Texte

Texte
15
05
ISSN
0722-186X

Emissions, Activity Data, and Emission Factors of Fluorinated Greenhouse Gases (F-Gases) in Germany 1995-2002

Umwelt
Bundes
Amt
Für Mensch und Umwelt

ENVIRONMENTAL RESEARCH OF THE
FEDERAL MINISTRY OF THE ENVIRONMENT,
NATURE CONSERVATION AND NUCLEAR SAFETY

Research Report 201 41 261/01
UBA-FB 000811/e

Texte
15
05
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Emissions, Activity Data, and Emission Factors of Fluorinated Greenhouse Gases (F-Gases) in Germany 1995-2002

Adaptation to the Requirements of International Reporting and Implementation of Data into the Centralised System of Emissions (ZSE)

by

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On behalf of the Federal Environmental Agency

This Publication is only available as Download under
http://www.umweltbundesamt.de

Publisher: Federal Environmental Agency (Umweltbundesamt)
P.O.B. 14 06
06844 Dessau
Tel.: +49-340-2103-0
Telefax: +49-340-2103 2285
Internet: http://www.umweltbundesamt.de

Edited by: Section III 1.4
Katja Schwaab

Berlin, June 2005

Report Cover Sheet

1. Report No. UBA-FB	2.	3.
4. Report Title Emissions, Activity Data, and Emission Factors of Fluorinated Greenhouse Gases (F-Gases) in Germany 1995-2002. Adaptation to the Requirements of International Reporting und Implementation of Data into the Centralised System of Emissions (ZSE) (In German)		

5. Authors, Family Names, First Names Dr. Winfried Schwarz	8. Report Date 08.06, 2004 9. Publication Date June 2004
6. Performing Organisation (Name, Address) Öko-Recherche, Büro für Umweltforschung und -beratung GmbH, Kaiserstr. 61, D-60329 Frankfurt am Main	10. UFOPLAN - Ref. No. 201 41 261/01 11. No. of Pages X + 275
7. Sponsoring Agency (Name, Address) Umweltbundesamt (German Federal Environmental Agency), Bismarckplatz 1, D-14193 Berlin	12. No. of References 13. No. of Tables 150 14. No. of Figures 1

15. Supplementary Notes

A full-length German version of this report is available at the sponsoring agency.

16. Abstract

Before the 1997 Kyoto Protocol on Climate Protection, the fluorinated greenhouse gases HFCs, PFCs, and SF_6 (F-gases) aroused little public attention. Since then, the standards on surveying and reporting on national emissions have been rising constantly. Amongst others, the annual reporting to the UNFCCC secretariat makes detailed declarations on use and emissions of F-gases necessary, which have to be filled in specified formats for submission (Common Reporting Format = CRF). The scientific basis has been set out by the UNFCCC guidelines on reporting, in accordance with the instructions laid down in IPCC good practice guidance.
Additionally, in Germany the Centralised System of Emissions (ZSE) shall provide a suitable tool to satisfy any quality needs of both activity data and emission factors. From 1995 onