior to a certain date, emission estimates a year or two after that date will nonetheless be accurate and relatively little accuracy will be gained by searching for or estimating chemical consumption from prior years.

Where delays in emission occur, the cumulative difference between the chemical that has been consumed in an application or sub-application and that which has already been released is known as a *bank*. Applications in which banks typically occur include refrigeration and air conditioning, fire protection, closed-cell foams, and often non-aerosol solvents. The definition of bank encompasses the presence of the chemical at all parts of the lifecycle and may even include waste streams. By way of example, blowing agent still present in foamed products which may have already been land-filled is still part of the bank, since it is chemical which has been consumed and still remains to be released. In practice, most equipment-related sub-applications (e.g. in refrigeration and fire protection) are unlikely to carry their charges into the waste stream and the total of the chemical contained in the equipment currently in use becomes a close approximation to the actual bank.

Estimating the size of a bank in an application or sub-application is typically carried out by evaluating the historic consumption of a chemical and applying appropriate emission factors. Where more than one sub-application exists, but a Tier 1 method is being followed, a composite emission factor needs to be applied. However, in view of the uncertainties surrounding such composite emission factors, Tier 2 methods will always be preferred for applications with multiple sub-applications, particularly where these are dissimilar in nature.

It is also sometimes possible to estimate the size of bank from a detailed knowledge of the current stock of equipment or products. A good example is in mobile air conditioning, where automobile statistics may be available providing information on car populations by type, age and even the presence of air conditioning. With knowledge of average charges, an estimate of the bank can be derived without a detailed knowledge of the historic chemical consumption, although this is still usually useful as a cross-check.

APPROACHES FOR EMISSION ESTIMATES

Even among those applications which retain the chemicals over time, there are some significant distinctions. In some instances (e.g., refrigeration) the quantity of HFC or PFC is typically topped-up during routine servicing. If equipment were topped-up annually and the market was otherwise static (i.e., no growth in the equipment stock), the actual emissions would be consistent with consumption for that year. Under such circumstances, it is not necessary to know the precise equipment stock as long as the consumption of HFC or PFC is known by type at the sub-application level. This is the basis of the mass-balance approach which is referred to throughout this chapter as Approach B. More discussion on the mass-balance approach is found in Chapter 1, Section 1.5 of this volume. However, a mass-balance approach is not appropriate for other situations or for other products (e.g., foams) where consumption occurs only at the point of manufacture, while emissions may continue to a limited extent throughout the lifetime of the product. In such instances, it is usually better to revert to an emission-factor approach (i.e., methods based on activity (consumption) data and emission factors). Such methods can be operated at both aggregated (Tier 1) and disaggregated (Tier 2) levels and are referred to throughout this chapter as Approach A. Accordingly, a Tier 1a method will be an emission-factor approach with a low level of disaggregation, while a Tier 2b method will be a mass-balance approach with a relatively high degree of disaggregation (at least to the sub-application level). Further information on the choice between using a mass-balance approach and an emission-factor approach is found in Chapter 1, Section 1.5. In general, mass-balance approaches are only considered for ODS substitutes stored or used in pressurised containers and so many applications do not consider Approach B at all. Where Approach B is considered (e.g., refrigeration and fire protection) the choice of method is discussed under that part of Chapter 7 addressing the application in question.

Some methods described for these specific applications can have characteristics of both approaches, and the mass-balance approach can be used to cross-check and validate the results of an activity (consumption) data/emission factor approach. Accordingly, whilst the labelling conventions will remain unchanged throughout

the reporting of emissions. Parties should make every effort to develop the necessary sources of data;'. (Decision 2/CP.3, Methodological issues related to the Kyoto Protocol)

to avoid confusion, it may be that some methods are labelled Tier 1a/b or Tier 2a/b because they are seen to contain elements of both approaches. This is most common in the case of Tier 1 methods where data is limited and one approach can be usefully used to cross-check the other.

Table 7.2 below summarises what kind of data are required to implement different tiers and approaches.

TABLE 7.2
OVERVIEW OF DATA REQUIREMENTS FOR DIFFERENT TIERS AND APPROACHES

	Approach A (emission-factor approach)	Approach B (mass-balance approach)
Tier 2 (emission estimation at a disaggregated level)	• Data on chemical sales and usage pattern by sub-application [country-specific or globally/regionally derived] • Emission factors by sub-application [country-specific or default]	• Data on chemical sales by sub-application [country-specific or globally/regionally derived] • Data on historic and current equipment sales adjusted for import/export by sub-application [country-specific or globally/regionally derived]
Tier 1 (emission estimation at an aggregated level)	• Data on chemical sales by application [country-specific or globally/regionally derived] • Emission factors by application [country-specific or (composite) default]	• Data on chemical sales by application [country-specific or globally/regionally derived] • Data on historic and current equipment sales adjusted for import/export by application [country-specific or globally/regionally derived]

In the six sections that follow (Sections 7.2 to 7.7), decision trees are included for each application to assist in the identification of data needs and the selection of approach for individual sub-applications, where these exist.

7.1.2.2 CHOICE OF METHOD

As already described, emissions of ODS substitutes can be estimated in a variety of ways with varying degrees of complexity and data intensity. This chapter provides less data-intensive Tier 1 methods, typically based on low levels of disaggregation, and more data-intensive Tier 2 methods, which require higher levels of disaggregation. A third Tier (Tier 3), based on actual monitoring and measurement of emissions from point sources, is technically possible for specific sub-applications but this is rarely, if ever, employed for ODS substitutes, because the individual point sources are widely disparate. Accordingly, Tier 3 methods are not addressed further in this chapter.

TIER 1 METHODS

Tier 1 methods tend to be less data-intensive and less complex than Tier 2 because emission estimates are usually carried out at the application level rather than for individual products or equipment types. However, the approaches proposed vary considerably depending on the characteristics of the specific application. There can be Tier 1a approaches, Tier 1b approaches and, sometimes, combinations of the two (Tier 1 a/b). The latter is often the case where data are in short supply. Effectively, the output of a Tier 1a approach can be cross-checked using a Tier 1b method. In general, however, the simple methods tend to be based primarily on a Tier 1a approach (emission-factor approach) with the default emission factor being up to 100 percent for prompt release applications.

For simpler Tier 1 approaches, the chemical sales data at the application level is usually sufficient. However, separating out individual components of blends can still represent a considerable challenge. Irrespective of the Tier 1 methodology chosen, countries will need to report emissions of individual HFCs and PFCs. Information on the practical use of the various commercial types of HFC/PFC refrigerants, blowing agents, solvents, etc. will therefore be required. Many of these products are mixtures of two or more HFCs and/or PFCs, and the composition of fluids for similar purposes may vary according to individual formulas developed by different chemical companies.

Tier 1a – Emission-factor approach at the application level

Tier 1a relies on the availability of basic activity data at the application level, rather than at the level of equipment or product type (sub-application). This activity data may consist of annual chemical consumption data and, for applications exhibiting delayed emissions, banks derived therefrom. Once activity data have been established at the application level, composite emission factors (see Section 7.1.2.3) are then also applied at the

application level. These more aggregated emission factors (e.g., all rigid foams) can be a composite or weighted average of the emission factors developed for Tier 2a covering individual equipment or product types, or can be a validated approximation approach (e.g., Gamlen *et al*. 1986).

The calculation formula for Net Consumption within the Tier 1a method is as follows:

EQUATION 7.1
CALCULATION OF NET CONSUMPTION OF A CHEMICAL IN A SPECIFIC APPLICATION

$$Net\ Consumption = Production + Imports - Exports - Destruction$$

Net Consumption values for each HFC or PFC are then used to calculate annual emissions for applications exhibiting prompt emissions as follows:

EQUATION 7.2A
CALCULATION OF EMISSIONS OF A CHEMICAL FROM A SPECIFIC APPLICATION

$$Annual\ Emissions = Net\ Consumption \bullet Composite\ EF$$

Where:

Net Consumption = net consumption for the application

Composite EF = composite emission factor for the application

Note that, as discussed in the Choice of Activity Data section, inventory compilers may have access to chemical consumption data at the aggregate level rather than by application. In this case, it will be necessary as an early step to determine the share of total consumption represented by each application.

In equation 7.1, *Production* refers to production of new chemical. Reprocessing of recovered fluid should not be included in consumption estimates. *Imports* and *Exports* include bulk chemicals but, for a Tier 1 method is unlikely to contain the quantity of chemical contained in products, such as refrigerators, air-conditioners, packaging materials, insulating foams, fire extinguishers etc. unless regional allocation system or other method of approximation has been used. The term *composite emission factor* refers to an emissions rate that summarises the emissions rates of different types of equipment, product or, more generally, sub-applications within an ODS application area. Composite emission factors should account for assembly, operation and, where relevant in the time-series, disposal emissions.

Although destruction of virgin HFCs and PFCs is not currently practised widely, and may be technically difficult in some cases (UNEP TEAP Task Force on Destruction Technologies (UNEP-TEAP, 2002)), it should be included as a potential option to reduce consumption. It should be noted that destruction of virgin chemicals, as considered here, is distinct from the destruction of HFCs and PFCs in the end-of-life phase, which is strictly an emission reduction measure. By-product emissions during HFC/PFC production and fugitive emissions related to production and distribution have to be calculated separately.

Even in simple Tier 1a methods, it is usually necessary to account for the potential development of banks, where these can occur. Banks are the amounts of chemical that have accumulated throughout the lifecycle, either in supply chains, products, equipment or even waste streams but which, as of the end of the most recent year, has not been emitted. At the application level, banks can be estimated using relatively straight-forward algorithms and assumptions provided that the historic Net Consumption is known for each year following the introduction of the substance or, where this period exceeds the average lifetime of the product or equipment, over that average lifetime. Relevant application level emission factors are then applied to the banks to deal with emissions during the lifetime of the products or equipment. This same process is carried out for Tier 2a methods but, in that case, at the sub-application level. More general information on banks is contained in Section 7.1.2.1.

In cases where banks occur, Equation 7.2A is then modified to the following:

EQUATION 7.2B
CALCULATION OF EMISSIONS OF A CHEMICAL FROM AN APPLICATION WITH BANKS

$$Annual\ Emissions = Net\ Consumption \bullet Composite\ EF_{FY} + Total\ Banked\ Chemical \bullet Composite\ EF_{B}$$

Where:

Net Consumption = net consumption for the application

Composite EF_{FY} = composite emission factor for the application for first year

Total Banked Chemical = bank of the chemical for the application

Composite EF_B = composite emission factor for the application for bank

Composite emission factors are determined by taking an average of the applicable sub-application emission factors, weighted according to the activity in each sub-application. Sub-application emission factors can be country-specific where known or default. In practice, if sub-application data are known, inventory compilers would opt for a Tier 2 (disaggregated approach). If only application level data are known, representative composite emission factors from other studies or default composite emission factors provided in this chapter can be used.

Tier 1b – Mass-balance approach at the application level

The mass balance approach also estimates emissions from assembly, operation, and disposal, but does not rely on emission factors. Instead, the method uses measured consumption (i.e., sales) of each chemical in the country or facility being considered. It is generally limited to ODS Substitutes contained in pressurised systems. The general equation is as follows[6]:

EQUATION 7.3
GENERAL MASS BALANCE EQUATION FOR TIER 1b

$$Emissions = Annual\ Sales\ of\ New\ Chemical - (Total\ Charge\ of\ New\ Equipment - Original\ Total\ Charge\ of\ Retiring\ Equipment)$$

Industry needs to purchase new chemical from manufacturers in order to replace leakage (i.e., emissions) from the current equipment stock, or the equipment will not function properly. If the equipment stock did not change from year to year, then annual chemical consumption alone would provide a reasonable estimate of actual leakage or emissions. The total equipment stock, and the chemical charge it contains, however, does change from year to year. Some amount of new equipment containing a chemical charge is introduced each year, and some amount of old equipment that was charged originally is retired each year. If the total chemical charge contained in all equipment is increasing as a result of this annual turnover, then total annual chemical consumption will overestimate emissions (i.e., the charge contained in new equipment is greater than the original charge of the retired equipment). Conversely, if the total chemical charge in all equipment is decreasing, then total annual chemical consumption will underestimate emissions.

In order to make good use of data on annual sales of new chemical, it is therefore also necessary to estimate the total charge contained in new equipment, and the original charge contained in retiring equipment. The total charge of new equipment minus the original total charge of retiring equipment represents the net change in the charge of the equipment stock. (Using the mass balance approach, it is *not* necessary to know the total amount of each chemical in equipment stock in order to calculate emissions.) Where the net change is positive, some of the new chemical is being used to satisfy the increase in the total charge, and therefore cannot be said to replace emissions from the previous year.

Industry also requires new chemical to replace destroyed gas and for stockpiles. Additionally, not all equipment will be serviced annually. Terms can be added to the general equation to account for these factors but are not typically adopted within simple Tier 1b methods.

This approach is most directly applicable to the pressure equipment used in refrigeration and air conditioning, and fire protection applications because these are where chemical sales are most typically used to offset operational emissions. However, since the basic method is relatively simple to apply, it is more typical to extend the approach to the sub-application level (i.e., a Tier 2b method). Further elaboration and modification of this approach is provided in the description of each application. In practice, Tier 1b methods are most commonly used as a further cross-check to Tier 1a methods. Where basic Net Consumption data is lacking, regional and international databases and models have been developed that allocate regional chemical sales for different end uses (sub-applications) at a country level. These can therefore be used to source relevant data.

TIER 2 METHODS – APPLIED AT THE SUB-APPLICATION LEVEL

There are two versions of the Tier 2 method, both of which result in emission calculations for each individual chemical and distinct types of products or equipment at the sub-application level or within a sub-application. The

[6] Boundary conditions: If there is no net change in the total equipment charge, then annual sales are equal to emissions. If the net change in the total equipment charge is equal to annual sales, then emissions are zero.

individual chemicals and products/equipment within the sub-application form the matrix referred to earlier in this section and their analysis is comparable with methods currently applied by the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) for CFCs, HCFCs and HFCs (McCulloch, Midgley and Ashford, 2001 and 2003; Ashford, Clodic, Kuijpers and McCulloch, 2004).

Both versions of the Tier 2 methodology follow two general steps:

i. Calculation or estimation of the time series of net consumption of each individual HFC and PFC chemical at a relatively detailed product and equipment level to establish the consumption basis for emission calculations. (e.g., refrigerators, other stationary refrigeration/AC equipment, appliance foams, insulated panels, pipe insulation, etc.)

ii. Estimation of emissions using the activity data and resulting bank calculations derived from step (i), and either emission factors that reflect the unique emission characteristics related to various processes, products and equipment (Tier 2a) or, relevant new and retiring equipment information at the sub-application level to support a mass balance approach. (Tier 2b).

The difference between Tier 2a and Tier 2b is the same as that for Tier 1a and Tier 1b – namely Tier 2a methods use an emission-factor approach while Tier 2b methods follow a mass-balance approach. Both, however, need to be operated at a level of disaggregation appropriate to a Tier 2 method, typically at least at the sub-application level.

If the requisite data are available, a Tier 2 method is preferred for estimating emissions from ODS substitutes, particularly where the sub-applications within an overall application area are relatively heterogeneous. Some countries may already have the relevant information available to apply a Tier 2 methodology. Other countries might not have access to data for Tier 2 at present, but they are encouraged to establish routines to collect either country-specific or globally or regionally-derived activity data by chemical and sub-application within an application area (e.g., different types of refrigeration and air conditioning sub-applications). Tier 1, in contrast, requires data collection at a more aggregated application level (e.g., refrigeration and air conditioning in its totality).

As a first step in using the Tier 2 method, countries may wish to make first order approximation of the information needed for step (i). This will give direction to more focused data collection efforts in certain application areas or sub-categories. Table 7.3 gives examples of HFC/PFC consumption distribution at the application level in 2002 among various application areas in selected countries. Since HFCs and PFCs have only recently entered the market in some applications, the relative size of consumption in each application will continue to change over time and should be updated regularly at a country level.

TABLE 7.3
EXAMPLE DISTRIBUTION OF HFC/PFC USE BY APPLICATION AREA (2002)[a]

Country	Refrigeration Air Conditioning	Foam Blowing	Solvent[b]	Fire Protection[b]	Aerosol Propellant[b]	Other Applications[b]
Austria	18%	81%	0%	1%	0%	0%
Denmark	81%	18%	0%	0%	1%	0%
Norway	72%	11%	0%	16%	1%	0%
Sweden	48%	42%	0%	4%	6%	0%
United Kingdom	31%	22%	0%	9%	38%	0%

[a] UNFCCC Reported Data for 2002 as re-submitted in 2004

[b] A zero declaration may not always reflect non-use but could reflect reporting under other categories.

G*ood practice guidance* in this section deals with variations of the Tier 2 method. Tier 1 methods, covered previously, are generally seen as default methods where the application is not a *key category* and data availability is limited. (Exceptionally, for Fire Protection, Tier 1a method with country-specific activity data and emission factor will be used in the case it is identified as *key category*.) Each sub-section of Sections 7.2 to 7.7 discusses how to apply these methods to specific ODS applications, reviews existing data sources, and identifies gaps therein.

Tier 2a – Emission-factor approach

The country-specific data required for a Tier 2a approach are derived from the number of products and end-uses relevant to each sub-application in which ODS substitutes are contained and from which ODS substitutes are ultimately emitted. This approach seeks information on the number of equipment units or products that use these chemicals, average chemical charges, average service life, emission rates, recycling, disposal, and other pertinent parameters. This information is generally collected at the level of distinct groups of products or equipment (e.g., for rigid foams: integral skin, continuous panel, discontinuous panel, appliance, injected foam products and others). Annual emissions are then estimated as a function of these parameters through the life of the units or products by the application of emission factors that are relevant to the lifecycle phases. Since equipment and other products vary significantly in the amount of chemical used, service life, and emission rates, the characterisation of this equipment can be a resource intensive task. The longer-lived the end-use equipment or product, and the more diverse the types of equipment or product within a particular sub-application, the more complex the sourced data approach has to be in order to account for emissions. However, the approach can provide an accurate estimate of emissions if the data called for by the following equation are available for all relevant types and vintages of equipment or product:

EQUATION 7.4
SUMMARY EMISSIONS EQUATION BASED ON PHASES OF THE LIFECYCLE

$$\begin{aligned} \textit{Total Emissions of Each PFC or HFC} = {} & \textit{Assembly/Manufacturing Emissions} \\ & + \textit{Operation Emissions} \\ & + \textit{Disposal Emissions} \end{aligned}$$

Manufacturing or Assembly Emissions occur as fugitives when new equipment is filled for the first time with a chemical or when a product is manufactured. *Operational Emissions* from equipment and products occur as leaks or by diffusion during the use phase of the product or equipment (including servicing). In some cases, there can even be intentional releases during operation. Finally, *Disposal Emissions* can occur when the equipment or product reaches its end-of-life and is decommissioned and disposed of. In this case, the remaining HFC/PFC in the product or equipment may escape to the atmosphere, be recycled, or possibly destroyed.

As with the Tier 1a method, there is a need to make provision for the development of banks in some applications. This can lead to complex multiple calculations at the sub-application level, since the dynamics of banks may vary considerably. However, because the individual algorithms rely on a simple sequential calculation of non-emitted consumption (i.e., consumption – emissions for each successive year), excellent emission assessments can result from a well-constructed and well-maintained national model.

The need to update equipment and product inventories on an annual basis can be a major implementation challenge for inventory compilers with limited resources. This challenge is made somewhat easier because it may not be necessary to collect annual chemical consumption if a comprehensive set of other market parameters is available (e.g., number of domestic refrigerators produced, etc.) In some countries or regions, trade associations can be a significant source of such data. Otherwise, specific market research may be necessary. Where such market parameters are the primary source of activity data, the potential magnitude of errors that can be introduced by small discrepancies at unit level makes it *good practice* to carry out a chemical consumption data cross-check to act as a means of providing quality assurance. The relevant QA/QC sections of this chapter give guidance on how to conduct such cross-checks for each relevant application.

In order to limit the burden of data management for both annual consumption data and the status of banks, it is possible to access international and regional databases of such information to gain the necessary inputs of globally or regionally validated data to maintain a national model. These databases can also help to overcome any confidentiality barriers that may exist in collecting and/or publishing data at a national level, particularly where the number of suppliers is low. More information on the use of such databases is contained in Section 7.1.2.4 and Box 7.1.

Even where comprehensive country-specific activity data exists at a country level, it is *good practice* to benchmark outputs against assessments made from databases of globally or regionally derived data. This need not be done on an annual basis but could reasonably be conducted every 2-3 years. Significant discrepancies can then be analysed and suitable actions taken to reconcile differences.

Tier 2b – Mass-balance approach

Tier 2 mass-balance approaches are similar to those described for Tier 1b, except that the process is applied at the sub-application level. This is a particularly valuable approach for the refrigeration sector where there are a significant number of relatively heterogeneous sub-applications. As is also the case for Tier 1 methods, it is not

uncommon to see mass-balance approaches used in combination with emission-factor approaches to ensure that the outputs achieved are as robust as possible. Such approaches can realistically be described as hybrid Tier 2a/b methods and they will be identified as such, where they occur in the relevant application-specific sections that follow.

Since mass-balance approaches also require activity data at the sub-application level, it may be more resource-efficient to use global or regional databases to obtain appropriate globally or regionally validated data. The same criteria for selection as set out for Tier 2a methods also apply for Tier 2b methods. Accordingly, equal care should be taken in selecting validated datasets.

7.1.2.3 CHOICE OF EMISSION FACTORS

Emission factors are required for all methods following Approach A. In general terms, emission factors can be of two distinct types:

1. Emission factors derived from actual measurements of products or equipment at a national level during the various phases of their lifecycle (*country-specific*),

or

2. Emission factors inferred from wider regional or global sub-application experience (e.g., *default*).

The type of emission factor required will depend on the level of homogeneity within the sub-application, the Tier approach being implemented, the dependence of emission factors on field practices applied, the role of banks and the likelihood of specific national circumstances. In some cases, the application will be or may be reasonably considered to be totally emissive, in which case the net consumption for a given year will become the emissions estimate for that year (e.g., many aerosol applications). In such a situation, a default emission factor would normally be more than adequate. However, in most cases involving ODS substitutes, some delay in emission is anticipated. Accordingly emission factors may need to be more sophisticated, particularly when applied at the sub-application level (Tier 2).

Because Tier 1 methods typically operate at the application level, it is necessary to use composite emission factors, which can be either based on weighted averages of known sub-application emission factors (country-specific or default) or on validated approximation approaches. Since Tier 1 methods are intended to be simple in their application, inventory compilers have the option of using existing composite emission factors based on the work of others. The Tier 1a approaches outlined in Sections 7.2 to 7.7 make such provision.

For Tier 2 methods, inventory compilers need to be aware of the specific circumstances surrounding the sub-applications in their countries. Although product and equipment types can be similar throughout a region or, even globally, there can be significant differences in emission factors over the lifetime of the product or equipment. Such differences can arise from climatic factors, construction methods, regulatory approaches and, in particular, from servicing methods where these apply. An additional factor to be considered in many countries is the management of the disposal of products and equipment at the end of its service life, which can have a profound effect on the total emissions. The chemical remaining in systems at that stage can be 90 percent or more of the original quantity used. Specific issues related to emission factors are discussed in the relevant application sections.

Therefore, inventory compilers should ensure that their derivation takes into consideration these potential sources of variation. This is often best done by comparing selections with those chosen by other countries with similar circumstances. Where emission factor variation is seen to be significant (e.g., distinction between developed and developing country experience with refrigeration equipment), the item is highlighted in relevant application-specific sections of this chapter.

As an additional support to inventory compilers, the most significant emission factors are included in the Emissions Factor Database (EFDB) administered by IPCC. The extensive editorial review process ensures that listed emission factors in the EFDB are properly examined to insure their robustness. Since emission factors in the EFDB tend to be adjusted less frequently than globally or regionally derived activity data, the review process can usually keep up with developments, thereby ensuring that listed values are broadly current.

7.1.2.4 CHOICE OF ACTIVITY DATA

For ODS substitutes, activity data consist of the net amount of each chemical consumed annually in a country in an application, sub-application or more detailed equipment/product type. When adopting a Tier 2a method, it is often necessary to collect activity data for the number of units of a particular equipment or product type in existence to estimate the amount of chemical consumed or in banks.

Where banks of chemical are likely to occur, it is also necessary to have information on historical annual net consumption patterns, either since the year of introduction of the chemical or over the average lifetime of products or equipment within the application or sub-application. This allows for the calculation of the cumulative bank in cases where emission factors must then be applied (Tier 1a or Tier 2a methods).

As noted previously, reprocessing of recovered fluid should not be included in consumption estimates. Imports and exports include not only bulk chemicals, but, for Tier 2 methods in particular, may also include the quantity of chemical contained in products, such as refrigerators, air-conditioners, packaging materials, insulating foams, fire extinguishers, etc., depending on whether regional allocation has been used or not. Usually, it is notoriously difficult to obtain data on HFCs and PFCs contained in equipment or products unless a specific customs regime has been set up to address this issue. This will only likely be practiced, if at all, in conjunction with the implementation of a Tier 2 method and is unlikely to be available for Tier 1 methods, making the availability of globally or regionally derived data particularly important, at least as a cross-check, if significant product or equipment trade is expected.

Such globally or regionally derived net consumption (activity) data can be obtained from the datasets contained in regional and global databases. Under this approach, chemical sales data are sometimes assigned from wider regional consumption information on the basis of some geo-economic factor such as population, GDP or number of dwellings. When using this market-based allocation method, it might not be necessary to take account of HFCs and PFCs contained in products being imported or exported, if the regional treatment causes netting out of intra-regional trade (i.e., imports and exports of products containing HFCs and PFCs within a region are roughly balanced). Where extra-regional trade is significant, then the HFCs and PFCs contained in products will need more careful consideration.

Since activity data will be more prone to annual change than emissions factors, the source of globally or regionally derived data used by the inventory compilers needs to be updated regularly. Reliable global databases carrying this information are regularly cross-checked with global sales data for individual chemicals and sub-applications, thereby ensuring regular validation. When accessing such databases, it is *good practice* for inventory compilers to ensure that the information they are receiving has been so validated. As noted in Box 7.1, Global and Regional Databases for ODS Substitutes, inclusion in the IPCC EFDB will indicate general adherence to due process, but it is *good practice* for countries to ensure that all data taken from the EFDB are appropriate for their national circumstances.

Specific considerations when collecting country-specific activity data

The collection of country-specific activity data requires an inventory of HFC/PFC net consumption for each chemical and, where emissions lag behind consumption, an inventory of banked chemicals. Some inventory compilers may have access to national data published in trade magazines or technical reports. If these data are not available directly, they can be estimated by means of a special study to estimate the inventory of existing units or chemicals. Expert panels can also facilitate the generation of this information. Care must be taken to ensure that the scope of any datasets cited is understood and that any remaining gaps are identified.

Inventory compilers may also decide to conduct annual studies to update their inventories of different types of equipment/products. An alternative to this may be to calculate or estimate production growth for each one of the sub-applications under consideration. Data need to reflect new units that are introduced each year, and old or poorly functioning units that are retired.

Data on national chemical use are more easily obtained than data for the amount of equipment responsible for emissions, provided that confidentiality constraints do not intervene. It is always *good practice* to obtain data on the total annual sales from the chemical manufacturers or importers. The best source of data on the total charge of new equipment is likely to be the equipment manufacturers or the trade associations that represent them. For the total charge of retiring equipment, it is essential to obtain information on or estimate (i) equipment/product lifetime, and (ii) either (a) the historical sales of equipment/product and the historical average charge size or formulation, or, (b) the growth rate of such sales and charge sizes over the period in question, where such information is known for the current year.

Inventory compilers in countries that import all or the majority of new chemicals consumed are likely to encounter different issues of data availability than those in countries with significant domestic chemicals production. If the majority of chemicals are imported, either in bulk or in equipment and products, some form of import data will be necessary for calculating emissions. Ideally, customs officials should track and make available chemical import statistics. For some products, such as foam and aerosols, it may not be possible for customs officials to track the type of chemical in the product (e.g., Hydrocarbons vs. HFCs in aerosols), or the presence of the product in the imported equipment (e.g., closed cell foam in refrigerators). In such cases, it may be necessary to collect or estimate data with the assistance of major distributors and end-users.

As noted previously in this Section, the ability to obtain relevant country-specific activity data and banking information on a consistent basis at a country level can be constrained by such issues as confidentiality, lack of

downstream industry networks and lack of trade information in products-containing HFCs and/or PFCs. Reconciliation is therefore often better achieved at regional level or even global level in some cases. In making this comment, it should be noted that the use of country-specific and globally or regionally derived data is not specifically an 'either/or' choice. In many cases, the development of a country's overall inventory may rely on a combination of data from both sources. In any event, the use of one to verify the other is actively encouraged as *good practice*.

Specific considerations when using the mass-balance approach (Tier 1b or 2b)

Activity data for a mass balance approach (Tier 1b or 2b) focus on chemical deployment rather than sources of emissions. These activity data include annual sales of new chemical, the total charge of new equipment, and the total charge of retiring equipment. If these data are not available at the national level, then globally or regionally derived data can be used, as for Approach A (emission-factor approach). Since the mass-balance approach is generally reserved for pressurised equipment in the refrigeration, air conditioning and fire protection applications, it is useful to know that comprehensive global databases already exist for these.

Time dependency of data contained in these Guidelines

The products and equipment in which ODS substitutes are used have changed significantly over time, and are expected to continue to change. As a result, where information on activity data and default emission factors is contained in these *Guidelines*, it should be noted that activity data will be a more volatile component than emission factors in determining overall emissions. Accordingly, any default activity information contained herein will 'age' more rapidly and will lead to greater inaccuracies with the passage of time unless appropriate adjustments are made for market growth in the interim. Global and regional databases for ODS substitutes noted in Box 7.1 will generally reflect these changes. Where ODS transitions are still in the future, the adoption of static activity data could lead to very significant errors in emission projections.

7.1.2.5 COMPLETENESS

Completeness is assured to a large extent for ODS Substitutes as a result of well-documented use patterns for ODSs themselves and by the fact that activity data, assessed at the application and sub-application levels, can be validated against total chemical sales. This is particularly the case for those HFCs and PFCs which are only used as ODS substitutes. However, it is still important to be able to identify all potential HFCs and PFCs in use. Table 7.1 gives an overview of the main HFCs and PFCs to be considered, but this may not be exhaustive, particularly when it comes to the components of blends, which can often be complex in their composition.

One set of emissions which is not covered routinely within this source category are those arising from chemical production itself. However, methods for assessing these emissions are covered within Chapter 3, Section 3.10.

It is possible for emissions to exceed consumption (activity) in a given year owing to emission of previously accumulated banks and therefore completeness of emissions reporting can only be established in Tier 2 approaches by plotting cumulative emission versus cumulative activity for the total period over which consumption and resulting emissions have occurred (i.e., cumulative consumption equals cumulative emissions plus current bank less cumulative destruction).

7.1.2.6 DEVELOPING A CONSISTENT TIME SERIES

Inventory compilers that have prepared basic (Tier 1) estimates in the past are encouraged to develop the capacity to prepare Tier 2 estimates in the future. It is *good practice* to ensure that only actual emission estimates are included in the same time series. Inventory compilers should recalculate historical emissions with the preferred actual method, if they change approaches. Since all Tier 1 and Tier 2 approaches are now actual emission methods, there is no problem in mixing these approaches for different applications or sub-applications. However, if potential emission methods have previously been used, the time series needs to be recalculated. If data are unavailable, the two methods should be reconciled to ensure consistency, following the guidance on recalculation provided in Volume 1, Chapter 5. It is *good practice* to provide full documentation for the recalculation, thereby ensuring transparency.

Emission factors generally come from historical data on other chemicals (e.g., CFCs) used in established markets. These factors need to be adapted to new chemicals (e.g., ODS substitutes) where new uptake occurs. National data on base year deployment is now available (or can be calculated with known uncertainty).

7.1.3 Uncertainty assessment

Over a long time (greater than 50 years in some applications) cumulative emissions of ODS substitutes within a country will tend to equal cumulative consumption in the same time frame unless significant end-of-life recovery has been practised. For a given year, the quantification of uncertainty for ODS is very difficult to estimate, due to the large number of different sources and the diversity of emission patterns. For the Tier 1b and 2b methods, the overall uncertainty will be directly related to quality and completeness of chemical sales and import data at either the application or the sub-application level. These factors will be equally important for Tier 1a methods but there will be additional sources of uncertainty arising from the use of composite emission factors and other assumptions required to complete specific algorithms. For the Tier 2a method, the uncertainty will reflect the completeness of the equipment survey, and the appropriateness of the emission factors developed at the sub-application level to characterise emissions. Further advice on uncertainties is provided in the separate sections on the six application areas that follow.

7.1.4 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation for all ODS substitutes applications

7.1.4.1 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) FOR ALL ODS SUBSTITUTES APPLICATIONS

It is *good practice* to conduct quality control checks as outlined in Volume 1, Chapter 6, and an expert review of the emissions estimates. Additional quality control checks as outlined in Volume 1, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from these applications or sub-applications. Inventory compilers are encouraged to use higher tier QA/QC for *key categories* as identified in Volume 1, Chapter 4. In addition to the guidance in Volume 1, specific procedures of relevance to this source category are outlined below.

Even with such provisions in place to deal with activity data, the real emission data for a given year will never be exactly known, irrespective of the refinement of the estimation methods. Hence, cross checking of integrated emission figures against real net consumption of HFC/PFC, together with judgement of banking over the same period of time must be performed at regular intervals, and the input factors have to be adjusted to achieve agreement over time.

Comparison of emissions estimates using different approaches

Inventory compilers should compare equipment/product based estimates at the sub-application level (Tier 2a) with the mass-balance Tier 1b or 2b approach, where appropriate, since emission factors at the product level have an inherent associated uncertainty. This technique will also minimise the possibility that certain end-uses are not accounted for in the equipment/product based approaches.

Potential emissions estimates as a reference scenario

Inventory compilers may also choose to use the potential emissions reference scenario as a check on the Tier 1 or Tier 2 actual estimates. Inventory compilers may consider developing accounting models that can reconcile potential and actual emissions estimates and may improve determination of country-specific emission factors over time. When taken alongside estimates of actual emission from determinations of atmospheric concentrations, this scenario can assist in monitoring the growth of banked greenhouse gases caused through delays in emission and, thereby, keeps track of likely future environmental burdens. This ultimate means of mass balance verification is particularly powerful for HFCs and PFCs because of their unique identities and lack of natural sources.

Potential emissions of a certain chemical are equal to the amount of virgin chemical consumed annually in the country minus the amount of chemical recovered for destruction or export in the year of consideration. (See Annex 2 of this volume.) All chemicals consumed will eventually be emitted to the atmosphere over time if not permanently encapsulated, chemically converted, or destroyed[7], and in the long term (in excess of 50 years for

[7] The destruction of fluorocarbons can be costly but there are several destruction processes recommended by the Parties to the Montreal Protocol: liquid injection incineration; reactor cracking; gaseous/fume oxidation; rotary kiln incinerators; cement kilns; plasma destruction; municipal solid waste incinerators (foams only).

some applications), cumulative potential emissions will equal cumulative actual emissions for those applications which ultimately cease use of HFCs and/or PFCs and where capture and destruction are not practised.

Since accumulation is thought to be the dominant process at the present time in the major areas of usage, such as refrigeration and foams, potential emission calculations will strongly overestimate emissions and are inappropriate as a formal annual reporting method.

The error is minimised when enough time has passed for HFC/PFC-containing equipment and products to begin to be retired, although, even then, the rate of subsequent emission may depend on the end-of-life strategy chosen. However, as long as emissions lag behind consumption and consumption continues to grow, the overestimation will persist. The error is zero only if there is no delay in emissions or if the consumption growth rate is zero for a long period of time.

National activity data check

For the Tier 2 method, inventory compilers should evaluate the QA/QC procedures associated with estimating equipment and product inventories, whether country-specific, regionally or globally derived, to ensure that they meet the general procedures outlined in the QA/QC plan and that representative sampling procedures were used. This is particularly important for the ODS substitutes equipment/product types because of the large populations of equipment and products.

For the Tier 1b (mass balance) method, inventory compilers should evaluate and reference QA/QC procedures conducted by the organisations responsible for producing chemical deployment information. Sales data may come from gas manufacturers, importers, distributors, or trade associations. If the QC associated with the secondary data is inadequate, then the inventory compiler should establish its own QC checks on the secondary data, reassess the uncertainty of the emissions estimates derived from the data, and reconsider how the data are used.

Emission factors check

Emission factors used for the Tier 2a method should ideally be based on country-specific studies. Where such an approach is used, inventory compilers should compare these factors with the defaults and any values which may be contained in the EFDB or elsewhere in support of Tier 2a methods. They should determine if the country-specific values are reasonable, given similarities or differences between the national circumstances surrounding the sub-application in question and those assumed within the defaults. Any differences between country specific factors and default factors should be explained and documented.

7.1.4.2 REPORTING AND DOCUMENTATION FOR ALL ODS SUBSTITUTES APPLICATIONS

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Volume 1, Section 6.11.

As discussed above, inventory compilers should prepare and report actual emissions estimates for as many sub-applications as possible. This is now aided by the availability of globally or regionally derived activity data in regional and global databases (see Box 7.1) together with emission factors for several sub-applications contained in the EFDB. For those equipment/product types where it is not possible to prepare actual emissions estimates at the sub-application level (i.e., Tier 2 estimates), even with this additional support, inventory compilers should prepare and report actual emission estimates using Tier 1 methods at the application level.

The balance between preservation of confidentiality and transparency of the data needs to be carefully addressed. Careful aggregation may solve some problems but will require that results are validated by other means (e.g., third party audit). Where data have been aggregated to preserve the confidentiality of proprietary information, qualitative explanations should be provided to indicate the method and approach for aggregation.

7.2 SOLVENTS (NON-AEROSOL)

7.2.1 Chemicals covered in this application area

HFCs are now used in solvent applications to a much lower extent than CFC-113 was used prior to phase-out, and PFCs are still only very rarely used. HFC/PFC solvent uses occur in four main areas as follows:

(i) Precision Cleaning;

(ii) Electronics Cleaning;

(iii) Metal Cleaning;

(iv) Deposition applications

HFCs are typically used in the form of an azeotrope or other blend for solvent cleaning. The most commonly used HFC solvent is HFC-43-10mee, with some use of HFC-365mfc, HFC-245fa (as an aerosol solvent[8]), and heptafluorocyclopentane (U.S. EPA, 2004b). This allows for tailoring the balance between effective cleaning and compatibility with materials of construction of the work-piece. The pure material does not have the cleaning power of CFC-113, since no chlorine atoms are present in the molecule.

In general, perfluorocarbons have little use in cleaning, as they are essentially inert, have very high GWPs and have very little power to dissolve oils - except for fluoro-oils and fluoro-greases for even deposition of these materials as lubricants in disk drive manufacture. Accordingly, PFCs only find rare uses in the solvent sector as blanketing fluids for 2-propanol cleaning systems (per British Aerospace military section) or in the now obsolete Advanced Vapour Degreasing (AVD) heterogeneous co-solvent system. Such PFCs can be used as blanketing fluids to prevent the loss of the more costly primary fluids in dual-fluid vapour phase soldering systems. PFCs can be used as the only working fluid in single-fluid vapour phase soldering systems. In the component manufacturing sector, PFCs are used to test the hermeticity of sealed components. Further information on the use of PFCs in the electronics industry is found within Chapter 6 of this volume.

In general, the major PFC manufacturers converted all former PFC users to HFC or hydrofluoroether (HFE) use in cleaning applications.

7.2.2 Methodological issues

7.2.2.1 CHOICE OF METHOD

Historically, emissions from solvent applications generally have been considered *prompt* emissions because 100 percent of the chemical is typically emitted within two years of initial use. (IPCC, 2000). In order to estimate emissions in such cases, it is necessary to know the total amount of each HFC or PFC chemical sold in solvent products each year. Emissions of HFCs and PFCs from solvent use in year t can be calculated as follows.

EQUATION 7.5
EMISSION ESTIMATION METHOD FOR SOLVENT USES

$$Emissions_t = S_t \bullet EF + S_{t-1} \bullet (1 - EF) - D_{t-1}$$

Where:

$Emissions_t$ = emissions in year *t*, tonnes

S_t = quantity of solvents sold in year *t*, tonnes

S_{t-1} = quantity of solvents sold in year *t*–1, tonnes

EF = emission factor (= fraction of chemical emitted from solvents in the year of initial use), fraction

D_{t-1} = quantity of solvents destroyed in year *t*–1, tonnes

Table 7.1 indicates the known HFCs and PFCs used in solvent applications, although *good practice* is to research the country-specific situation in case any previously unidentified applications have arisen. The scope of

[8] Emissions of aerosol solvents are included as an aerosol (see Section 7.3).

the search is aided by the fact that the inventory compiler is only looking for applications where ODSs were previously used.

The approach set out in Equation 7.5 can be applied as either a Tier 1a or a Tier 2a method, based as it is on Approach A (emission-factor approach). Whether the approach qualifies as a Tier 1 or Tier 2 method will depend on whether there are identifiable sub-applications within the solvent usages in the reporting country (e.g., the four main areas identified above). As trends have developed towards more controlled solvent environments, the need for a Tier 2 approach has increased. In some cases, there may be highly controlled sub-applications (e.g., in the precision electronics industry) where specific emission factors are fully characterised. These would be treated differently from more general solvent applications which may remain based on the default emission factor. It should be noted that Equation 7.5 assumes total release of solvent within two years regardless of the emission factor applied in year t. Additionally, there is no consideration of recovery and recycling, which may be a factor in some situations. However, it would be assumed that recovery and recycling would, in general, be reflected in reduced sales of virgin materials. Solvent recovered and subsequently destroyed is considered, but is an unlikely course in practice bearing in mind the cost of the chemicals involved.

7.2.2.2 CHOICE OF EMISSION FACTORS

The emission factor EF represents the fraction of chemical emitted from solvents in year t. The product lifetime is assumed to be two years, and thus any amount not emitted during the first year is assumed by definition to be emitted during the second and possibly final year. A decision tree for estimating actual emissions is included in Figure 7.2, Decision Tree for Actual Emissions from the Solvents application. The data collection process is described in Section 7.2.2.3.

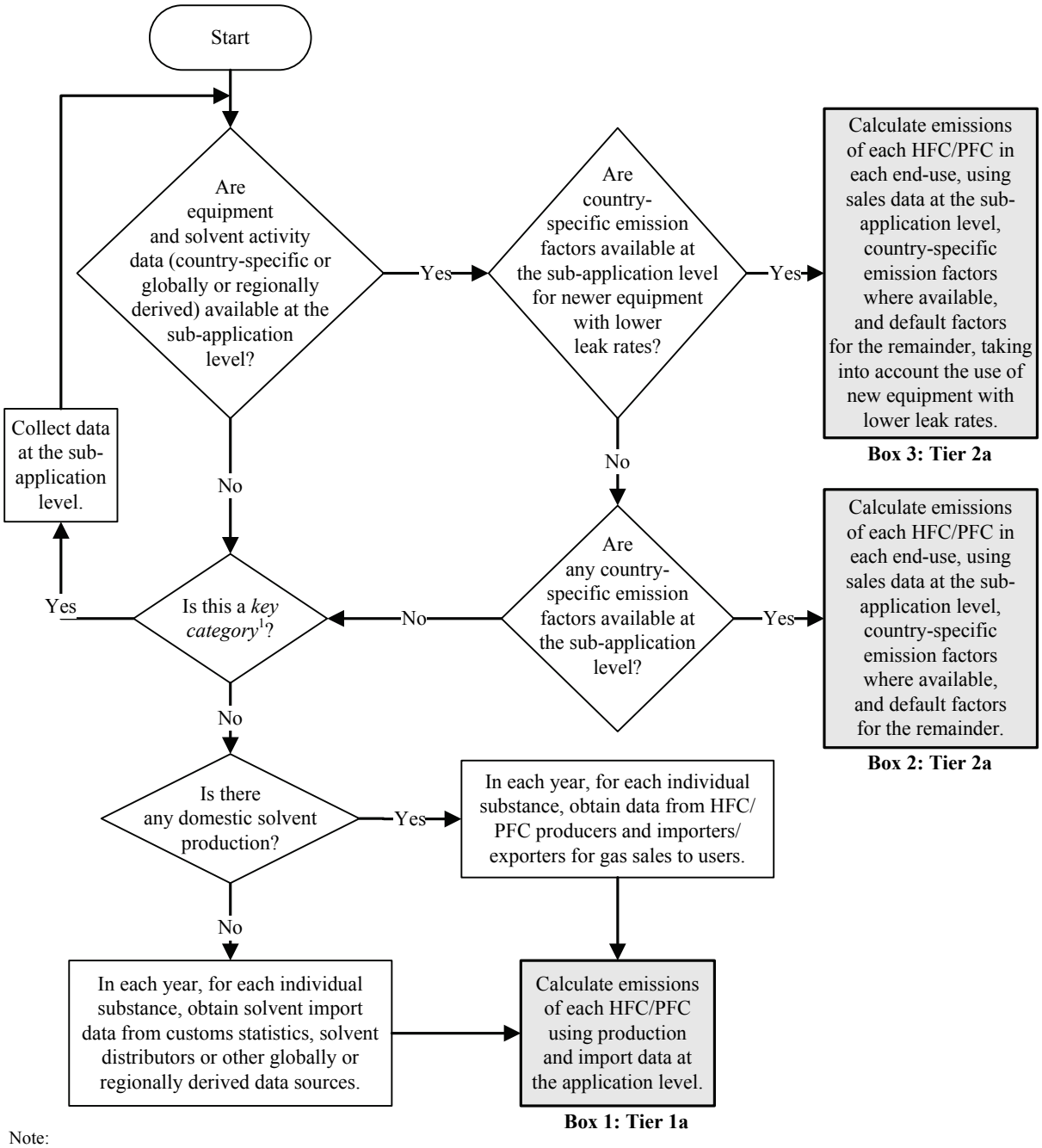
In the absence of country-specific data, it is *good practice* to use a default emission factor of 50 percent of the initial charge/year for solvent applications.[9] In certain applications with new equipment incorporating low emission design features, it is very possible that much lower loss rates will be achieved and that emissions will occur over a period of more than two years. Alternative emission factors can be developed in such situations, using data on the use of such equipment and empirical evidence regarding alternative emission factors.[10] Such country-specific emission factors should be documented thoroughly (Tier 2a). The 'mix' of hand operated batch cleaning systems and automated conveyorised systems within a country or region may result in very different emissions. Attention to proper work practices, setup of the work area and proper training of the workers will significantly lower solvent emissions. Within such groups (batch or conveyorised), there is a wide range of equipment age, low emission design sophistication, workpiece design, workpiece load size and maintenance diligence. All of these factors will affect emissions from a particular piece of equipment or region.

Modifications for the recovery and recycling of solvents can be applied if an appropriate estimate of retrofitted equipment can be obtained. While HFC and PFC solvents may be recovered and recycled multiple times during their use owing to their high costs, in most emissive end uses (sub-applications) these chemicals will be released considerably more quickly after being placed in use than those in sealed refrigeration applications.

[9] *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC, 2000).

[10] As guidance, for sales to new equipment, approximately 10-20 percent may be emitted with the rest of the solvent used to fill the equipment. In subsequent years sales are for replenishment and can eventually be considered 100 percent emitted.

Figure 7.2 Decision tree for actual emissions from the solvents application



Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

7.2.2.3 CHOICE OF ACTIVITY DATA

Equation 7.5 should be applied to each chemical individually and, depending on the disaggregation in available data, it may be appropriate to assess net consumption of each chemical by sub-application (Tier 2a). Wherever possible, activity data should be collected directly from the suppliers of solvent or the users in support of either Tier 1a or 2a methods. However, where this is not possible, globally or regionally derived activity data at the application level or the sub-application level can be used where this is available.

The activity data for this end-use are equal to the quantity of each relevant chemical sold as solvent in a particular year. Accordingly, data on both domestic and imported solvent quantities should be collected from suppliers. Depending on the character of the national solvent industry, this can then be cross-checked with users

where this is practicable. In most countries, the end-users will be extremely diverse and a supplier-based approach would be most practical. Nonetheless, a combination of both approaches is often the most effective.

SUPPLIER DATA

Supplier activity data refers to the amount of chemical solvent sold or imported annually into a country. Domestic solvent sales should be available directly from chemical manufacturers. As solvents are only produced in a few countries, most countries will import some or all of their consumption. Data on imported solvents can be collected from the exporting manufacturers, although information on exports to individual countries may be considered confidential. Alternatively, import statistics from customs agencies or the distributors of imported solvents can be used. Solvent import data are generally more easily obtained than aerosol import data because solvent is usually imported in bulk rather than in small containers.

If specific emission factors are developed for particular types of equipment, it will be necessary to disaggregate the consumption data into these equipment classes. In general, this will require a bottom-up approach.

USER DATA

User activity data include the number of pieces of equipment or canisters containing solvent and their charge. The bottom-up approach is suitable where large corporations consume most of the solvent sold, because it should be possible to obtain detailed solvent end-use data from a few large entities. The bottom-up approach may also be most appropriate when equipment-specific emission factors are available.

7.2.2.4 COMPLETENESS

Completeness depends on the availability of activity data. Inventory compilers in countries without domestic solvent production may need to use expert judgement in estimating activity data, because import statistics are likely to be incomplete (see Volume 1, Chapters 2 and 3).

There is a potential for double-counting with Volume 3 Chapter 6 which deals with HFC and PFC use in the electronics industry. This should not occur if care is taken to identify previous ODS consumption patterns. It is always *good practice* to cross-reference of both parts of a submission by inventory compilers to confirm that no double-counting has occurred.

With respect to double-counting, care should also be taken where HFCs and PFCs acting as solvents are contained in aerosols. A clear policy should be established as to how these are accounted. It is normally *good practice* to account for these uses under consumption in aerosols to avoid problems in making distinctions between solvents and propellants, particularly where one chemical can act in both roles. This matter is covered further in Section 7.3.

As noted in Section 7.2.2.1, it is also *good practice* to carry out some research to confirm that no HFCs or PFCs other than those listed in Table 7.1 are being used for solvent applications. Producers, importers and distributors should be able to confirm the situation.

7.2.2.5 DEVELOPING A CONSISTENT TIME SERIES

Emissions from the solvent sector should be calculated using the same method and data sources for every year in the time series. Where consistent data are unavailable for any years in the time series, gaps should be recalculated according to the guidance provided in Volume 1, Chapter 5.

7.2.3 Uncertainty assessment

The assumption that all solvent may be emitted within approximately two years (50 percent in Year t and 50 percent in Year t+1) has been widely accepted by experts as a reasonable default (IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, 2000). However, the magnitude of the error caused by this assumption will depend on the nature of solvent usage patterns in the country being reported. In general, the default assumption will over-estimate emissions for a given year as leak tightness of equipment improves, although not on a cumulative basis unless destruction is being practised. Conversely, growth in the destruction of recovered or recycled solvent over time will influence the assumption of 100 percent eventual release. Activity data should be reliable at the application level because of the small number of chemical manufacturers, the high cost of the solvent, and the 100 percent emissive nature of the use over time in most applications. However, uncertainty at the sub-application level will depend largely on the quality of data provided by users and the level of completeness achieved in surveying them.

7.2.4 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

7.2.4.1 QUALITY ASSURANCE/QUALITY CONTROL

It is *good practice* to conduct quality control checks as outlined in Volume 1, Chapter 6, and an expert review of the emissions estimates. Additional quality control checks as outlined in Volume 1, Chapter 6, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this application. Inventory compilers are encouraged to use higher tier QA/QC for *key categories* as identified in Volume 1, Chapter 4.

In addition to the guidance in Volume 1, specific procedures of relevance to this application are outlined below:

- For accurate quality control/assurance both top-down and end-use data should be compiled. To allow independent assessment of the level of quality of the data reporting, the number of manufacturers and distributors plus end users interviewed should be quantified.
- When applying emission factors and activity data specific to various solvent applications, the activity data should be obtained at the same level of detail.

7.2.4.2 REPORTING AND DOCUMENTATION

Inventory compilers should report the emission factor used, and the empirical basis for any country-specific factors. For activity data, chemical sales and imports should be reported, unless there are confidentiality concerns arising from the limited number and location of manufacturers. (At present, for example, there may be only one producer of each compound.) Where there are less than three manufacturers of specific chemicals used as solvents, reporting could be aggregated into the aerosol section, because both are considered 100 percent emissive applications (see Section 7.3.4.2 below). In this case, to preserve confidentiality, emissions of individual gases should not be specified and emissions should be reported in CO_2-equivalent tonnes.

7.3 AEROSOLS (PROPELLANTS AND SOLVENTS)

7.3.1 Chemicals covered in this application area

Most aerosol packages contain hydrocarbon (HC) as propellants but, in a small fraction of the total, HFCs and PFCs may be used as propellants or solvents. Emissions from aerosols usually occur shortly after production, on average six months after sale. However, the period between manufacture and sale could vary significantly depending on the sub-application involved. During the use of aerosols, 100 percent of the chemical is emitted (Gamlen *et al.*, 1986; U.S. EPA, 1992b). The 5 main sub-applications are as follows:

(i) Metered Dose Inhalers (MDIs);

(ii) Personal Care Products (e.g., hair care, deodorant, shaving cream);

(iii) Household Products (e.g., air-fresheners, oven and fabric cleaners);

(iv) Industrial Products (e.g., special cleaning sprays such as those for operating electrical contact, lubricants, pipe-freezers);

(v) Other General Products (e.g., silly string, tyre inflators, klaxons).

The HFCs currently used as propellants are HFC-134a, HFC-227ea, and HFC-152a, as shown in Table 7.1. The substances HFC-245fa, HFC-365mfc, HFC-43-10mee and a PFC, perfluorohexane, are used as solvents in industrial aerosol products. Of these, HFC-43-10mee is the most widely used.[11] HFC-365mfc is also expected to be used within aerosols in the near future.

7.3.2 Methodological issues

7.3.2.1 CHOICE OF METHOD

Aerosol emissions are considered *prompt* because all the initial charge escapes within the first year or two after manufacture, typically six months after sale for most sub-applications. Therefore, to estimate emissions it is necessary to know the total amount of aerosol initially charged in product containers prior to sale. Emissions of each individual aerosol in year t can be calculated as follows:

EQUATION 7.6
EMISSION ESTIMATION METHOD FOR AEROSOL USES

$$Emissions_t = S_t \bullet EF + S_{t-1} \bullet (1 - EF)$$

Where:

$Emissions_t$ = emissions in year *t*, tonnes

S_t = quantity of HFC and PFC contained in aerosol products sold in year *t*, tonnes

S_{t-1} = quantity of HFC and PFC contained in aerosol products sold in year *t*–1, tonnes

EF = emission factor (= fraction of chemical emitted during the first year), fraction

This equation should be applied to each chemical individually. Wherever possible, activity data should be collected directly from the manufacturers or distributors of aerosols, ideally at the sub-application level to facilitate a Tier 2a approach. Globally or regionally derived activity data can be used to provide sub-application analysis where country-specific data does not exist. If data at the sub-application level is not available from either source, activity data at the application level should be obtained and applied using Equation 7.6 (Tier 1a).

Since the lifetime of the product is assumed to be no more than two years, any amount not emitted during the first year must by definition be emitted during the second and final year. In reality, most emissions occur within the first year after product purchase, but Equation 7.6 rightly accounts for the lag period between the time of manufacture and the time of purchase and use. When applying Equation 7.6, however, care must be taken to define the Point of Sale which, for the purposes of emission estimation, is viewed as sales by the manufacturer to

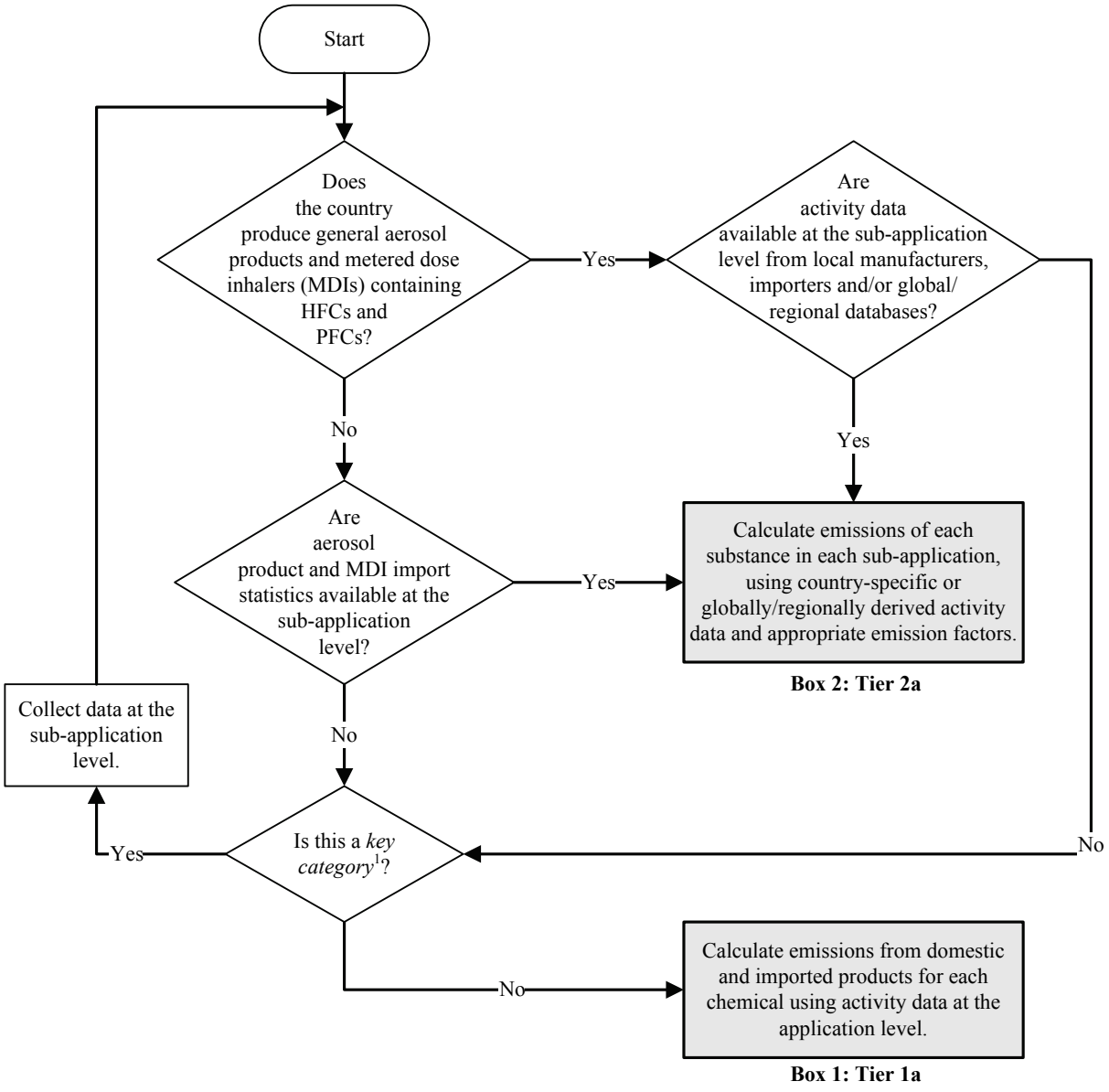
[11] HFC-43-10mee is used solely as a solvent, but is counted as an aerosol when delivered through aerosol canisters.

the supply chain and not by the retailer to the end-user. This approach is most appropriate because sales data will normally be collected from manufacturers and major distributors.

In contrast with the situation for solvents, there is rarely a need to account for recovery, recycling or destruction, since this is only likely to occur when stockpiled product becomes out-of-date. Under normal supply-chain management conditions this is a rare event.

A decision tree for estimating actual emissions is included in Figure 7.3, Decision Tree for Actual Emissions from the Aerosol Application. The data collection process is described below.

Figure 7.3 Decision tree for actual emissions from the aerosol application



Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

7.3.2.2 CHOICE OF EMISSION FACTORS

It is *good practice* to use a default emission factor of 50 percent of the initial charge per year for the broad spectrum of aerosol products when assessed at the application level (Tier 1a). This means that half the chemical charge escapes within the first year and the remaining charge escapes during the second year (Gamlen *et al.*, 1986). Inventory compilers should use alternative emission factors only when empirical evidence is available for the majority of aerosol products at either the application level (Tier 1a) or the sub-application level (Tier 2a). In

any event, the percentage emission factors should in general sum to 100 percent over the time during which it is assumed that the charge will escape. The development of country-specific emission factors should be documented thoroughly. General aerosol and MDI manufacturers may be able to provide data on process losses.

As a general observation, the consistently emissive nature of aerosols makes the distinction between country-specific and the default emission factor on the one hand and any differences between emission factors in the various sub-applications on the other hand, less influential on overall emissions estimates than is the case in other application areas. Therefore the benefit of following a more disaggregated Tier 2a approach in favour of a Tier 1a approach is less pronounced in the case of aerosols. Inventory compilers should therefore consider carefully how much resource to invest in developing a Tier 2 approach. However, there may be other reasons for keeping reporting of some sub-applications separate and it is expected many countries may wish to monitor emissions from MDIs separately to other general aerosols for policy reasons.

7.3.2.3 CHOICE OF ACTIVITY DATA

For the Tier 1a method, the activity data required are the total quantity of each relevant chemical contained in all aerosol products consumed within a country (both domestic sales and imports). For countries that import 100 percent of aerosol products, activity data are equal to imports.

Activity data for this application can be collected at the sub-application level using either a supplier-based or a user-based approach, depending on the availability and quality of the data (Tier 2a). The user-based approach requires data on the number of aerosol products sold and imported at the sub-application level (e.g., number of individual metered dose inhalers, hair care products, and tyre inflators), and the average charge per container. This may require globally or regionally derived activity data for some sectors of use. The supplier-based approach involves collecting aerosol and MDI chemical sales data directly from chemical manufacturers where their sales analysis is sufficiently robust at a country level. In many cases, a mix of both sources of data may be necessary.

Domestic aerosol production: For countries with domestic production, general aerosol and MDI manufacturers can usually provide data on the quantity of aerosol products produced for consumption in the country, the number of aerosols exported, the average charge per aerosol, and the type of propellant or solvent used (i.e. which HFC/PFC). Total use of domestically produced aerosol products in each year can then be calculated as the number of aerosol products sold domestically in a given year times the charge of HFC/PFC in each product. Of course, imported aerosols will still need to be added to this assessment to provide the total picture. If sub-application data from indigenous aerosol producers are not available, domestic chemical producers can often provide data on the amount of HFCs sold to domestic manufacturers in metered dose inhalers, and aggregate sales data to producers of other aerosols (categories (ii), (iii), (iv) and (v) above). If domestic aerosol and MDI manufacturers import HFCs, information may also be sought from chemical importers or their overseas suppliers, although the latter may not be able to provide data on exports destined for individual countries because of confidential business concerns. Customs officials and chemical distributors are another possible source for chemical import data. Globally or regionally derived activity data may also have a role both to fill gaps in the existing dataset and to cross-check data obtained from aerosol manufacturers and chemical suppliers.

Imported aerosol production: Most countries will import a significant share of their total aerosol products. Data on imports of HFC-containing general aerosols may be difficult to collect because official import statistics for aerosol products do not typically differentiate HFC-containing aerosols from others. When usable import statistics are unavailable from customs agencies, data may be available from product distributors and specific end-users. For example, in the case of MDIs, a limited number of pharmaceutical companies typically import products, and these companies can be surveyed to obtain the required information. Again globally or regionally derived activity data may be helpful in certain cases.

7.3.2.4 COMPLETENESS

Completeness depends on the availability of activity data on each chemical to be covered. Section 7.3.1 (and Table 7.1) provides an assessment of HFCs and PFCs currently used, but inventory compilers should check the situation with in-country sources to confirm those chemical relevant to the local situation. Inventory compilers in countries without domestic aerosol production may need to use expert judgement in estimating activity data, because import statistics are likely to be incomplete (see Volume 1, Chapters 2 and 3), particularly with reference to the propellants and solvents contained. Globally or regionally validated activity databases may be particularly helpful in such instances, where these exist.

7.3.2.5 DEVELOPING A CONSISTENT TIME SERIES

Emissions from aerosols should be calculated using the same method and data sources for every year in the time series. Where consistent data are unavailable for any year in the time series, gaps should be recalculated according to the guidance provided in Volume 1, Chapter 5.

7.3.3 Uncertainty assessment

The use of HFCs in the general aerosol sector is typically larger than in the MDI sector. Data from HFC manufacturers and importers of sales to the general aerosol sector are, at the present time, not well-defined other than for HFC-134a on a global scale. These data can be improved through additional data collection activities and the development of global and regional databases. The diffuse nature of the general aerosol sector means that the acquisition of reliable bottom-up data (Tier 2a) requires specific study on a country basis through local industry experts, whose advice should be sought on uncertainties using the approaches to expert judgement outlined in Volume 1, Chapter 3.

There are several sources of reliable data for the MDI sector, leading to a high level of confidence in the data reported that should be reflected in inventory emissions estimates. However, in reporting for a single country, the absence of reliable data for the general aerosol sector could mean that emission data could be over or under estimated by a factor of between one third and three times.

7.3.4 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

7.3.4.1 QUALITY ASSURANCE/QUALITY CONTROL (QA /QC)

It is *good practice* to conduct quality control checks as outlined in Volume 1, Chapter 6, and to organise an expert review of the emissions estimates. Additional quality control checks as outlined in Volume 1, Chapter 6, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this application. Inventory compilers are encouraged to use higher tier QA/QC for *key categories* as identified in Volume 1, Chapter 4.

In addition to the guidance in Volume 1, specific procedures of relevance to this application are outlined as follows. Aerosol manufacturing and importing data, on the one hand, and chemical supply data, on the other hand, can be used to cross-check one another during or after the development of an emission estimate. Data used to calculate emissions from year t–1 should be consistent with data used in the previous year's inventory estimate, so the two-year total sums to 100 percent. If this is not the case, then the reason for the inconsistency should be reported. Data collection carried out in accordance with the section on data collection above should provide adequate quality control. To allow independent assessment of the level of quality of the data reporting, the number of manufacturers of aerosols plus importers should be quantified.

7.3.4.2 REPORTING AND DOCUMENTATION

The emission estimate for metered dose inhalers may be reported separately from the emission estimate for other aerosols by some inventory compilers. In such cases, the specific emission factor used should be documented. If a country-specific emission factor is used in preference to a default factor, its development should be documented. Detailed activity data should be reported to the extent that it does not disclose confidential business information. Where some data are confidential, qualitative information should be provided on the types of aerosol products consumed, imported, and produced within the country. It is likely that the type of HFC used as a propellant or solvent and the sales of MDIs and general aerosols into individual countries could be viewed as confidential.[12] Where there are less than three manufacturers of specific chemicals used as solvents, reporting could be aggregated into this section, because both are considered 100 percent emissive applications (see Section 7.2.4.2 above).

[12] Quantification of use data for individual general aerosol sectors will enable more reliable future projections to be developed and emission reduction strategies to be considered.

7.4 FOAM BLOWING AGENTS

7.4.1 Chemicals covered in this application area

Increasingly, HFCs are being used as replacements for CFCs and HCFCs in foams and particularly in insulation applications. Compounds that are being used include HFC-245fa, HFC-365mfc, HFC-227ea, HFC-134a, and HFC-152a, as shown in Table 7.1. The processes and applications for which these various HFCs are being used are shown in Table 7.4 with predominantly open-celled foams being in shaded rows.

TABLE 7.4
USE OF HFCS IN THE FOAM BLOWING INDUSTRY (FOAM PRODUCT EMISSIONS BY GAS – ODS REPLACEMENTS)

Cell Type	Sub-application	HFC Foam Blowing Agent Alternatives			
		HFC-134a	HFC-152a	HFC-245fa	HFC-365mfc (+ HFC-227ea)
OPEN	PU[a] Flexible Foam				
	PU Flexible Moulded Foam				
	PU Integral Skin Foam	✔		✔	
	PU One Component Foam	✔	✔		
CLOSED	PU Continuous Panel	✔		✔	✔
	PU Discontinuous Panel	✔		✔	✔
	PU Appliance Foam	✔		✔	✔
	PU Injected Foam	✔		✔	✔
	PU Continuous Block			✔	✔
	PU Discontinuous Block			✔	✔
	PU Continuous Laminate			✔	✔
	PU Spray Foam			✔	✔
	PU Pipe-in-Pipe	✔		✔	✔
	Extruded Polystyrene	✔	✔		
	Phenolic Block			✔	✔
	Phenolic Laminate			✔	✔

[a] PU denotes polyurethane

The division of foams into open-cell or closed-cell relates to the way in which blowing agent is lost from the products. For open-cell foam, emissions of HFCs used as blowing agents are likely to occur during the manufacturing process and shortly thereafter. In closed-cell foam, only a minority of emissions occur during the manufacturing phase. Emissions therefore extend into the in-use phase, with often the majority of emission not occurring until end-of-life (de-commissioning losses). Accordingly, emissions from closed cell foams can occur over a period of 50 years or even longer from the date of manufacture.

Open-celled foams are used for applications such as household furniture cushioning, mattresses, automotive seating and for moulded products such as car steering wheels and office furniture. Closed-cell foams, on the other hand, are primarily used for insulating applications where the gaseous thermal conductivity of the chosen blowing agent (lower than air) is used to contribute to the insulating performance of the product throughout its lifetime.

7.4.2 Methodological issues

The previous *Guidelines* presented an equation for calculating emissions from closed cell foam that accounted for the first two emission points (i.e., manufacturing and during the in-use phase). This remains generally sufficient to account for the early stages of HFC uptake. However, in order to prepare a *complete* estimate of emissions from this source, it is *good practice* to add third and fourth terms to the equation to account for decommissioning losses and chemical destruction, where data are available. Thus, the relevant equation is:

EQUATION 7.7
GENERAL EMISSION-FACTOR APPROACH (A) FOR FOAMS

$$Emissions_t = M_t \bullet EF_{FYL} + Bank_t \bullet EF_{AL} + DL_t - RD_t$$

Where:

$Emissions_t$ = emissions from closed-cell foam in year *t*, tonnes

M_t = total HFC used in manufacturing new closed-cell foam in year *t*, tonnes

EF_{FYL} = first year loss emission factor, fraction

$Bank_t$ = HFC charge blown into closed-cell foam manufacturing between year t and year *t-n*, tonnes

EF_{AL} = annual loss emission factor, fraction

DL_t = docommissioning losses in year *t* = remaining losses of chemical at the end of service life that occur when the product/equipment is scrapped, calculated from the amount of remaining chemical and the end-of-life loss factor which depends on the type of end-of-life treatment adopted[13], tonnes

RD_t = HFC emissions prevented by recovery and destruction of foams and their blowing agents in year *t*, tonnes

n = product lifetime of closed-cell foam

t = current year

(*t-n*) = The total period over which HFCs used in foams could still be present

It should be noted that Equation 7.7, although targeted at closed cell foams, can be equally applied to open celled foams. In this sense it is a universal equation for all foams. In the case of open-celled foams the first-year Loss Emission Factor is typically 100 percent and the equation simplifies to its first component only, which then further simplifies to Equation 7.8.

Accordingly, where the nature of a foam is uncertain, Equation 7.7 should be applied to each chemical and major foam sub-application individually when pursuing a Tier 2a method.

Since emission profiles vary substantially by sub-application within the overall foam application, there is significant incremental value in adopting a Tier 2 method wherever possible. Ideally, this should be achieved by the researching of individual country activities. However, in practice, the intra-regional trade in foams coupled with the significant difficulty in setting up systems to identify the blowing agents used in foams already manufactured, makes a method based on country-specific activity data very difficult to implement at the sub-application level. Recognising that both disaggregated activity data and the related emission factors may be difficult to obtain at a country level, there have been several efforts by the UNEP Foams Technical Options Committee (UNEP-FTOC, 1999; UNEP-FTOC, 2003) and others to provide globally or regionally derived activity data and default emissions factors by sub-application for CFCs, HCFCs and hydrocarbons (HCs). Although HFCs are only now being used significantly as additional ODS alternatives, it is expected that a similar approach can be carried forward for these chemicals, with emission factors being available within the EFDB in order to provide a helpful source of information for inventory compilers. Other databases are emerging from the original FTOC work for activity data, and will be particularly helpful for countries where the trade in products-containing HFCs is significant, but difficult to track.

As an additional methodological consideration, it should be noted that many of the emissions from closed-cell insulation foams arise from banks of blowing agent built up from previous years of consumption. This point was

[13] Most decommissioning procedures will not result in the release of all remaining blowing agent. Even processing through an open auto-shredder has been found to result in emission of less than 50 percent of the remaining blowing agent at the point of processing (U.S. EPA/AHAM, 2005). Accordingly, blowing agent banks can accumulate further along the waste stream (e.g., landfills) – see Section 7.4.2.1.

highlighted in the IPCC Special Report on Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons (IPCC/TEAP, 2005) where it was noted that CFC emissions could continue from banked blowing agents in foams until the middle of the 21st century. This illustrates the importance of using an emissions estimation method which adequately reflects the development of banks.

An additional characteristic of foam inventories is that a significant majority of emissions occur from closed cell foam at the point of decommissioning or thereafter. Therefore, inventory compilers should be careful to research decommissioning practices and any recovery and destruction practices within their country closely. As a further consequence, methods which assume total release of blowing agent over the manufacturing and use phases are likely to significantly over-estimate emissions for any given year. Accordingly, methods should typically assume complete release of blowing agent at decommissioning only where there is definite evidence to support this and should normally attribute emissions to subsequent years based on a more appropriate release function. The relevant columns in Tables 7.6 and 7.7 therefore represent 'maximum potential' losses. In practice such emissions are likely to be spread over a substantial number of years following decommissioning if the foam remains broadly intact (i.e., average particle size > 8mm) (U.S. EPA/AHAM, 2005).

As a general observation, the mass-balance approach (Approach B) is inappropriate for foams since there is no mechanism by which such products are serviced in practice.

7.4.2.1 CHOICE OF METHOD

Open-Cell Foam: Since HFCs used for open-cell foam blowing are released immediately, the emissions in almost all cases will occur in the country of manufacture. The only exception may be in the case of OCF (One Component Foams) where the filled container may be manufactured in one country but the emissions occur in another country because the containers are easily traded. Emissions are calculated according to the following equation:[14]

EQUATION 7.8
GENERIC CALCULATION METHOD FOR EMISSIONS FROM OPEN-CELLED FOAMS

$$Emissions_t = M_t$$

Where:

$Emissions_t$ = emissions from open-cell foam in year *t*, tonnes

M_t = total HFC used in manufacturing new open-cell foam in year *t*, tonnes

This equation must be applied for each chemical used in open-celled foam applications. Although, there is little variation in emission factor across the open-cell sub-applications, it may still be advantageous to use a disaggregated Tier 2a method in order to make it easier to accurately assess net consumption activity data. Such an approach will naturally address the trade in one-component foams. Where there is little use of one-component foam, it could be logical to revert to a Tier 1a method where Equation 7.8 is applied at the application level.

Closed-Cell Foam: Emissions from closed-cell foam occur at three distinct points, which have already been highlighted in Equation 7.7:

(i) First Year Losses from Foam Manufacture and Installation: These emissions occur where the product is manufactured or installed.

(ii) Annual Losses (in-situ losses from foam use): Closed-cell foam will lose a fraction of its initial charge each year until decommissioning. These emissions occur where the product is used.

(iii) Decommissioning Losses: Emissions upon decommissioning also occur where the product is used.

To implement an approach which captures these three phases it is necessary to collect current and historical data on annual chemical sales to the foam industry for the full length of time HFCs have been used in this application period up to and including the average lifetime of closed-cell foam (as long as 50 years). The import or export of foam formulations which already include HFCs should be also taken into account. Similarly, there should be adjustments made for articles such as domestic or commercial refrigerators and freezers or of construction sector applications such as sandwich panels, boards, blocks and insulated pipes which are produced in one country but may be used in another country.

[14] For these applications, actual emissions of each chemical are equal to potential emissions.

In earlier assessments the calculation of decommissioning losses has been based on the premise that all blowing agent remaining in a foam at end-of-life will be lost at the decommissioning stage. From an emissions standpoint, this is a worst case scenario, even for disposal methods which are not targeted at recovery and destruction (see footnote 13). In practice, recovery and destruction of blowing agent or direct destruction (e.g., incineration) will further alleviate these losses. Hence Equation 7.7 carries a fourth component to allow for HFC emissions prevented in this way. The UNEP TEAP Task Force Report on Foams End-of-Life (UNEP-TEAP, 2005) addresses the many of the potential ways in which foam blowing agent emissions can be avoided and introduces the concept of Recovery and Destruction Efficiency (RDE) to assess the effectiveness of such methods.

Even where active recovery and destruction methods are not practised, it is still unlikely that all blowing agent will be released at end of life, particularly when foams are typically left in tact during disposal (e.g. during land-filling). Under these circumstances, a considerable proportion of the blowing agent will remain in the waste stream and an additional *banked* emission source will be established. Since the emission rates from such a bank will be lower than 100 percent, Equation 7.7 will over-estimate emissions where a significant proportion of the foam containing HFCs used in the country has already been decommissioned. Although it would be possible to envisage a fifth component to Equation 7.7 to address this element of emission, it is not deemed of sufficient relevance to warrant such an approach for the global phase of HFC use being covered by these *Guidelines*. However, some of the more sophisticated globally or regionally-derived assessments may address this issue.

If it is not possible to collect data for potential losses upon decommissioning, it should be assumed that all chemical not emitted in manufacturing is emitted over the lifetime of the foam. However, particular care should be taken to check whether articles such as domestic or commercial refrigerators and freezers are exported to another country for re-use. Where the foam application cannot be disaggregated to the sub-application level and no globally or regionally derived activity data is available, a Tier 1a method needs to be followed. *Good practice* in the choice of a Tier 1 method is to assume that all closed cell foam emissions follow the Gamlen model (see Table 7.5)

TABLE 7.5
DEFAULT EMISSION FACTORS FOR HFC FROM CLOSED-CELL FOAM

Emission Factor	Default Values
Product Lifetime	n = 20 years
First Year Losses	10% of the original HFC charge/year, although the value could drop to 5% if significant recycling takes place during manufacturing.
Annual Losses	4.5% of the original HFC charge/year

Source: Gamlen *et al.* (1986).

If both historical and current country-specific activity data is available for closed cell foams at the application level, it is possible to apply the Gamlen model to this information. However, the primary challenge for inventory compilers is usually in the characterisation of historic activity data at a country level. If such difficulties exist, it is usually possible to estimate activity data at a country level from the application of geo-economic factors provided that regional, globally or regionally-validated activity data are known. This approach is covered further in Section 7.4.2.3.

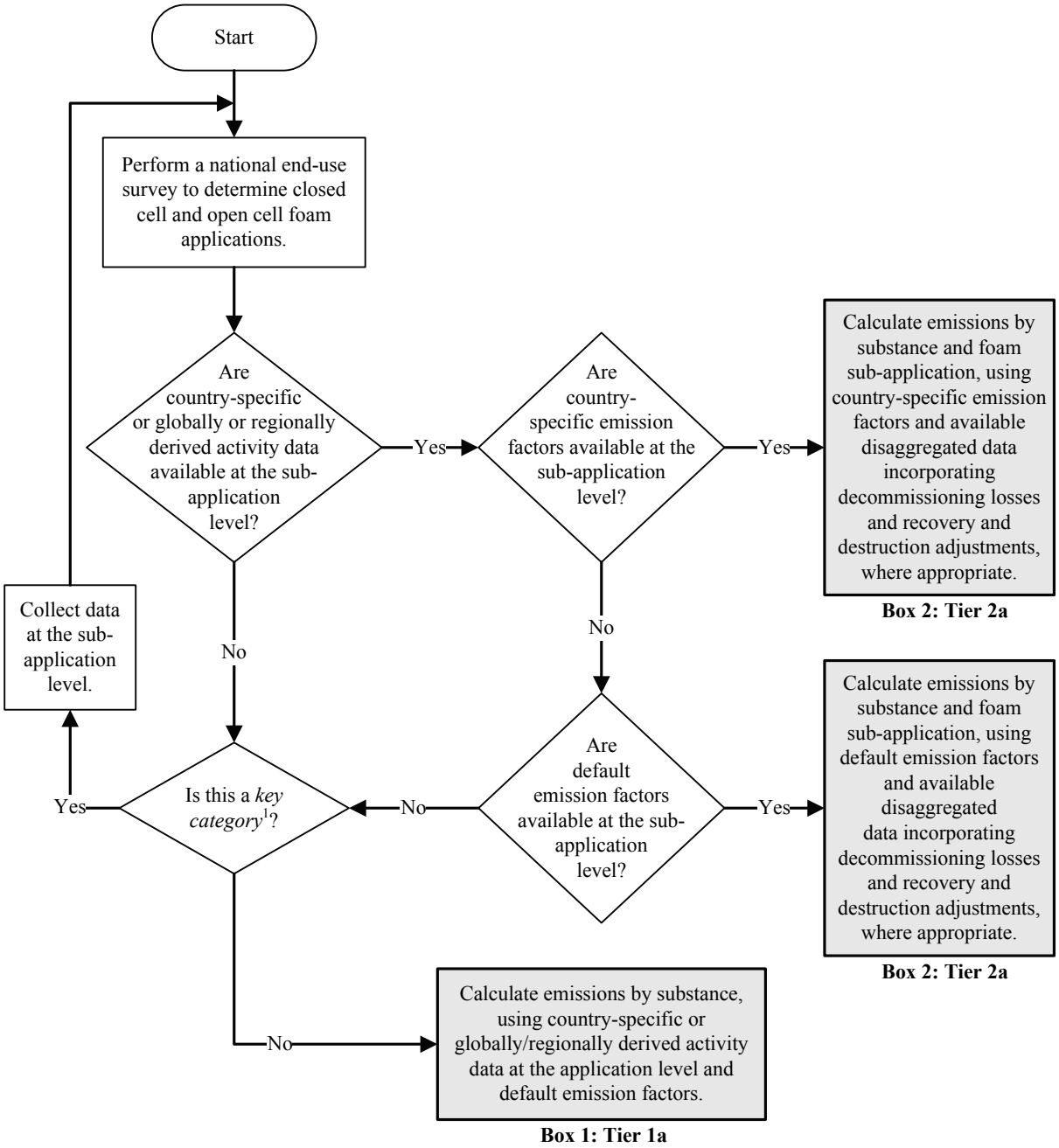
Where net consumption activity data is available at the sub-application level, either from sources of country-specific data or from globally or regionally derived activity datasets, it is *good practice* to use Tier 2 methods that reflect the level of disaggregation. This is particularly important for foams because of the heterogeneous nature of the various sub-applications involved. The decision tree in Figure 7.4 describes *good practice* in selecting methods for estimating emissions.

7.4.2.2 CHOICE OF EMISSION FACTORS

As in other applications, the first choice for emission factors is to develop and use peer-reviewed and well documented country-specific data based on field research on each foam type (open cell and closed cell) in support of a Tier 2a approach. As noted previously, if no information is available at the sub-application level, emission factors can be adopted from the Emission Factor Database (EFDB) or from the data contained in this section. However, it should be noted that the data contained in this section will not be replaced with updated

values in the same way as may happen for the EFDB. Either country-specific or globally/regionally-derived approaches will lead to the necessary assessment of decommissioning losses.[15]

Figure 7.4 Decision tree for emissions from the foam application



Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

Table 7.6, Default Emission Factors for HFC-134a/HFC-152a (Foam Sub-Application) and Table 7.7, Default Emission Factors for HFC-245a/HFC-365mfc/HFC-227ea (Foam Sub-Application) lists default emission factors

[15] It has also been noted that decommissioning may not necessarily involve total loss of blowing agent at that point, either because of a level of secondary use or because the item has been discarded intact (e.g., many refrigerators). These could be considered as some of the end-of-life management options available to nations, but are clearly less effective than proper destruction or recovery technologies. Emission models should focus proper attention to end-of-life issues.

assumptions for the most important current closed-cell foam applications. Use of these factors will require data on chemical sales at the sub-application level for both current and historic consumption in order that the bank of chemical in equipment/products for these sub-applications is properly considered.

TABLE 7.6
DEFAULT EMISSION FACTORS FOR HFC-134a AND HFC-152a USES (FOAM SUB-APPLICATIONS)
(IPCC/TEAP, 2005)

Sub-Application	Product Life in years	First Year Loss %	Annual Loss %	Maximum Potential End-of-Life Loss %
Polyurethane – Integral Skin	12	95	2.5	0
Polyurethane – Continuous Panel	50	10	0.5	65
Polyurethane – Discontinuous Panel	50	12.5	0.5	62.5
Polyurethane – Appliance	15	7	0.5	85.5
Polyurethane – Injected	15	12.5	0.5	80
One Component Foam (OCF) [a]	50	95	2.5	0
Extruded Polystyrene (XPS)[b] - HFC-134a	50	25	0.75	37.5
Extruded Polystyrene (XPS) - HFC-152a	50	50	25	0
Extruded Polyethylene (PE) [a]	50	40	3	0

Source:
[a] Ashford and Jeffs (2004) assembled from UNEP FTOC Reports (UNEP-FTOC, 1999; UNEP-FTOC, 2003).
[b] Vo and Paquet (2004): An Evaluation of Thermal Conductivity over time for Extruded Polystyrene Foams blown with HFC-134a and HCFC-142b

Some articles, such as reefers or insulated truck bodies, may spend almost all of their practical lives in transit between countries. Since these applications have very low in-use emissions it is reasonable if only the manufacturing and decommissioning losses are taken into account.

TABLE 7.7
DEFAULT EMISSION FACTORS FOR HFC-245fa/HFC-365mfc/HFC-227ea USES (FOAM SUB-APPLICATION)

HFC-245a/HFC-365mfc Applications	Product Life in years	First Year Loss %	Annual Loss %	Maximum Potential End-of-Life Loss %
Polyurethane – Continuous Panel	50	5	0.5	70
Polyurethane – Discontinuous Panel	50	12	0.5	63
Polyurethane – Appliance	15	4	0.25	92.25
Polyurethane – Injected	15	10	0.5	82.5
Polyurethane – Cont. Block	15	20	1	65
Polyurethane – Disc. Block for pipe sections	15	45	0.75	43.75
Polyurethane – Disc. Block for panels	50	15	0.5	60
Polyurethane – Cont. Laminate / Boardstock	25	6	1	69
Polyurethane – Spray	50	15	1.5	10
Polyurethane – Pipe-in-Pipe	50	6	0.25	81.5
Phenolic – Discontinuous Block	15	45	0.75	43.75
Phenolic – Discontinuous Laminate	50	10	1	40
Polyurethane – Integral Skin	12	95	2.5	0

Source: Ashford and Jeffs (2004) assembled from UNEP FTOC Reports (UNEP-FTOC, 1999; UNEP-FTOC, 2003)

If only aggregated chemical sales data for closed-cell foam are available and information on specific foam types cannot be obtained, the general default emission factors shown in Table 7.5 can be used in support of a Tier 1a

method.[16] This replicates the previous Tier 2 guidance contained in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997) but is now classified as a Tier 1a method following the exclusion of potential emission methods for ODS substitutes.

Use of these default emission factors will result in 90 percent of the initial charges being emitted over twenty years of annual use, after the initial 10 percent during the first year.

7.4.2.3 CHOICE OF ACTIVITY DATA

Two types of activity data are needed in order to prepare the emissions estimates:

1. the amount of chemical used in foam manufacturing in a country and not subsequently exported, and
2. the amount of chemical contained in foam imported into the country.

Data collection issues related to these two areas differ.

Chemical used in foam manufacture

The amount of bulk chemicals used in the foam blowing industry should include both domestically produced and imported HFCs. Domestic chemical sales data to the foam industry should be available directly from chemical suppliers or foam manufacturers at the application level (Tier 1a) and may extend to a sub-application analysis (Tier 2a). As with other ODS substitute applications, imported chemical data may be available from customs officials or chemical distributors.

Historic consumption data is required to build an adequate picture of the development of blowing agent banks. However, this does not apply to open-celled foams which lose their blowing agents in the first year. For open-cell foam, all emissions will occur during manufacture, with the exception of the OCF sub-sector mentioned above. Thus, it is necessary to determine the share of chemical associated with the manufacture of open-celled foam. These data can be determined through an end-use survey, or approximated by reviewing similar end-use data gathered on CFCs and HCFCs.

Chemical contained in imported and exported foams

Inventory compilers in countries that export closed-cell foam should subtract these volumes from their calculations of annual banks and ultimately decommissioning losses, since the in-use emissions will occur in the importing country. Data on the chemical charge of exported closed-cell foam may be available from large manufacturers. However, customs data itself is unlikely to yield relevant information on blowing agent type unless special provisions have been set up by the reporting country.

Similarly, inventory compilers in countries that import products containing closed-cell foam, should include estimates of emissions from these imported products for completeness. Since the inventory compiler will have even less knowledge and control of products manufactured outside of the country than for those manufactured and subsequently exported, information on the blowing agents contained in closed-cell foam products imported is even more difficult to collect. Accordingly, inventory compilers in countries whose emissions occur only from imported closed-cell foam may need to use expert judgement in estimating this data (see Volume 1, Chapters 2 and 3).

In the past, inventory compilers were not able to use international HFC production and consumption data sets to develop estimates of chemical contained in imported closed-cell foam because these data sets did not include regional use and trade pattern databases. For example, the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) statistics-gathering process compiled global activity data up until 1997 for HFC-134a in the foam sector[17] but regional breakdowns were unavailable.

To help resolve this problem, some databases now contain national mechanisms to assist inventory compilers by taking advantage of international HFC/PFC consumption and emission data sets to access globally or regionally derived activity data and bank estimates for blowing agents contained in closed cell foams within their own countries. These can be applied within Tier 2a assessments and will provide estimated consumption and bank data at the sub-application level, to which the default emission factors contained in Tables 7.6 and 7.7 (or updated versions thereof carried in the EFDB or elsewhere) can be applied.

[16] No emission factors are provided for open-cell foams because all emissions occur during the first year.

[17] HFC-134a is the most commonly used HFC. AFEAS data can found at http://www.afeas.org.

7.4.2.4 SUMMARISING THE PRIMARY METHODS

Stepwise through the Tier 2a method using proxy data

The Box 7.2 illustrates the typical steps required to implement a Tier 2a method using proxy data:

BOX 7.2
TIER 2a IMPLEMENTATION FOR THE FOAM APPLICATION USING GLOBALLY OR REGIONALLY DERIVED DATA

There are up to 16 sub-applications in the foam sector. A reporting country needs to consider which of these sub-applications are relevant to its situation and carry out the following steps for each such process/application.

Consumption

1. Identify the tonnage of foam used in the process/application
2. Establish the average density for the foam used in the process/application and hence foam volume ('foam volume per unit' is the commonly used metric for houses and buildings)
3. Identify the number of houses built in the year or appliances manufactured/sold in the year to determine a nominal foam volume ratio (foam volume per unit)
4. Assess growth trends in both the number of units and the foam volume ratio and apply these trends to estimate the tonnage of foam for previous and future years (i.e., years in which data from Step 3 might not be available).
5. Assess the market split, or share of various blowing agents (chemicals) used for each process/application. Particular care should be taken when dealing with blends.
6. Identify typical foam formulations for each blowing agent type and apply these formulations to the proportion of the process/application using that blowing agent.
7. Multiply the foam tonnage by the formulation (weight/weight) and market share details to obtain blowing agent consumption by blowing agent type (typically up to 14 types).
8. Cross-check with any sales information available on specific blowing agents at country-level.

Emissions-in-Use

9. Establish the first year loss rate for the process/application. Multiply this loss rate by the chemical consumption to estimate losses emanating from this phase. *These emissions should be added to the other sources of emission.*
10. The balance of the non-emitted consumption for that year is added to the bank of blowing agent stored in that process/application.
11. Apply a linear emission rate to banked materials, thus eliminating the need to run parallel models based on the vintage of the bank contribution.
12. Apply the average in-use emission rate to the bank and *add the resulting emissions to the emissions total.*
13. Based on the predicted average product life, establish how much of the bank will be decommissioned in the current year and subtract it from the bank.

Decommissioning, recovery and destruction

14. There are a number of end-of-life options for foams, but *good practice* suggests that four major options should be considered:
    a. Re-use
    b. Landfill without shredding
    c. Shredding without recovery
    d. Total recovery and capture (including shredding with recovery, direct incineration etc.)

15. The decommissioned portions of the banks for a given year should be ascribed to the four options outlined above in proportion to the practice of the country.
16. Emission factors during decommissioning and other end-of-life management steps should be established. These should then be applied to the decommissioned portions of the process/application. *These emissions should be added to the other sources of emission.* The maximum emission factors in Tables 7.6 and 7.7 should be applied only where instantaneous release can reasonably be assumed to occur.
17. Where emissions from end-of-life management may be on-going (e.g., re-use, landfill and shredding without recovery), further end-of-life banks should be established to keep track of accumulation of blowing agents and to estimate the on-going annual emissions from these sources.
18. Annual emission factors for each of these sources should be applied to the end-of-life banks. *These emissions should be added to the other sources of emission.*

Using the Tier 1a method based on Gamlen model

As a more limited alternative, it is possible to use a Tier 1a method based on the Gamlen model (Table 7.5) to estimate emissions from the total bank of closed cell foam in a country. The following spreadsheet excerpt illustrates the method[18]:

Figure 7.5 Example of spreadsheet calculation for Tier 1a method

Country	**Belgium**	
Agent	**HFC-134a**	
Closed Cell Foam Consumption		Leave blank to use database value
Open Cell Foam Consumption		Leave blank to use database value

Current Year	**2005**	**(Year for which estimate is made)**
Year of Introduction	**1993**	
Emission in first year	10%	(Emissions from manufacture and installation)
Emission in subsequent years	4.50%	(Annual in-use losses)

Emissions from closed cell foams	55.4 tonnes
Emissions from open cell foams	0.8 tonnes
(Bank of agent in closed cell foams	635.9 tonnes)

Emissions from Closed Cell Foams							
Age	Year	Known Consumption data (tonnes)	interpolated consumption data	emission in first year	emission from bank	bank	total emission
0	2005	**133.6**	133.6	13.4	42.1	635.9	55.4
1	2004		123.3	12.3	36.1	557.8	48.4
2	2003		113.1	11.3	30.5	482.9	41.8
3	2002		102.8	10.3	25.4	411.6	35.7

Emissions from Open Cell Foams		
Known consumption data (tonnes)	interpolated consumption data	emission in first year
0.828939	0.8	0.8
	0.7	0.7
	0.6	0.6
	0.5	0.5

In this instance, Belgium is estimated to have consumed 133.6 tonnes of HFC-134a for closed cell foams in 2005 and to have emitted 13.4 tonnes from first year foam manufacturing activities, and 42.1 tonnes emissions from the accrued bank of foams, making a total of 55.4 tonnes of HFC-134a from closed cell foams in 2005. This assessment is based on the understanding that HFC-134a was introduced substantively in Belgium in 1993, so the estimate includes 13 years of data. The overall approach, when based on regionally derived data, assumes that the average uptake of HFC-134a-based technologies in Europe is reflected in the country in question.

This method has particular attraction for countries and regions that have low rates of foam consumption (e.g., developing countries), and where the foam volume ratio in buildings is low and emissions are likely to be minimal over the effective period of these *Guidelines*. However, for the regions consuming larger volumes of HFCs in buildings, Tier 2 methods are strongly recommended to avoid the misallocation of consumption and, in particular, emissions because of the assumptions implicit in the Gamlen model (Table 7.5) and the averaging of consumption patterns.

[18] Where introduction is slow, the 'year of introduction' should be taken as the first year of substantive use.

7.4.2.5 COMPLETENESS

At least sixteen foam potential sub-applications and five potential chemicals used as blowing agents (HFC-134a, HFC-152a, HFC-245fa, HFC-365mfc and HFC-227ea) have been identified within the foam application. For completeness, inventory compilers should determine whether HFC blowing agents are used in each sub-application being practised in their countries, which suggests up to 80 theoretically possible combinations (see Table 7.4, Use of HFCs in the Foam Blowing Industry). In practice, this list reduces to 53 realistic potential chemical/application combinations, although there are some potential regional variations.

It should also be noted that, at this stage, the methods described do not explicitly address the use of blends, although, in theory, this should be covered in the chemical-by-chemical assessment. The challenge, as with refrigerants (see Section 7.5) will be one of activity monitoring and reporting. The use of blends is undoubtedly increasing and may include combinations of, for example, HFC-245fa and HFC-365mfc. Blends of HFC-365mfc with minor proportions of HFC-227ea are also being introduced by one manufacturer. However, it is premature at this stage to assign different emission factors to such systems.

7.4.2.6 DEVELOPING A CONSISTENT TIME SERIES

An inventory compiler should maintain a consistent method in assessing its emissions over the time period. If, for example, no system is established to monitor actual decommissioning at the outset of the inventory process, it will be very difficult to obtain data retrospectively if a change from globally or regionally-derived to country-specific data is considered. This decision should therefore be the subject of careful consideration at the outset of the reporting process. Any recalculation of estimates should be done according to the guidance provided in Volume 1, Chapter 5. In contrast, changes in approach for Activity Level determinations will be easier to implement retrospectively.

7.4.3 Uncertainty assessment

For net consumption activity data, current sales data indicate that the global estimates are accurate to within 10 percent, regional estimates are in the 30 - 40 percent range, and the uncertainty of country specific consumption information may be more than 50 percent. It should be noted that the calculation of the total emissions for a year will be only partially dependent on the accuracy of estimates of new consumption in that year. The remainder of the emissions will arise from banked blowing agent in installed foam and from those foams decommissioned in that year. The estimation of these contributors will depend fundamentally on the accuracy of historic consumption data.

Using Approach A (emission-factor approach), emission factors will add to the uncertainties, particularly if only default emission factors can be used. Since decommissioning will be the trigger for the majority of emissions in many cases, the product end-of-life assumptions may introduce the greatest degree of uncertainty. It is therefore very important that inventory compilers keep records of their estimates of HFC-containing products and develop some mechanism for monitoring actual decommissioning if possible. These records may help ensure that the summed emissions do not exceed total inputs over time.

7.4.4 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

7.4.4.1 QUALITY ASSURANCE/QUALITY CONTROL

It is *good practice* to conduct quality control checks as outlined in Volume 1, Chapter 6, and an expert review of the emissions estimates. Additional quality control checks as outlined in Volume 1, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this application. Inventory compilers are encouraged to use higher tier QA/QC for *key categories* as identified in Volume 1, Chapter 4.

One of the main concerns will be to ensure that the preservation of the integrity of regional and global data will be maintained by the summation of individual country estimates and a major part of the QA/QC review process will need to concern itself with this cross reference.

7.4.4.2 REPORTING AND DOCUMENTATION

Emissions factors should be reported, along with documentation for the development of country-specific data. Chemical sales to the foam blowing industry should be reported in a manner that addresses confidentiality concerns. Most confidentiality issues arising from any data collection process relate to the most highly concentrated activities. To deal with this, emissions from foam could be reported as a single number, provided that the development of the number could be reviewed under suitable terms of confidentiality. Of course, a declaration of consolidated emissions from manufacture (first year), use (product life) and decommissioning (end-of-life) will always be preferable to allow continued focus on improvements being made in each of these areas. If inventory compilers use activity data derived from global or regional databases, they should report the results of how they allocated emissions to the country level.

7.5 REFRIGERATION AND AIR CONDITIONING

7.5.1 Chemicals covered in this application area

Refrigeration and air-conditioning (RAC) systems may be classified in up to six sub-application domains or categories (UNEP-RTOC, 2003), although less sub-applications are typically used at a single country level. These categories correspond to sub-applications that may differ by location and purpose, and are listed below:

(i) Domestic (i.e., household) refrigeration,

(ii) Commercial refrigeration including different types of equipment, from vending machines to centralised refrigeration systems in supermarkets,

(iii) Industrial processes including chillers, cold storage, and industrial heat pumps used in the food, petrochemical and other industries,

(iv) Transport refrigeration including equipment and systems used in refrigerated trucks, containers, reefers, and wagons,

(v) Stationary air conditioning including air-to-air systems, heat pumps, and chillers[19] for building and residential applications,

(vi) Mobile air-conditioning systems used in passenger cars, truck cabins, buses, and trains.[20]

For all these sub-applications, different HFCs are progressively replacing CFCs and HCFCs. For example, in developed and several developing countries, HFC-134a has replaced CFC-12 in domestic refrigeration, high-pressure chillers and mobile air conditioning systems, and blends of HFCs such as R-407C (HFC-32/HFC-125/HFC-134a) and R-410A (HFC-32/HFC-125) are replacing HCFC-22 mainly in stationary air conditioning. HFC blends R-404A (HFC-125/HFC-143a/HFC-134a) and R-507A (HFC-125/HFC-143a) have replaced R-502 (CFC-22/CFC-115) and HCFC-22 in commercial refrigeration. Other, non-HFC substances are also used to replace CFCs and HCFCs such as iso-butane (HC-600a) in domestic refrigeration or ammonia in industrial refrigeration.

A large number of blends containing HFCs and/or PFCs are being used in Refrigeration and Air Conditioning applications. Table 7.8 shows the most common of these blends.

[19] Comfort air conditioning in large commercial buildings (including hotels, offices, hospitals, universities, etc.) is commonly provided by water chillers coupled with an air handling and distribution system.

[20] The sub-application of mobile air conditioning systems is likely to represent the largest share of HFC emissions within the Refrigeration and Air Conditioning application for many countries. See Section 7.5.2.4, Applying Tier 2 Methods – The Example Of Mobile Air Conditioning (MAC), for an example of how to calculate these emissions. The reader will see that limited information is needed to approximate these emissions, and essentially becomes a simple multiplication of an average emission factor and the number of cars with HFC air conditioning, and possibly adding emissions relating to container management, charging and end-of-life.

TABLE 7.8
BLENDS (MANY CONTAINING HFCS AND/OR PFCS)

Blend	Constituents	Composition (%)
R-400	CFC-12/CFC-114	Should be specified[1]
R-401A	HCFC-22/HFC-152a/HCFC-124	(53.0/13.0/34.0)
R-401B	HCFC-22/HFC-152a/HCFC-124	(61.0/11.0/28.0)
R-401C	HCFC-22/HFC-152a/HCFC-124	(33.0/15.0/52.0)
R-402A	HFC-125/HC-290/HCFC-22	(60.0/2.0/38.0)
R-402B	HFC-125/HC-290/HCFC-22	(38.0/2.0/60.0)
R-403A	HC-290/HCFC-22/PFC-218	(5.0/75.0/20.0)
R-403B	HC-290/HCFC-22/PFC-218	(5.0/56.0/39.0)
R-404A	HFC-125/HFC-143a/HFC-134a	(44.0/52.0/4.0)
R-405A	HCFC-22/ HFC-152a/ HCFC-142b/PFC-318	(45.0/7.0/5.5/42.5)
R-406A	HCFC-22/HC-600a/HCFC-142b	(55.0/14.0/41.0)
R-407A	HFC-32/HFC-125/HFC-134a	(20.0/40.0/40.0)
R-407B	HFC-32/HFC-125/HFC-134a	(10.0/70.0/20.0)
R-407C	HFC-32/HFC-125/HFC-134a	(23.0/25.0/52.0)
R-407D	HFC-32/HFC-125/HFC-134a	(15.0/15.0/70.0)
R-407E	HFC-32/HFC-125/HFC-134a	(25.0/15.0/60.0)
R-408A	HFC-125/HFC-143a/HCFC-22	(7.0/46.0/47.0)
R-409A	HCFC-22/HCFC-124/HCFC-142b	(60.0/25.0/15.0)
R-409B	HCFC-22/HCFC-124/HCFC-142b	(65.0/25.0/10.0)
R-410A	HFC-32/HFC-125	(50.0/50.0)
R-410B	HFC-32/HFC-125	(45.0/55.0)
R-411A	HC-1270/HCFC-22/HFC-152a	(1.5/87.5/11.0)
R-411B	HC-1270/HCFC-22/HFC-152a	(3.0/94.0/3.0)
R-411C	HC-1270/HCFC-22/HFC-152a	(3.0/95.5/1.5)
R-412A	HCFC-22/PFC-218/HCFC-142b	(70.0/5.0/25.0)
R-413A	PFC-218/HFC-134a/HC-600a	(9.0/88.0/3.0)
R-414A	HCFC-22/HCFC-124/HC-600a/HCFC-142b	(51.0/28.5/4.0/16.5)
R-414B	HCFC-22/HCFC-124/HC-600a/HCFC-142b	(50.0/39.0/1.5/9.5)
R-415A	HCFC-22/HFC-152a	(82.0/18.0)
R-415B	HCFC-22/HFC-152a	(25.0/75.0)
R-416A	HFC-134a/HCFC-124/HC-600	(59.0/39.5/1.5)
R-417A	HFC-125/HFC-134a/HC-600	(46.6/50.0/3.4)
R-418A	HC-290/HCFC-22/HFC-152a	(1.5/96.0/2.5)
R-419A	HFC-125/HFC-134a/HE-E170	(77.0/19.0/4.0)
R-420A	HFC-134a/HCFC-142b	(88.0/12.0)
R-421A	HFC-125/HFC-134a	(58.0/42.0)
R-421B	HFC-125/HFC-134a	(85.0/15.0)
R-422A	HFC-125/HFC-134a/HC-600a	(85.1/11.5/3.4)
R-422B	HFC-125/HFC-134a/HC-600a	(55.0/42.0/3.0)
R-422C	HFC-125/HFC-134a/HC-600a	(82.0/15.0/3.0)
R-500	CFC-12/HFC-152a	(73.8/26.2)
R-501	HCFC-22/CFC-12	(75.0/25.0)
R-502	HCFC-22/CFC-115	(48.8/51.2)
R-503	HFC-23/CFC-13	(40.1/59.9)
R-504	HFC-32/CFC-115	(48.2/51.8)
R-505	CFC-12/HCFC-31	(78.0/22.0)
R-506	CFC-31/CFC-114	(55.1/44.9)
R-507A	HFC-125/HFC-143a	(50.0/50.0)
R-508A	HFC-23/PFC-116	(39.0/61.0)
R-508B	HFC-23/PFC-116	(46.0/54.0)
R-509A	HCFC-22/PFC-218	(44.0/56.0)

[1] R-400 can have various proportions of CFC-12 and CFC-114. The exact composition needs to be specified, e.g., R-400 (60/40).

7.5.2 Methodological issues

7.5.2.1 CHOICE OF METHOD

As discussed in the introductory section to this chapter, both Tier 1 and Tier 2 result in estimates of *actual* emissions rather than estimates of *potential* emissions. Actual estimates, which account for the lag between consumption and emissions, are particularly important for both the refrigeration and air conditioning sector because of the potentially long retention of refrigerants in products and equipment utilised in these applications.

The options available to the refrigeration and air conditioning application are shown in the decision tree shown in Figure 7.6.

TIER 1

Tier 1 a/b

It is expected that the refrigeration and air conditioning will be a *key category* for many countries. The implication of this conclusion from Table 7.2 and the decision tree in Figure 7.6 is that either country-specific or globally or regionally derived activity data will be required at the sub-application (disaggregated) level in order to complete the reporting task. However, in the rare instances that the refrigeration and air conditioning application is much less significant, there should be available a suitable Tier 1 method for aggregated data.

From experience of studying the dynamics of refrigerant consumption and banks in several countries (UNEP-RTOC, 2003; Ashford, Clodic, Kuijpers and McCulloch, 2004; and supporting materials), it is possible to derive assumptions that allow for the assessment of the use of refrigerant that may help in assessing sales of a given refrigerant at a country level. Such a hybrid Tier 1a/b approach may use the following assumptions:

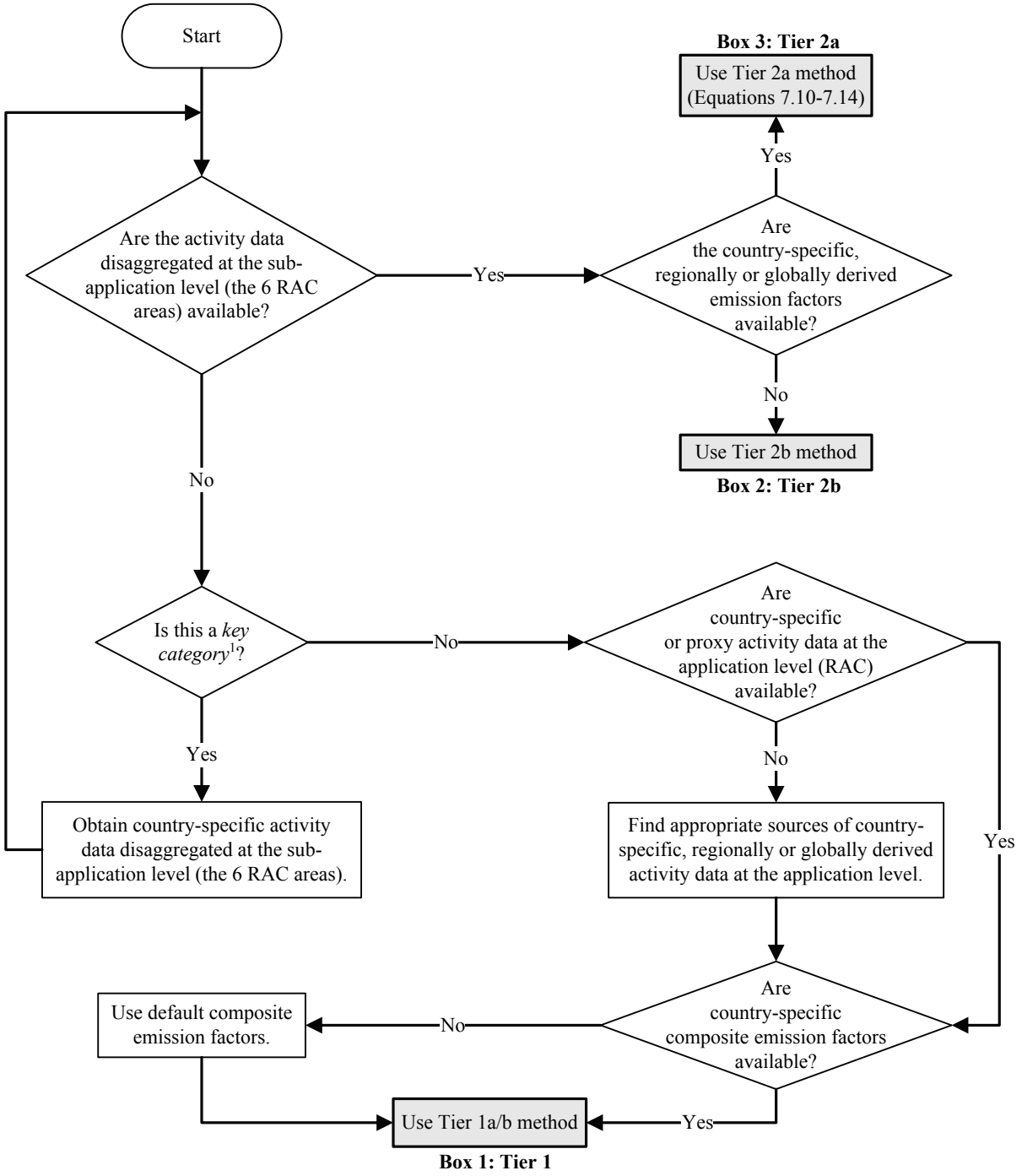
1. Servicing of equipment containing the refrigerant does not commence until 3 years after the equipment is installed.
2. Emissions from banked refrigerants average 15 percent annually across the whole RAC application area. This assumption is estimated to be a weighed average across all sub-applications, for which default emission factors are shown in Table 7.9.
3. In a mature market two thirds of the sales of a refrigerant are used for servicing and one third is used to charge new equipment. A mature market is one in which ODS substitute-employing refrigeration equipment is in wide use, and there are relationships between suppliers and users to purchase and service equipment.
4. The average equipment lifetime is 15 years. This assumption is also estimated to be a weighed average across all sub-applications.
5. The complete transition to a new refrigerant technology will take place over a 10 year period. From experiences to date, this assumption is believed to be valid for a single chemical in a single country.

With these assumptions in place, it is possible to derive emissions, if the following data can be provided:

- Sales of a specific refrigerant in the year to be reported
- Year of introduction of the refrigerant
- Growth rate in sales of new equipment (usually assumed linear across the period of assessment)
- Assumed percentage of new equipment exported
- Assumed percentage of new equipment imported

The Tier 1a/b method then back-calculates the development of banks of a refrigerant from the current reporting year to the year of its introduction. In mapping this period, the method also models the transition from sales to new equipment (100 percent initially) to the mature market position assumed based on experience to be 33 percent to new equipment and 67 percent to servicing requirements. It is assumed that the transition to new refrigerant technology is reflected identically in any imported equipment.

Figure 7.6 Decision tree for actual emissions from the refrigeration and air conditioning (RAC) application



Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

The following spreadsheet example indicates how the Tier 1a/b method would estimate a seven-year time series of emissions of the selected refrigerant, following its initial introduction in 1998, with the knowledge that there were sales of 1 000 tonnes in 2005. The spreadsheet contained in the *2006 Guidelines* CDROM mirrors this calculation, and globally or regionally derived datasets[21] at both application and consolidated sub-application levels should be available at a country level to assist in completion of this spreadsheet.

[21] As noted in Box 7.1, inclusion in the IPCC Emission Factor Database (EFDB) will indicate general adherence to due process, but it is *good practice* for countries to ensure that all data taken from the EFDB are appropriate for their national circumstances.

Figure 7.7 Example of spreadsheet calculation for Tier 1a/b assessments

Tier 1 Refrigeration
Argentina - HFC-143a

HFC-143a

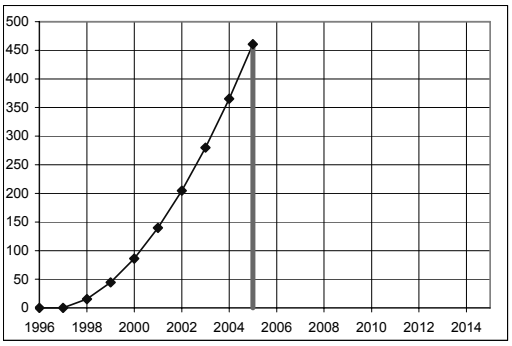
Summary
Country: Argentina
Agent: HFC-143a
Year: 2005
Emission: 460.7 tonnes
In Bank: 3071.1 tonnes

Current Year	2005

Use in current year - 2005 (tonnes)	**Data Used Here**
Production of HFC-143a	800
Imports in current Year	200
Exports in current year	0
Total new agent to domestic market	*1000*

Year of Introduction of HFC-143a	1998
Growth Rate in New Equipment Sales	3.0%

Tier 1 Defaults	
Assumed Equipment Lifetime (years)	15
Emission Factor from installed base	15%
% of HFC-143a destroyed at End-of-Life	0%



Estimated data for earlier years	1996	1997	1998	1999	2000	2001	2002	2003	2004	**2005**
Production	0	0	81	167	259	355	458	566	680	**800**
Agent in Exports	0	0	0	0	0	0	0	0	0	**0**
Agent in Imports	0	0	20	42	65	89	114	141	170	**200**
Total New Agent in Domestic Equipment	0	0	102	209	323	444	572	707	850	**1000**
Agent in Retired Equipment	0	0	0	0	0	0	0	0	0	**0**
Destruction of agent in retired equipment	0	0	0	0	0	0	0	0	0	**0**
Release of agent from retired equipment	0	0	0	0	0	0	0	0	0	**0**
Bank	0	0	102	296	575	933	1365	1867	2437	**3071**
Emission	0	0	15	44	86	140	205	280	365	**461**

In this hypothetical example, the production of a specific refrigerant are 800 tonnes with an additional 200 tonnes in imported equipment, in 2005 making a total consumption of 1 000 tonnes. Based on this consumption figure and knowledge of the year of introduction of the refrigerant, it can be seen that the Tier 1a/b method predicts emissions of 461 tonnes based on the development of banks over the previous seven years. The bank in 2005 is estimated at 3 071 tonnes.

It should be noted that, while such methods allow for the estimation of emissions when data are difficult to obtain, it is still necessary to have an accurate assessment of country-specific or globally or regionally derived net consumption activity data. When the content of Table 7.8 is considered (particularly when some of these blends may be being imported in equipment) it is clear that there needs to be considerable knowledge of technology selection in the market. Refrigerant suppliers should be able to assist inventory compilers in this area, but the burden of developing high quality activity datasets may lead inventory compilers to the conclusion that Tier 2 options provide more value with little extra work. Indeed, where globally or regionally validated data activity is sought, this will normally be a reconstitution of disaggregated data originally at the sub-application level, so it might be most logical to take full advantage of that versatility and pursue a Tier 2 approach from the outset.

TIER 2

Overview

The Tier 2a methodology:

a) Takes into account the phase out or the phase down of CFCs and HCFCs depending on the Montreal Protocol schedule and possible national or regional regulations, in order to establish the refrigerant choice for all applications;

b) Defines the typical refrigerant charge and the equipment lifetime per sub-application;

c) Defines the emission factors for refrigerant charge, during operation, at servicing and at end-of-life.

Calculation of emissions throughout the equipment lifetime requires deriving the total stock of equipment independent of their vintage. In doing so the refrigerant bank is established per sub-application.

In order to achieve consistency it is suggested to derive the annual market of refrigerants from the refrigerant quantities charged in the brand new equipment and from the refrigerant quantities used for servicing of the total stock of equipment.

The Tier 2b mass-balance approach relies on a knowledge of the annual sales of refrigerant, refrigerant destroyed and any changes in equipment stock that occur (i.e., new equipment sales and equipment decommissioned) on a sub-application basis. It does not require an absolute knowledge of equipment stocks or emission factors relating to each refrigeration and air conditioning sub-application.

Examples of how the Tier 2 methodology may be applied are given in the remainder of this section.

Tier 2b - Mass-balance approach

The mass-balance approach is particularly applicable to the Refrigeration and Air Conditioning application because of the significant servicing component required to maintain equipment. The general approach to Tier 2b is introduced in Chapter 1 of Volume 3.

For the mass-balance approach, the four emission stages (charging, operation servicing and end-of-life) identified above are addressed in the following simplified equation:

EQUATION 7.9
DETERMINATION OF REFRIGERANT EMISSIONS BY MASS BALANCE

$$Emissions = Annual\ Sales\ of\ New\ Refrigerant - Total\ Charge\ of\ New\ Equipment + Original\ Total\ Charge\ of\ Retiring\ Equipment - Amount\ of\ Intentional\ Destruction$$

Annual Sales of New Refrigerant is the amount of a chemical introduced into the refrigeration sector in a particular country in a given year. It includes all chemical used to fill or refill equipment, whether the chemical is charged into equipment at the factory, charged into equipment after installation, or used to recharge equipment at servicing. It does not include recycled or reclaimed chemical.

Total Charge of New Equipment is the sum of the full charges of all the new equipment that is sold in the country in a given year. It includes both the chemical required to fill equipment in the factory and the chemical required to fill the equipment after installation. It does not include charging emissions or chemical used to recharge equipment at servicing.

Original Total Charge of Retiring Equipment is the sum of the full charges of all the retiring equipment decommissioned in a country in a given year. It assumes that the equipment will have been serviced right up to its decommissioning and will therefore contain its original charge.

Amount of Intentional Destruction is that quantity of the chemical duly destroyed by a recognised destruction technology.

In each country there is a stock of existing refrigeration equipment that contains an existing stock of refrigerant chemical (*bank*). Therefore, annual sales of new chemical refrigerant must be used for one of three purposes:

- To increase the size of the existing chemical stock (bank) in use (including retrofitting equipment from a previous chemical to the given chemical)
- To replace that fraction of last year's stock of chemical that was emitted to the atmosphere (through, for example, leaks or servicing losses)
- To provide supply-chain priming or stockpiles

Since the third item in this list is rarely required in a steady-state market, it is not included in Equation 7.9. Terms to account for stockpiling and retrofitting could be added to Equation 7.9 if such situations exist.

The difference between the total quantity of gas sold and the quantity of that gas used to increase the size of the chemical stock equals the amount of chemical emitted to the atmosphere. The increase in the size of the chemical stock is equal to the difference between the total charges of the new and retiring equipment.

By using data on current and historical sales of gas, rather than emission factors referenced from literature, the equation reflects assembly, operation, and disposal emissions at the time and place where they occur. Default emission factors may not be accurate because emissions rates may vary considerably from country to country and even within a single country.

As discussed in Chapter 1, Section 1.5 of Volume 3, one drawback of the mass-balance approach is that it can underestimate emissions when equipment stocks are growing, because there is a lag between the time the emissions occur and the time they are detected (through equipment servicing). This underestimate will be relatively large in countries where HFCs have been used in equipment for less than ten years, because much of

the equipment will have leaked without ever being serviced. Thus, countries where HFCs have been used for less than ten years are encouraged to estimate emissions using alternative approaches. In general, the longer HFCs are used in a country, the smaller the underestimate associated with the mass-balance approach. Once equipment containing HFCs begins to retire, the underestimate declines to a low level.

Equation 7.9 can be applied either to individual types of equipment (sub-applications), or more generally to all air conditioning and refrigeration equipment in a country (i.e., Tier 1b), depending on the level of disaggregation of available data. If disaggregated data are available, emissions estimates developed for each type of equipment and chemical are summed to determine total emissions for the application.

Tier 2a – Emission-factor approach

In a Tier 2a calculation, refrigerant emissions at a year **t** from each of the six[22] sub-applications of refrigeration and air conditioning systems are calculated separately. These emissions result from:

- $E_{containers,t}$ = emissions related to the management of refrigerant containers
- $E_{charge,t}$ = emissions related to the refrigerant charge: connection and disconnection of the refrigerant container and the new equipment to be charged
- $E_{lifetime,t}$ = annual emissions from the banks of refrigerants associated with the six sub-applications during operation (fugitive emissions and ruptures) and servicing
- $E_{end\text{-}of\text{-}life,t}$ = emissions at system disposal

All these quantities are expressed in kilograms and have to be calculated for each type of HFC used in the six different sub-applications.

EQUATION 7.10
SUMMARY OF SOURCES OF EMISSIONS

$$E_{total,t} = E_{containers,t} + E_{Charge,t} + E_{lifetime,t} + E_{end-of-life,t}$$

Methods for estimating average emission rates for the above-mentioned sectors are outlined below and need to be calculated on a refrigerant by refrigerant basis for all equipment regardless of their vintage. If information on container and charging emissions is not available, inventory compilers can estimate these losses as a percent of the bank and revise the lifetime (operation plus servicing) emission factor in Equation 7.13 below to account for such losses.

Refrigerant management of containers

The emissions related to the refrigerant container management comprises all the emissions related to the refrigerant transfers from bulk containers (typically 40 tonnes) down to small capacities where the mass varies from 0.5 kg (disposable cans) to 1 tonne (containers) and also from the remaining quantities - the so-called refrigerant *heels* (vapour and /or liquid) - left in the various containers, which are recovered or emitted.

EQUATION 7.11
SOURCES OF EMISSIONS FROM MANAGEMENT OF CONTAINERS

$$E_{containers,t} = RM_t \bullet \frac{c}{100}$$

Where:

$E_{containers,t}$ = emissions from all HFC containers in year *t*, kg

RM_t = HFC market for new equipment and servicing of all refrigeration application in year *t*, kg

c = emission factor of HFC container management of the current refrigerant market, percent

The emissions related to the complete refrigerant management of containers are estimated between 2 and 10 percent of the refrigerant market.

Refrigerant charge emissions of new equipment

The emissions of refrigerant due to the charging process of new equipment are related to the process of connecting and disconnecting the refrigerant container to and from the equipment when it is initially charged.

[22] More than six sub-applications can be used, depending on the level of disaggregated data available.

EQUATION 7.12
SOURCES OF EMISSIONS WHEN CHARGING NEW EQUIPMENT

$$E_{charge,t} = M_t \bullet \frac{k}{100}$$

Where:

$E_{charge, t}$ = emissions during system manufacture/assembly in year *t*, kg

M_t = amount of HFC charged into new equipment in year *t* (per sub-application), kg

k = emission factor of assembly losses of the HFC charged into new equipment (per sub-application), percent

Note: the emissions related to the process of connecting and disconnecting during servicing are covered in Equation 7.13.

The amount charged (M_t) should include all systems which are charged in the country, including those which are produced for export. Systems that are imported pre-charged should not be considered.

Typical range for the emission factor k varies from 0.1 to 3 percent. The emissions during the charging process are very different for factory assembled systems where the emissions are low (see Table 7.9) than for field-erected systems where emissions can be up to 2 percent.

Emissions during lifetime (operation and servicing)

Annual leakage from the refrigerant banks represent fugitive emissions, i.e., leaks from fittings, joints, shaft seals, etc. but also ruptures of pipes or heat exchangers leading to partial or full release of refrigerant to the atmosphere. Besides component failures, such as compressor burn-out, equipment is serviced mainly when the refrigerating capacity is too low due to loss of refrigerant from fugitive emissions. Depending on the application, servicing will be done for instance every year or every three years, or sometimes not at all during the entire lifetime such as in domestic refrigeration sub-applications. For some sub-applications, leaks have to be fixed during servicing and refrigerant recovery may be necessary, so the recovery efficiency has to be taken into account when estimating emission factors. In addition, knowing the annual refrigerant needs for servicing per sub-application allows the determination of the national refrigerant market by adding the refrigerant quantities charged in new equipment (see Paragraph Quality assurance/Quality control). The following calculation formula applies:

EQUATION 7.13
SOURCES OF EMISSIONS DURING EQUIPMENT LIFETIME

$$E_{lifetime,t} = B_t \bullet \frac{x}{100}$$

Where:

$E_{lifetime, t}$ = amount of HFC emitted during system operation in year *t*, kg

B_t = amount of HFC banked in existing systems in year *t* (per sub-application), kg

x = annual emission rate (i.e., emission factor) of HFC of each sub-application bank during operation, accounting for average annual leakage and average annual emissions during servicing, percent

In calculating the refrigerant bank (B_t) all systems in operation in the country (produced domestically and imported) have to be considered on a sub-application by sub-application basis.

Examples of typical leakage rates (x) for various types of equipment describing the respective refrigeration sub-applications are given in Table 7.9.

Emissions at end-of-life

The amount of refrigerant released from scrapped systems depends on the amount of refrigerant left at the time of disposal, and the portion recovered. From a technical point of view, the major part of the remaining fluid can be recovered, but recovery at end-of-life depends on regulations, financial incentives, and environmental consciousness.

The following calculation formula (Equation 7.14) is applicable to estimate emissions at system disposal:

EQUATION 7.14
EMISSIONS AT SYSTEM END-OF-LIFE

$$E_{end-of-life,\,t} = M_{t-d} \bullet \frac{p}{100} \bullet (1 - \frac{\eta_{rec,\,d}}{100})$$

Where:

$E_{end\text{-}of\text{-}life,\,t}$ = amount of HFC emitted at system disposal in year *t*, kg

$M_{t\text{-}d}$ = amount of HFC initially charged into new systems installed in year (*t-d*), kg

p = residual charge of HFC in equipment being disposed of expressed in percentage of full charge, percent

$\eta_{rec,d}$ = recovery efficiency at disposal, which is the ratio of recovered HFC referred to the HFC contained in the system, percent

In estimating the amount of refrigerant initially charged into the systems ($M_{t\text{-}d}$), all systems charged in the country (for the domestic market) and systems imported pre-charged should be taken into account.

7.5.2.2 CHOICE OF EMISSION FACTORS

Tier 1a/b method

As explained within Section 7.5.2.1, Choice of Method, a composite emission factor is required to complete a Tier 1 method. Since the sub-applications within the refrigeration and air conditioning application are relatively heterogeneous, the validity of any single composite emission factor must be in doubt unless it takes into consideration the particular mix of sub-applications in the country. It is therefore *good practice* to develop composite emission factors on the basis of research within the country. The over-arching default emissions factor of 15 percent of the bank annually is used in the example of spreadsheet calculation contained in the *2006 Guidelines* CDROM attached to these *Guidelines*.

Tier 2a method

Good practice for choosing emission factors is to use country-specific data, based on information provided by equipment manufacturers, service providers, disposal companies, and independent studies. When national data are unavailable, inventory compilers should use the default emission factors shown in Table 7.9, Estimates for Charge, Lifetime and Emission Factors, which summarises best estimates of equipment charge, lifetime, and emission factors. These default values reflect the current state of knowledge about the industry, and are provided as ranges rather than point estimates. The lower end of the lifetime and emission factor ranges is intended to indicate the status within developed countries, while the upper end of each range is intended to indicate the status within developing countries. Inventory compilers should choose from the range according to country-specific conditions, and document the reasons for their choices. If data collected from the field cannot be broken down into the sub-applications as in Table 7.9, it is *good practice* to use expert judgement to estimate the relative share of each type of equipment, and calculate composite emission factors weighted according to that relative share, as proposed for Tier 1a/b, or use the emission factor appropriate to the most common type(s) of equipment.

TABLE 7.9
ESTIMATES[1] FOR CHARGE, LIFETIME AND EMISSION FACTORS FOR REFRIGERATION AND AIR-CONDITIONING SYSTEMS

Sub-application	Charge (kg)	Lifetimes (years)[2]	Emission Factors (% of initial charge/year)[3]		End-of-Life Emission (%)	
Factor in Equation	**(M)**	**(d)**	**(k)**	**(x)**	**($\eta_{rec,d}$)**	**(p)**
			Initial Emission	**Operation Emission**	**Recovery Efficiency[4]**	**Initial Charge Remaining**
Domestic Refrigeration	$0.05 \le M \le 0.5$	$12 \le d \le 20$	$0.2 \le k \le 1$	$0.1 \le x \le 0.5$	$0 < \eta_{rec,d} < 70$	$0 < p < 80$
Stand-alone Commercial Applications	$0.2 \le M \le 6$	$10 \le d \le 15$	$0.5 \le k \le 3$	$1 \le x \le 15$	$0 < \eta_{rec,d} < 70$	$0 < p < 80$
Medium & Large Commercial Refrigeration	$50 \le M \le 2000$	$7 \le d \le 15$	$0.5 \le k \le 3$	$10 \le x \le 35$	$0 < \eta_{rec,d} < 70$	$50 < p < 100$
Transport Refrigeration	$3 \le M \le 8$	$6 \le d \le 9$	$0.2 \le k \le 1$	$15 \le x \le 50$	$0 < \eta_{rec,d} < 70$	$0 < p < 50$
Industrial Refrigeration including Food Processing and Cold Storage	$10 \le M \le 10{,}000$	$15 \le d \le 30$	$0.5 \le k \le 3$	$7 \le x \le 25$	$0 < \eta_{rec,d} < 90$	$50 < p < 100$
Chillers	$10 \le M \le 2000$	$15 \le d \le 30$	$0.2 \le k \le 1$	$2 \le x \le 15$	$0 < \eta_{rec,d} < 95$	$80 < p < 100$
Residential and Commercial A/C, including Heat Pumps	$0.5 \le M \le 100$	$10 \le d \le 20$	$0.2 \le k \le 1$	$1 \le x \le 10$	$0 < \eta_{rec,d} < 80$	$0 < p < 80$
Mobile A/C	$0.5 \le M \le 1.5$	$9 \le d \le 16$	$0.2 \le k \le 0.5$	$10 \le x \le 20$[5]	$0 < \eta_{rec,d} < 50$	$0 < p < 50$

[1] Based on information contained in UNEP RTOC Reports (UNEP-RTOC, 1999; UNEP-RTOC, 2003)

[2, 3] Lower value for developed countries and higher value for developing countries

[4] The lower threshold (0%) highlights that there is no recovery in some countries.

[5] Schwarz and Harnisch (2003) estimates leakage rates of 5.3% to 10.6%; these rates apply only to second generation mobile air conditioners installed in European models in 1996 and beyond.

7.5.2.3 CHOICE OF ACTIVITY DATA

Tier 1a/b method

Inventory compilers in countries that manufacture refrigerant chemicals should estimate Annual Sales of New Refrigerant using information provided by chemical manufacturers. Data on imported chemical should be collected from customs statistics, importers, or distributors.

Total Charge of New Equipment can be estimated using either:

- Information from equipment manufacturers/importers on the total charge of the equipment they manufacture or import; or
- Information from chemical manufacturers/importers on their sales to equipment manufacturers and distributors.

Ensure this information only includes sales as refrigerant, not feedstock or other uses. The difference between the total sales of new refrigerant and that charged in new equipment is assumed to be used for servicing. Where information on new equipment charges is unavailable, it can be assumed that, in a mature market, two thirds of refrigerant is used for servicing while one third is used for new equipment. However, the adoption of such assumptions must be accompanied by some justification about the state of the market and how well these assumptions are likely to apply.

Tier 2 methods

Both Tier 2a and Tier 2b methods require the development of a matrix for each sub-application based on equipment type on the one hand and refrigerant type on the other hand. In order to derive the number of pieces of equipment for all the vintages, historic net consumption activity data is also required. The annual update of the matrix makes it possible to recalculate all emission types as detailed in Equations 7.10 to 7.14 each year. Moreover, the refrigerant choice has to be assessed on a year-by-year basis owing to changing national regulations (often relating to CFC and HCFC phase-out at different dates) and changing technological choices. In some countries HFC refrigerant regulations have started to enter into force.

Where country-specific data cannot be analysed to this level, globally or regionally validated activity data can be obtained from reputable databases based on refrigerant charges and lifetimes provided in Table 7.9, for all sub-applications, to facilitate Tier 2 methods. A number of refinements are usually necessary dependent on the particular circumstances of the country. Assistance for this can be obtained from application experts.

Other shared issues

Whether collecting country-specific activity data in support of a Tier 1 or a Tier 2 method, inventory compilers must take care in dealing with refrigerant blends. Table 7.8 illustrates the complexity already existing and blends are only expected to increase in popularity as manufacturers of equipment seek for further improvements in performance, particularly in respect of energy efficiency. Where blends contain both HFCs and other components, only the reportable elements need to be considered. This is even the case for other components with significant GWPs (e.g., CFCs and HCFCs).

Inventory compilers also need to consider how to monitor the movement of trade in equipment and products containing HFCs and/or PFCs. The Box 7.3 below sets out some of the measures required to estimate imports and exports adequately.

BOX 7.3
ACCOUNTING FOR IMPORTS AND EXPORTS OF REFRIGERANT AND EQUIPMENT

In estimating *Annual Sales of New Refrigerant*, *Total Charge of New Equipment*, and *Original Total Charge of Retiring Equipment*, as required for Tier 2b, inventory compilers should account for imports and exports of both chemicals and equipment. This will ensure that they capture the actual domestic consumption of chemicals and equipment. For example, if a country imports a significant share of the HFC-134a that it uses, the imported quantity should be counted as part of **Annual Sales**. Alternatively, if a country charges and then exports a significant number of household refrigerators, the total charge of the exported refrigerators should be subtracted from the total charge of the household refrigerators manufactured in the country to obtain **Total Charge of New Equipment**.

GENERAL APPROACH: In general, the quantity Annual Sales should be estimated using the following formula:

Annual Sales = Domestically Manufactured Chemical
+ Imported Bulk Chemical
− Exported Bulk Chemical
+ Chemical Contained in Factory-Charged Imported Equipment
− Chemical Contained in Factory-Charged Exported Equipment

All quantities should come from the year for which emissions are being estimated. Similarly, the quantity of **Total Charge of New Equipment** should be estimated using the following:

Total Charge of New Equipment
= Chemical to Charge Domestically Manufactured Equipment that is not Factory-Charged
+ Chemical to Charge Domestically Manufactured Equipment that is Factory-Charged
+ Chemical to Charge Imported Equipment that is not Factory-Charged
+ Chemical Contained in Factory-Charged Imported Equipment
− Chemical Contained in Factory-Charged Exported Equipment

Original Total Charge of Retiring Equipment should be estimated the same way as *Total Charge of New Equipment*, except all quantities should come from the year of manufacture or import of the retiring equipment.

SIMPLIFIED APPROACH: In estimating *Annual Sales* and *Total Charge of New Equipment*, it is possible to ignore the quantities of chemical imported or exported inside of factory-charged equipment if these quantities cancel out in the calculation of emissions. However, inventory compilers that use the simplified calculation should ensure that: (1) they treat imports and exports of factory-charged equipment consistently in estimating both *Annual Sales* and *Total Charge New of Equipment*; and (2) they continue to account for imports and exports of factory-charged equipment in estimating *Original Total Charge of Retiring Equipment*. As new equipment will eventually become retiring equipment, countries may wish to track imports and exports of factory-charged equipment even if this information is not strictly necessary to develop the current year's estimate.

The simplified formula for **Annual Sales** is:

Annual Sales = Domestically Manufactured Chemicals
+ Imported Bulk Chemicals
− Exported Bulk Chemicals

The simplified formula for **Total Charge of New Equipment** is:

Total Charge of New Equipment
= Chemicals to Charge Domestically Manufactured Equipment
+ Chemical to Charge Imported Equipment that is not Factory-Charged

The full formula, accounting for imports and exports of pre-charged equipment, must be used to calculate *Original Total Charge of Retiring Equipment*.

7.5.2.4 APPLYING TIER 2 METHODS – THE EXAMPLE OF MOBILE AIR CONDITIONING (MAC)

The Box 7.4 below sets out the step-by-step approach required to assess the emissions from the mobile air conditioning sub-application of a hypothetical country's inventory. The method adopted is primarily a Tier 2a approach, although there are also elements which would be equally applicable to Tier 2b. This example, therefore, highlights the reality that pure approaches and methods are rare in practice. There will often be a mix of emission-factor approach and mass–balance approach as well as a mix of country-specific data and globally or regionally derived data. As pointed out in Section 7.1.2.1, one method, approach or dataset will often be used to cross-check another. This example also demonstrates that a detailed implementation of the Tier 2a method requires a significant amount information gathering about a sub-application. Once established, it is less burdensome to implement the approach in subsequent years. Also note that assumptions made are for example only; inventory compilers should collect country-specific information rather than using the assumptions shown.

BOX 7.4
EXAMPLE OF THE APPLICATION OF A TIER 2a CALCULATION FOR MOBILE AIR CONDITIONING

Introduction

National inventories and other studies to date show that emissions of HFC-134a from mobile air conditioners (MACs) contribute significantly to the Refrigeration and Air Conditioning (RAC) Application emissions and the ODS Substitutes Category emissions. For many countries, emissions from MACs will comprise 50 percent or more of the RAC emissions and possibly more than 50 percent of the total ODS Substitutes Category emissions. This is due to many factors, including:

- The phaseout of ODSs to HFCs in MACs occurred earlier and more quickly than other Sub-Applications, such as residential (stationary) air conditioning and commercial refrigeration (supermarkets), which still rely substantially on ODSs.
- MACs are subject to extremes in terms of physical shock and vibration and hence emissions tend to be large.
- The lifetime of MACs tends to be shorter than many other RAC Sub-Applications, so that end-of-life emissions are seen earlier and equipment stocks relying on ODSs are replaced sooner with HFCs.
- Due to the small charge of refrigerant involved, recovery from MACs is often seen as uneconomical and hence is not often practiced during service and disposal.

In addition, data on vehicle purchases and registrations in a country are often known to a higher degree of quality or are easily obtained. Hence, it is *good practice* to estimate emissions from this Sub-Application. The following text describes how the general equations for the RAC Application can be applied to the MAC Sub-Application.

Data Gathering and Assumptions

An accurate estimate of MAC emissions may be obtained by collecting some data at the Sub-Application level and applying a few basic assumptions to simplify the data and calculations required, as follows:

Refrigerant Type. It will be important to separate each data point by refrigerant, so that emissions of each refrigerant are calculated separately. For MACs, this may be simplified by the fact that all MACs produced since the mid- to late-1990s use HFC-134a as the refrigerant. However, CFC-12 was used in the past and still exists in some operating systems. Furthermore, for the future other refrigerants such as HFC-152a and R-744 (carbon dioxide) are being considered.

Refrigerant Sold in Containers (RM_t). For MACs, refrigerant generally comes in three basic types of containers – 'bulk containers' sent to vehicle manufacturers to fill new MACs, 'small cans' containing about 300-500 grams of refrigerant generally used by individuals servicing their own equipment, and 'cylinders' containing about 10-15 kilograms of refrigerant used by shops that service many vehicles. If one assumes no losses from bulk containers (see below), then in order to calculate $E_{containers}$, one needs to know the total refrigerant sold in small cans (RM_{sc}) and cylinders (RM_{cy}). It will be important to distinguish the refrigerant sold into different Sub-Applications (e.g., HFC-134a is also used in the chillers and domestic refrigeration Sub-Applications) so that only the

refrigerant sold for MACs is used in the calculations. This data may be obtained from small can packagers and refrigerant producers/distributors.

Container Heels (*c*). For this example, we assume the heels from service containers are not recovered (e.g., the cylinders are discarded, not reused) and are c_{sc} = 20% for the small can and c_{cy} = 2% for the cylinder. Because bulk refrigerant containers generally go back to the refrigerant producer and are refilled, we can assume there are no heels that would be emitted and hence c_{bulk} = 0%.

MACs Produced Each Year (N_t). If the number of MACs placed in service each year is not known, an estimate can be made by multiplying the number of cars placed in service each year by an estimate of the percentage that were sold with MACs. These data may be available from automobile manufacturers, MAC producers/suppliers, or government agencies involved in transportation, infrastructure and highway safety. If more than one type of refrigerant is used, it is important to separate each Nt into the different refrigerants, e.g., $N_{1994} = N_{1994,CFC-12} + N_{1994,HFC-134a}$.

Nominal Charge of Each MAC (m_t). This factor would likely vary by the type of vehicle; for instance small passenger cars will likely have lower refrigerant charges than buses or larger cars, especially those with multiple evaporators. Likewise, this could vary over time, for instance decreasing as manufacturers make smaller systems for the same vehicle size, or increasing as larger cars and more multiple-evaporator units enter the market. For this example, we assume a constant over time at an average m = 0.7 kg, which is typical of small to medium-sized passenger cars.

Refrigerant Charged into New Equipment (M_t). This is easily calculated as $M_t = N_t \bullet m_t = 0.7 \bullet N_t$.

Assembly Losses (*k*). This is used to calculate the Charge Emissions, also referred to as 'First-Fill Emissions.' The loss rate is often small, on the order of k = 0.5% or smaller. For simplicity, we assume k = 0 in this example.

Lifetime (*d*). The presumed lifetime of a MAC. This variable can be based on national data and can be different for different types of MACs (passenger cars, buses, etc.) For this example, we assume the lifetime of all MACs is d = 12 years.

Bank in Existing Equipment (*B*). The bank will be the amount of refrigerant in MACs put into service, minus the amount of refrigerant in MACs disposed, plus the amount of refrigerant used to service MACs, minus the amount that has leaked. In actuality, a given MAC will probably leak over several years before being serviced. Rather than attempting to account for this, for this example we apply Equation 7.13 which assumes all MACs are serviced each year such that the estimated charge of each MAC is the same as the nominal charge. The annual emission rate is averaged to account for this assumption. This will only produce small errors unless the year-to-year sales of MACs fluctuate widely. Hence the bank in any given year is the sum of the Refrigerant Charged into New Equipment each year from the current year back to the assumed average lifetime of the equipment. Thus,

$$B_t = \sum_{i=1}^{d} M_{t-i+1}$$

For example, using d = 12 years, the bank in 2006 would be $B_{2006} = M_{2006} + M_{2005} + M_{2004} + \ldots + M_{1997} + M_{1996} + M_{1995}$.

Annual Emission Rate (*x*). This factor accounts for both leaks from equipment as well as any emissions during service. Both of these items can be different for different types of MACs and can also vary by when the MAC was produced (i.e., older MACs may leak more than newer MACs). If annual servicing does not occur, the amount emitted at any servicing event needs to be average over the number of years between servicing event to obtain the annual rate. This amount is likely to vary considerably depending on national conditions and what type(s) of service is (are) performed. Whether recovery of the given charge before service is performed must be considered, and may be deduced in part by examining the amount of refrigerant sold in small cans versus cylinders. For this example, we assume that 15% of the nominal charge is leaked each year and 11% on average is emitted during servicing. Hence, x = 26%.

Residual Charge in MACs Disposed (*p*). Assuming that the MAC is serviced the year before it is disposed, and that the annual emission rate is estimated, this is easily calculated as p = 1 – x. In our example, p = 1 – 26% = 0.74

Recovery Efficiency (*nrec*). If no regulations or incentives exist to require recovery of refrigerant

from MACs disposed, then likely very little will occur. So, for this example, we assume that nrec = 0.

Calculation of Different Types of Emissions

Now that these data have been gathered and assumptions have been made, calculating the emissions may be performed. An example for year t = 2006 follows:

Container Emissions (Equation 7.11).

$$E_{containers,2006} = RM_{cy,2006} \bullet c_{cy} + RM_{sc,2006} \bullet c_{sc} = 0.02 \bullet RM_{cy,2006} + 0.2 \bullet RM_{sc,2006}$$

Charging Emissions (Equation 7.11).

$$E_{charge,2006} = M_{2006} \bullet k = 0$$

Lifetime (Operating and Servicing) Emissions (Equation 7.13).

$$\begin{aligned} E_{operation,2006} &= B_{2006} \bullet x = 0.26 \bullet B_{2006} = 0.26 \bullet \sum_{i=1}^{d} M_{t-i+1} \\ &= 0.26 \bullet (M_{2006} + M_{2005} + M_{2004} + \cdots + M_{1997} + M_{1996} + M_{1995}) \\ &= 0.26 \bullet m \bullet (N_{2006} + N_{2005} + N_{2004} + \cdots + N_{1997} + N_{1996} + N_{1995}) \\ &= 0.26 \bullet 0.7 \bullet (N_{2006} + N_{2005} + N_{2004} + \cdots + N_{1997} + N_{1996} + N_{1995}) \\ &= 0.182 \bullet (N_{2006} + N_{2005} + N_{2004} + \cdots + N_{1997} + N_{1996} + N_{1995}) \end{aligned}$$

End-of-Life Emissions (Equation 7.14).

$$\begin{aligned} E_{end-of-life,2006} &= M_{2006-d} \bullet p \bullet (1 - n_{rec}) = M_{2006-12} \bullet 0.74 \bullet (1 - 0) \\ &= 0.74 \bullet M_{1994} = 0.74 \bullet 0.7 \bullet N_{1994} = 0.518 \bullet N_{1994} \end{aligned}$$

Calculation of Total Emissions

Total MAC Emissions (Equation 7.8).

$$\begin{aligned} E_{total,2006} &= E_{containers,2006} + E_{charge,2006} + E_{lifetime,2006} + E_{servicing,2006} + E_{end-of-life,2006} \\ &= 0.02 \bullet RM_{cy,2006} + 0.2 \bullet RM_{sc,2006} + 0 \\ &\quad + 0.182 \bullet (N_{2006} + N_{2005} + N_{2004} + \cdots + N_{1997} + N_{1996} + N_{1995}) + 0.518 \bullet N_{1994} \\ &= 0.02 \bullet RM_{cy,2006} + 0.2 \bullet RM_{sc,2006} \\ &\quad + 0.182 \bullet (N_{2006} + N_{2005} + N_{2004} + \cdots + N_{1997} + N_{1996} + N_{1995}) + 0.518 \bullet N_{1994} \end{aligned}$$

The only unknowns are:

- RM_{sc} – refrigerant (in kilograms) sold in small cans to service MACs, which may be obtained from small can packagers;
- RM_{cy} – refrigerant (in kilograms) sold in cylinders to service MACs, which may be obtained from refrigerant producers/distributors; and,
- N_t – the number of MACs put in service each year, which may be available from automobile manufacturers, MAC producers/suppliers, or government agencies involved in transportation, infrastructure and highway safety.

If the emissions from refrigerant containers and from end-of-life are not included, for example if it is believed that service cylinders are completely evacuated and minimal MACs reach their end-of-life in the given year, this equation becomes simply an activity (the number of MACs) multiplied by an emission factor (annual emission rate times average charge size, in this case 0.182 kg per MAC). This calculation yields the total emissions in kilograms of refrigerant. Keeping each refrigerant separate and multiplying each sum by the refrigerant's GWP will yield kilograms of CO_2 equivalent emissions. Dividing by 1 billion (10^9) will yield emissions in teragrams of CO_2 equivalent ($TgCO_2eq$).

7.5.2.5 COMPLETENESS

Completeness for the Tier 1a/b method can be achieved if data for new refrigerants, and refrigerants in equipment that is retired in the current year, are available. For the Tier 2a and 2b methods, completeness depends on a thorough accounting of the existing equipment banks, and this may involve tracking large amounts of data.

7.5.2.6 DEVELOPING A CONSISTENT TIME SERIES

Emissions from refrigeration and air conditioning should be calculated using the same method and data sources for every year in the time series. Where consistent data are unavailable for the more rigorous method for any years in the time series, these gaps should be recalculated according to the guidance provided in Volume 1, Chapter 5.

7.5.3 Uncertainty assessment

Table 7.8, Estimates for Charge, Lifetime and Emission Factors for Refrigeration and Air-Conditioning Systems, presents emission factor ranges that highlight the uncertainty associated with this sector. Generally, disaggregated methods (Tier 2) have less uncertainty than Tier 1 methods because of the heterogeneous nature of the sub-applications. Those Tier 2 methods that rely on emission factors (Tier 2a) have more uncertainty than mass balance methods that use chemical sales data (Tier 2b). This occurs largely because of the small unit size of most equipment and the potential for the multiplication of a small unit error. Inventory compilers should seek industrial advice on uncertainties, using the approaches to obtaining expert judgements outlined in Volume 1, Chapter 3.

7.5.4 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

7.5.4.1 QUALITY ASSURANCE/QUALITY CONTROL

In order to conduct a quality control for Tier 2 method, it is possible, but not necessary in order to satisfy the requirements of *good practice,* to compare the annual national HFC refrigerant market as declared by the chemical manufacturers or the refrigerant distributors with the annual HFC refrigerant needs as derived by the Tier 2 method. Refrigerant will be needed for either charging new equipment or servicing existing equipment. What is needed (i.e., purchased) to charge equipment includes the refrigerant that is actually charged in the equipment plus any associated emissions (either during the charging process or from containers that are used for charging but not completely emptied before they are discarded). What is needed for service is refrigerant to replace that which is lost from existing equipment due to leaks and lost during servicing, as well as refrigerant from containers that are not completely emptied before they are discarded. The following formula leads to this verification.

EQUATION 7.15
VERIFICATION OF SUPPLY AND DEMAND ASSESSMENTS

$$RN_t = \sum_{j=1}^{6}\left(S_{prod_t,j} \bullet m_{t,j}\right) + \sum_{j=1}^{6}\left(M_{t,j} \bullet k_j\right) + \sum_{j=1}^{6}\left(B_{t,j} \bullet x_j\right) + RM_t \bullet c$$

Where:

RN_t = HFC refrigerant needs in year *t*, kg

j = counter from 1 to 6 (or the number of sub-applications chosen for the Tier 2 method)

$S_{prod_t,j}$ = national production of equipment using HFC refrigerant for sub-application domain *j* in year *t*, number of equipment

$m_{t,j}$ = initial average charge of HFC in sub-application *j* type of equipment, kg

$M_{t,j}$ = amount of HFC charged into the equipment of sub-application *j* at manufacturing in year *t*, kg

k_j = emission factor of assembly losses of the HFC charged into new equipment of sub-application *j*, fraction

$B_{t,j}$ = amount of HFC banked in existing systems of sub-application *j* in year *t* (per sub-application), kg

x_j = annual emission rate (i.e., emission factor) of HFC banked in sub-application *j* during operation, accounting for average annual leakage and average annual emissions during servicing, fraction

RM_t = HFC market for new equipment and servicing of all refrigeration sub-applications in year *t*, kg

c = emission factor of HFC container management of the refrigerant market, fraction

The first term corresponds to the refrigerant charge of new refrigerating and air conditioning system produced in the country at the current year *t* including exports.

The second term corresponds to the refrigerant emitted during the initial charging of new refrigeration and air conditioning systems produced in the country at the current year *t* including exports.

The third term corresponds to the refrigerant charge used for servicing, assuming the refrigerant emitted from leaks and during servicing is topped-off each year.

The final term represents the refrigerant emitted from containers across the entire refrigeration and air conditioning market in the given year *t*.

Refrigerant recovered and recharged directly to the same owner's equipment are not seen as a need; however, refrigerant recovered and sent for reclamation is accounted for in the declared market.

The annual refrigerant market as declared by chemical manufacturers or refrigerant distributors RD is calculated by Equation 7.16

EQUATION 7.16
CALCULATION OF ANNUAL REFRIGERANT MARKET

$$RD_t = R_{prod_t} - R_{exp_t} + R_{imp_t} + R_{recl_t} - R_{dest_t}$$

Where:

R_{prod_t} = quantities of HFC refrigerant production in the country, kg

R_{exp_t} = quantities of HFC refrigerant produced in the country and exported, kg

R_{imp_t} = quantities of imported HFC refrigerant, kg

R_{recl_t} = quantities of HFC refrigerant recovered and reprocessed for sale as reclaimed HFC refrigerant less quantities going to reclaimers that have not yet been sold, kg

R_{dest_t} = quantities of HFC refrigerant destroyed, kg

All quantities are calculated for the current year *t*.

Comparing RN_t that is the HFC refrigerant needs as derived from the inventory method and RD_t the HFC refrigerant market as declared by refrigerant manufacturers and distributors gives a clear quality control of the inventory method, and also of the global emissions. RN_t and RD_t are calculated for each HFC type.

Inventory compilers are encouraged to use higher tier QA/QC for *key categories* as identified in Volume 1, Chapter 4.

It is difficult to provide adequate QA/QC procedures for the Tier 1 a/b method without carrying out a Tier 2 analysis to verify the choice of composite emission factor. Since this defeats the object of the Tier 1 approach, the most appropriate strategy is to seek external evaluation of the derivation of the composite emission factor where it is country-specific. An alternative will be to compare Tier 1 outputs with the predictions of regional or global databases.

7.5.4.2 REPORTING AND DOCUMENTATION

The supporting information necessary to ensure transparency in reported emissions estimates is shown in Table 7.10, Good Practice Documentation for Refrigerating and Air-Conditioning Systems.

TABLE 7.10
GOOD PRACTICE DOCUMENTATION FOR REFRIGERATION AND AIR-CONDITIONING SYSTEMS

Data Source	Data to be Reported	Tier 1a/b	Tier 2a and 2b
Regulation for phase-out of CFCs and HCFCs	Schedule of phase out for charging of brand new equipment and for servicing	X	X
Government Statistics or Disposal Companies	Number of equipment disposed of for each type of application	X	X
Refrigerant Manufacturers and Distributors	All virgin refrigerants sold for charging new equipment and for servicing in the different sectors	X	X
Manufacturer Association or Marketing Studies	Equipment produced on a national level using HFC refrigerants (for the six sub-applications)	X	X
Import/Export Companies, Governement Statistics, Manufacturer Association or Marketing Studies	Number of equipment using HFCs (imported and exported)	X	X
Government or Refrigerant Distributors	HFC refrigerants recovered for re-processing or for destruction	X	X
Manufacturer Association	Average equipment lifetime	NA	X
Manufacturer Association	Initial charge of systems	X	X

7.6 FIRE PROTECTION

7.6.1 Chemicals covered in this application area

There are two general types of fire protection (fire suppression) equipment that use HFCs and/or PFCs as partial replacements for halons: portable (streaming) equipment, and fixed (flooding) equipment. HFCs, PFCs and more recently a fluoroketone are mainly used as substitutes for halons, typically halon 1301, in flooding equipment. PFCs played an early role in halon 1301 replacement but current use is limited to replenishment of previously installed systems. HFCs in portable (streaming) equipment, typically replacing halon 1211, are available but have achieved very limited market acceptance due primarily to their high cost. PFC use in new portable extinguishers is currently limited to a small proportion (few percent) in an HCFC blend.

While actual emissions from the fire protection sub-sector are expected to be quite small, the use is normally non-emissive in provision of stand-by fire protection and is growing. This results in an accumulating bank of future potential emissions.

HFCs and PFCs that might still be involved in fire protection are shown in Table 7.1.

7.6.2 Methodological issues

7.6.2.1 CHOICE OF METHOD

As with the refrigeration and air conditioning application, the fire protection application offers the possibility of using both Approach A (emission-factor approach) and Approach B (mass–balance approach). The latter is justified by the fact that a considerable proportion of net consumption is likely to be targeted at equipment servicing rather than new equipment. However, the fire protection application differs from the refrigeration and air conditioning application in that the sub-applications are less numerous and more homogeneous. This means that the Tier 1a or Tier 1b method may be sufficient to provide appropriate emissions reporting, although, to be strictly correct, the inclusion of end-of-life considerations would normally warrant a Tier 2 approach.

However, as with both foam and refrigeration/air conditioning, it is necessary in the fire protection application to deal with the development and tracking of banks. This means that an historical time series of country-specific or globally or regionally derived activity data is required dating back to the introduction of any new HFC or PFC.

Since HFCs and PFCs in fire protection are emitted over a period longer than one year, countries need to represent emissions from equipment charged during previous years. Choosing an annual production-based emission factor to reflect a multi-year emission process can lead to considerable error and is not considered *good practice*.

Equation 7.17 indicates how the approach should be modified to consider the time dependence of the emissions and to consider what activity data could most likely be made available.

EQUATION 7.17
TIME DEPENDENCE OF EMISSIONS FROM FIRE PROTECTION EQUIPMENT

$$Emissions_t = Bank_t \bullet EF + RRL_t$$

and

$$Bank_t = \sum_{i=t_0}^{t} \left(Production_i + Imports_i - Exports_i - Destruction_i - Emissions_{i-1} \right) - RRL_t$$

Where:

$Emissions_t$ = emissions of agent from fire protection equipment in year *t*, tonnes

$Bank_t$ = bank of agent in fire protection equipment in year *t*, tonnes

EF = fraction of agent in equipment emitted each year (excluding emissions from retired equipment or otherwise removed from service), dimensionless

RRL_t = Recovery Release or Loss: emissions of agent during recovery, recycling or disposal at the time of removal from use of existing fire protection equipment in year *t*, tonnes

$Production_t$ = amount of newly supplied agent (i.e., excluding recycled agent) in fire protection equipment produced in year *t*, tonnes

$Imports_t$ = amount of agent in fire protection equipment imported in year *t*, tonnes

$Exports_t$ = amount of agent in fire protection equipment exported in year *t*, tonnes

$Destruction_t$ = amount of agent from retired fire protection equipment that is collected and destroyed, tonnes

t = year for which emissions are being estimated (e.g., 2006, 2007, etc.)

t_0 = first year of chemical production and/or use

i = counter from first year of chemical production and/or use t_0 to current year *t*

It is *good practice* to apply Equation 7.17 to each individual greenhouse gas used in fire protection equipment. The calculation of the emissions must be performed for each year and applied to the next year's calculation.

With this background in mind, the decision tree for the fire protection application as set out in Figure 7.9 becomes very straight-forward.

As with Tier 1 methods adopted in both foams and refrigeration and air conditioning, it is possible to create a simple spreadsheet that accounts for the development of banks and the subsequent emissions from them. The following spreadsheet extract provides an example:

Figure 7.8 Example of spreadsheet calculation for Tier 1 method

Tier 1 FIRE PROTECTION
Austria - HFC-227ea

HFC-227ea

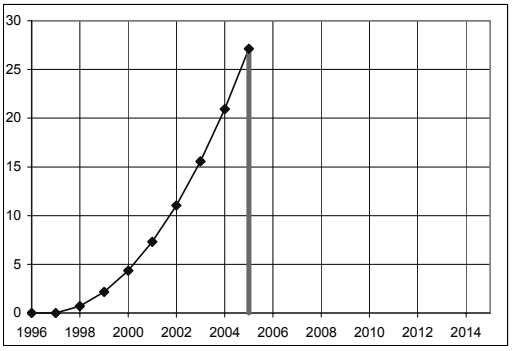
Summary
Country: Austria
Agent: HFC-227ea
Year: 2005
Emission: 27.1 tonnes
In Bank: 678.4 tonnes

Current Year	2005

Use in current year - 2005 (tonnes)	**Data Used Here**
Production of HFC-227ea	120
Imports in current Year	80
Exports in current year	24
Total new agent to domestic market	*176*

Year of Introduction of HFC-227ea	1998
Growth Rate in New Equipment Sales	3.0%

Tier 1 Defaults	
Assumed Equipment Lifetime (years)	15
Emission Factor from installed base	4%
% of HFC-227ea destroyed at End-of-Life	0%

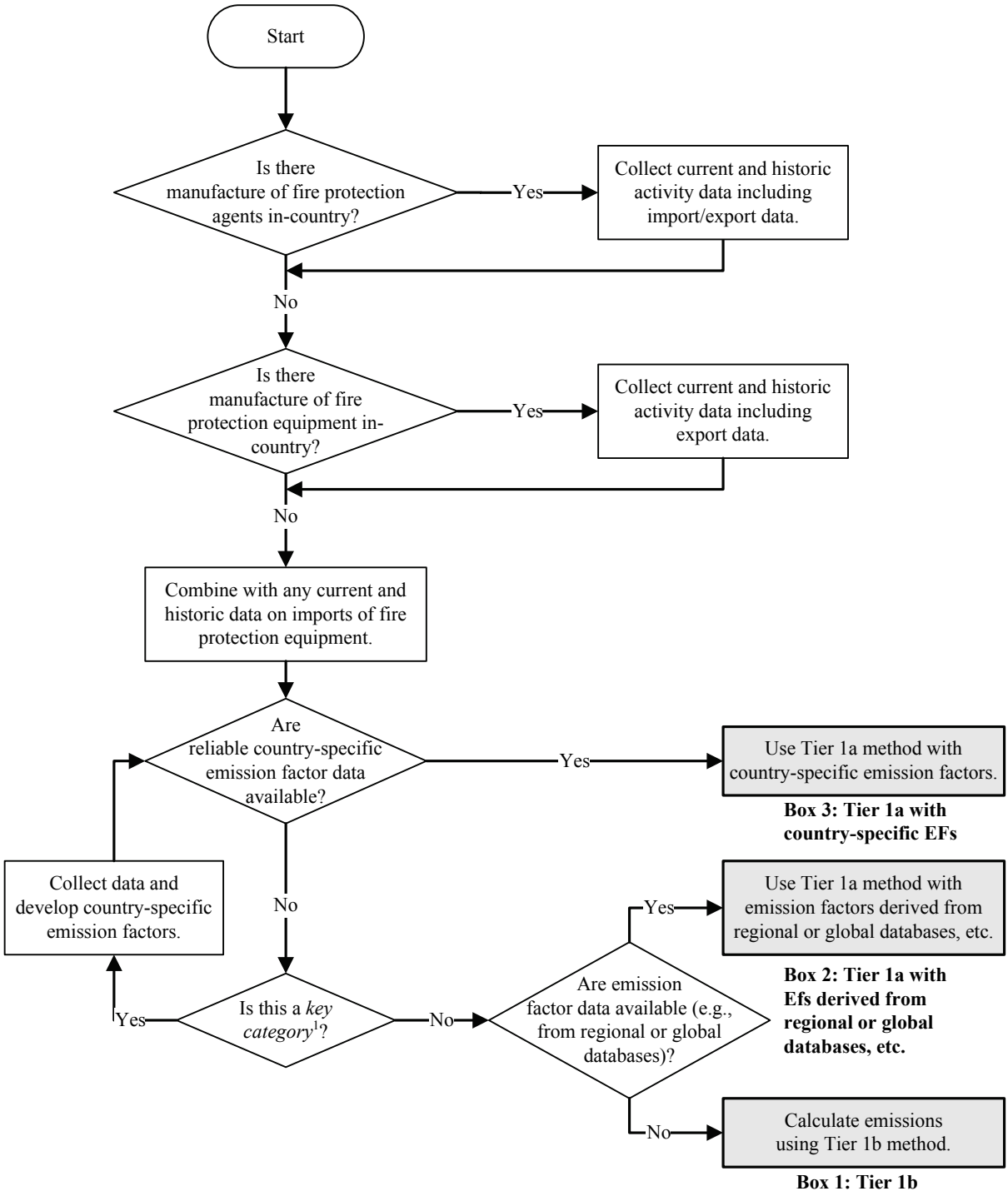


Estimated data for earlier years	1996	1997	1998	1999	2000	2001	2002	2003	2004	**2005**
Production	0	0	12	25	39	53	69	85	102	**120**
Agent in Exports	0	0	2	5	8	11	14	17	20	**24**
Agent in Imports	0	0	8	17	26	36	46	57	68	**80**
Total New Agent in Domestic Equipment	0	0	18	37	57	78	101	124	150	**176**
Agent in Retired Equipment	0	0	0	0	0	0	0	0	0	**0**
Destruction of agent in retired equipment	0	0	0	0	0	0	0	0	0	**0**
Release of agent from retired equipment	0	0	0	0	0	0	0	0	0	**0**
Bank	0	0	18	54	109	183	276	389	523	**678**
Emission	0	0	1	2	4	7	11	16	21	**27**

It is intended that such a spreadsheet facilitates the calculation for the Fire Protection application, supported, where necessary, by activity data from an appropriate globally or regionally derived dataset[23].

[23] As noted in Box 7.1, inclusion in the IPCC Emission Factor Database (EFDB) will indicate general adherence to due process, but it is *good practice* for countries to ensure that all data taken from the EFDB are appropriate for their national circumstances.

Figure 7.9 Decision tree for actual emissions from the fire protection application



Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

7.6.2.2 CHOICE OF EMISSION FACTORS

Experience gained during the phase-out of halons substances has taught some valuable lessons regarding use and emission patterns, and it is reasonable to expect that these lessons are relevant for greenhouse gases used for similar purposes. Fire protection equipment is designed to release its initial charge during an actual fire incident. A recent study shows that annual emissions from installed flooding systems are in the range of 2 ± 1 percent of the installed base (Verdonik and Robin, 2004). For halon 1211 portable extinguishers, the Halons Technical

Options Committee (2003) estimated that the emission rate for 2000 is approximately twice that of fixed systems. Applying that factor provides a range of 2 to 6 percent (that is, 4% ±2%) of the in-use quantities.

Given the nature of this application, there are opportunities to recover the gas at the end of life of the equipment (or whenever removed from service). The recovered gas may be destroyed or recycled. Therefore, the default assumption of zero end-of-life recovery may overestimate end-of-life emissions. The inventory compiler should establish contacts with relevant industries to collect information on recovery that may occur due to legislation, Industry Codes of Practice or other measures. It is *good practice* to document this information and report any assumptions.

For those countries without a national Industry Code of Practice, it is *good practice* to assume that the agent will not be recovered at the end of the system life and is emitted. Typical lifetimes for flooding systems are 15 to 20 years. In specialised applications, such as aircraft and military systems, systems can remain in use for 25 to 35 years or longer (UNEP-HTOC, 1994).

7.6.2.3 CHOICE OF ACTIVITY DATA

For countries that produce the fire protection agent, it is *good practice* to assign all of the production of that agent to that country unless known to have been 1) exported in bulk or 2) destroyed. For countries that do not produce the agent but produce and fill fire protection systems, all of the bulk agent imported into the country is considered to remain in the country unless known to have been 1) re-exported in bulk or 2) destroyed. Countries that do not produce the agent or systems would use the activity data developed by the producer countries to develop their inventory or, baring evidence of export into the country, estimate the emissions from fire protection as below the significance of their overall greenhouse gas emissions, i.e., essentially zero. This default methodology places the major responsibility on the countries that produce the agent or use them for the manufacture of systems. In order for producer countries to use this methodology, activity data would need to be developed on production, bulk imports and exports, and destruction.

In summary, activity data comes from countries that are producers of fire protection agents or systems, with the exception of destruction. In order for the producer country to decrease the amount credited toward that country from production of agent, bulk exports must be demonstrated. These bulk exports while reducing the producer countries installed base would also serve as activity data for importing countries to determine their installed base.

7.6.2.4 COMPLETENESS

Inventory compilers should ensure that all greenhouse gases used in the fire protection industry are included in the estimate. It is also necessary to apply Equation 7.17 beginning in the first year that greenhouse gas fire protection agents were employed in the country.

7.6.2.5 DEVELOPING A CONSISTENT TIME SERIES

In some countries, historical activity data for the greenhouse gases charged into new equipment or used to service existing equipment may be difficult to determine because of the recent introduction of these substances. If inventory compilers use preliminary emission factors for these years based on historical data for halons, and then switch they should follow *good practice* in ensuring time series consistency, as described in Volume 1, Chapter 5.

7.6.3 Uncertainty assessment

On the global level, a high degree of certainty could be expected because assessments will be based on production and provides for a complete material balance. At any time, Aggregate Global Production will always equal Aggregate Global Emissions plus the Aggregate Total Contained in Equipment. There is more uncertainty in the country-specific data. A small error is built into the method as importing and exporting of filled systems is not included in the method. However, based on experience with halon and their greenhouse gas substitutes, accurate data on filled system import/export is likely not obtainable at a reasonable level of effort.

Verdonik (2004) compared reports on halon consumption against the manufacturers' reports of global halon production from CEFIC[24], reported developing country production and reported CEIT[25] production. The results

[24] CEFIC – European Chemical Industry Association

[25] CEIT – Countries with Economies in Transition

were a standard deviation of 16 percent for developed countries, 15 percent for developing countries and 13 percent globally. It is anticipated that the uncertainty in HFC/PFC emission estimates would be comparable or higher than the uncertainty seen in halon consumption estimates.

7.6.4 Quality Assurance/Quality control (QA/QC), Reporting and Documentation

7.6.4.1 QUALITY ASSURANCE/QUALITY CONTROL

It is *good practice* to conduct quality control checks as outlined in Volume 1, Chapter 6, and an expert review of the emissions estimates. This may involve direct reference to global or regional databases for parallel assessments which allow benchmarking. Additional quality control checks as outlined in Volume 1, Chapter 6, and quality assurance procedures would be applicable, if higher tier methods were used to determine emissions from this application. However, if this is not the case, the basic QA/QC approaches outlined in Volume 1, Chapter 6 can be adopted.

In addition to the guidance in Volume 1, specific procedures of relevance to this application are outlined in the references at the end of the chapter.

7.6.4.2 REPORTING AND DOCUMENTATION

Access to data such as chemical sales may depend on the ability of inventories to preserve confidentiality. The balance between preservation of confidentiality and transparency of the data is an important issue, especially in a low use application such as fire protection. These ODS substitutes are manufactured by a few producers, in quantities very much lower than ODS substitutes used in other applications. Careful aggregation of GWP-weighted data may be a means to resolve this issue.

7.7 OTHER APPLICATIONS

7.7.1 Chemicals covered in this application area

HFCs and PFCs represent a large range of gases whose properties make them attractive for a variety of niche applications not covered separately in this Chapter. These include electronics testing, heat transfer, dielectric fluid, medical applications and potentially many new applications not yet developed. There are also some historical uses of PFCs, as well as emerging use of HFCs, in these applications. These applications have leakage rates ranging from 100 percent emissive in year of application to around 1 percent per annum. However, this chapter is specifically focused on those uses of HFCs and PFCs which directly replace Ozone Depleting Substances and these are much more limited in scope.

There is a need to be sure that double-counting does not occur with the electronics category covered in Chapter 6 of this Volume, including electronics testing, heat transfer and dielectric applications. Other double-counting is possible in the coverage of solvents or where HFCs and/or PFCs are contained as solvents in industrial aerosols. This is a prime example where the delineation between what is acting as an ODS Substitute and what is not can be very fine. To avoid confusion, this chapter has taken the approach that only those technology transitions which occur directly from ODSs to HFC and/or PFC technologies should be considered.

Bearing in mind that ODS phase-out (both CFCs and HCFCs) is moving towards completion in developed countries, the number of new applications emerging is expected to be very limited. However, in theory at least, new applications could emerge right up until the final global phase-out of ODSs in 2040.

7.7.2 Methodological issues

7.7.2.1 CHOICE OF METHOD

The choice of *good practice* methods depends on national circumstances (see decision tree in Figure 7.10, Decision Tree for Actual Emissions from the Other Applications).

When choosing a method for this application area, there is a need to consider whether to treat each *Other Application* as a separate application or whether to address them as a group. The former will lead to a series of Tier 2 methods, while the latter will lead to a single Tier 1 approach.

The end-users for these niche applications will be extremely diverse. As a result, investigating each of these applications separately may not be feasible. Instead, it is suggested that these other miscellaneous applications be divided into highly emissive applications similar to solvents and aerosols, and less emissive contained applications similar to closed-cell foam and refrigerators. The breakdown of annual gas consumption going to either category should be determined by a survey of end-use applications.

The split of usage will be:

- Emissive = X% of total consumption (where X would normally be expected to be typically >50%)
- Contained = (100 – X)% of total consumption

The consequence of this approach is that, depending on the number of sub-applications in each class, it could be possible to follow an exclusively Tier 1 approach or alternatively adopt a Tier 2 method. Since the primary differentiator is the rate of emission, and it is not known whether sub-applications will require servicing or not, it is recommended that exclusively Approach A (emission-factor approach) be used (i.e., Tier 1a and/or Tier 2a).

Modelling of these two classes of sub-application is considered in turn.

EMISSIVE APPLICATIONS

It is *good practice* to use a Tier 1a method, similar to the methods described for aerosols and solvents. During use of fluids in these applications, 100 percent of the chemical is emitted on average six months after sale. In other words emissions in year t can be calculated according to the equation for solvents and aerosols as follows:

EQUATION 7.18
ASSESSMENT OF PROMPT EMISSION SOURCES FROM OTHER APPLICATIONS

$$Emissions_t = S_t \bullet EF + S_{t-1} \bullet (1 - EF)$$

Where:

$Emissions_t$ = emissions in year *t*, tonnes

S_t = quantity of HFC and PFC sold in year *t*, tonnes

S_{t-1} = quantity of HFC and PFC sold in year *t*–1, tonnes

EF = emission factor (= fraction of chemical emitted during the first year after manufacture), fraction

The emission factor (EF) represents that fraction of chemical emitted during the first year after manufacture. By definition, emissions over two years must equal 100 percent. This equation should be applied to each chemical individually.

CONTAINED APPLICATIONS

Certain applications have much lower loss rates. Where appropriate data are available, a separate emissions model will be required to adjust for this lower leakage rate. Where no data exist, globally or regionally derived activity data and emission factors can be used. Thus, the equation for annual emissions is as follows:

EQUATION 7.19
ASSESSMENT OF EMISSIONS FROM OTHER CONTAINED APPLICATIONS

$$Emissions = Product\ Manufacturing\ Emissions + Product\ Life\ Emissions + Product\ Disposal\ Emissions$$

Where:

Product Manufacturing Emissions = Annual Sales ● Manufacturing Emission Factors

Product Life Emissions = Bank ● Leakage Rate

Product Disposal Emissions = Annual Disposal ● Disposal Emission Factors

7.7.2.2 CHOICE OF EMISSION FACTORS

Emission factors for those sub-applications with prompt emissions will follow similar selection criteria to those for solvents (Section 7.2.2.2) and aerosols (Section 7.3.2.2).

Emission factors for contained sub-applications will depend on the particular nature of that sub-application. If a series of sub-applications is fairly homogeneous in nature it may still be possible to work with a composite emission factor and adopt a Tier 1a method. However, where there is considerable variation in the nature of contained sub-applications, it will be more appropriate to research these specifically, if appropriate emission factors are not available. In either case, the need for separate emission factors will lead to the adoption of a Tier 2a method.

7.7.2.3 CHOICE OF ACTIVITY DATA

Activity data will always be difficult to establish for small niche applications and inventory compilers will be reliant on the co-operation of chemical suppliers to identify qualifying sub-applications. However, once identified, they should be relatively easy to quantify at a country level because they are likely to be fairly specialist in nature.

As indicated in Figure 7.10, it is *good practice* to conduct an end-use survey periodically.

7.7.2.4 COMPLETENESS

As noted in Section 7.7.2.3, the key challenge will be to keep updated with new *Other Application* as they emerge. Regular cross-reference with ODS Substitution Reviews (e.g., UNEP Technical & Economic Assessment Panel Reports) will assist in this respect.

7.7.2.5 DEVELOPING A CONSISTENT TIME SERIES

Emissions from *Other Application* should be calculated using the same method and data sources for every year in the time series. Where consistent data are unavailable for any year in the time series, gaps should be recalculated according to the guidance provided in Volume 1, Chapter 5.

7.7.3 Uncertainty assessment

There may be a wide range of *other applications* and therefore it is not possible to give default uncertainties for these sources. However, procedures should be put in place to assess levels of uncertainty in accordance with the practices outlined in Volume 1 Chapter 3.

7.7.4 Quality assurance/quality control (QA/QC), reporting and documentation

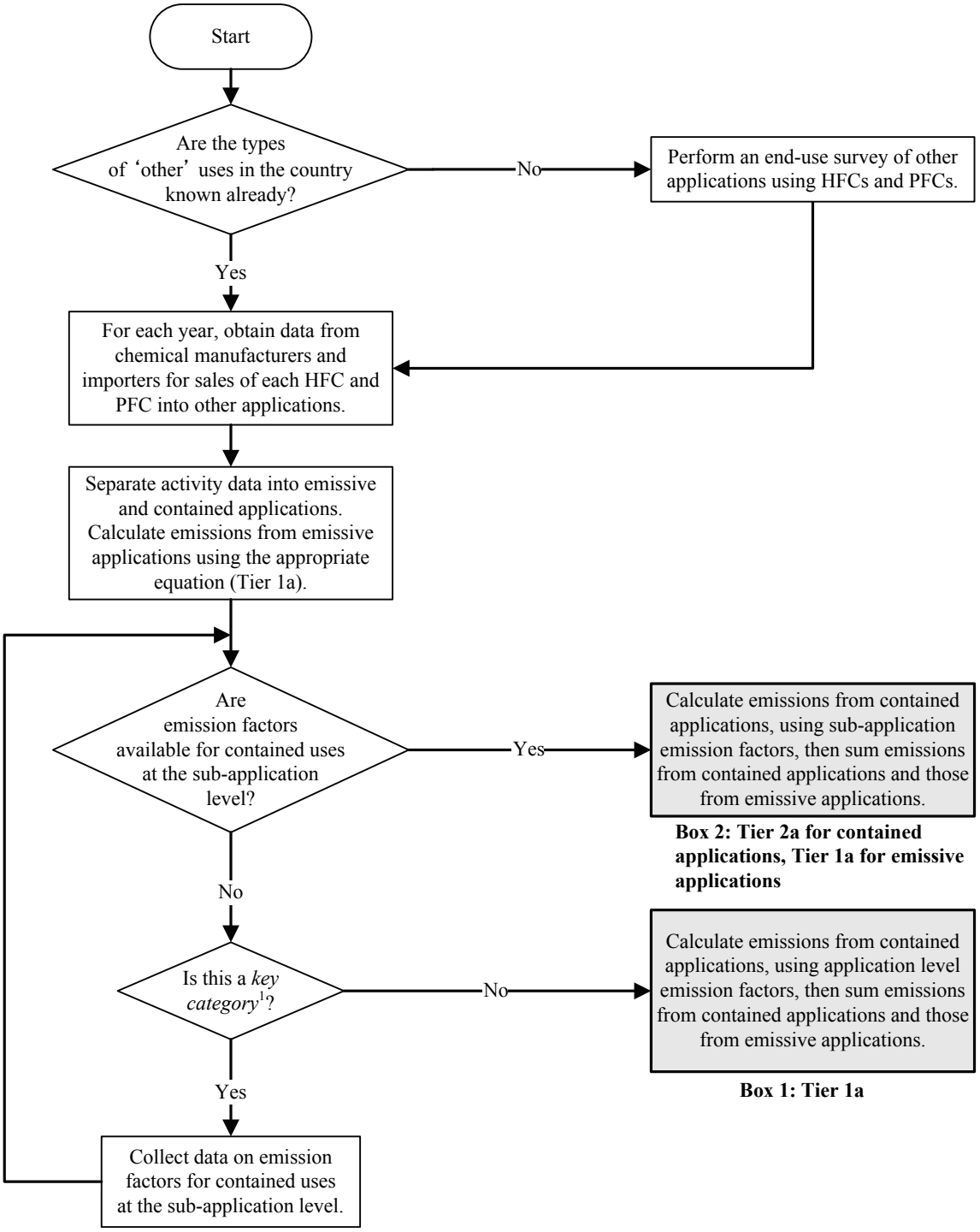
7.7.4.1 QUALITY ASSURANCE/QUALITY CONTROL

It is *good practice* to conduct quality control checks as outlined in Volume 1, Chapter 6, and an expert review of the emissions estimates. This may involve direct reference to global or regional databases for parallel assessments which allow benchmarking. Additional quality control checks as outlined in Volume 1, Chapter 6, and quality assurance procedures may be applicable, if higher tier methods are used to determine emissions from these sub-applications. However, if this is not the case, the basic QA/QC approaches outlined in Volume 1, Chapter 6 can be adopted.

7.7.4.2 REPORTING AND DOCUMENTATION

The balance between preservation of confidentiality and transparency of the data is an important issue, especially in low-use sub-applications. Specialist ODS substitutes are often manufactured by only a few producers, in quantities very much lower than ODS substitutes used in other applications. Careful aggregation of GWP-weighted data may be a means to resolve this issue.

Figure 7.10 Decision tree for actual emissions from the other applications



Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

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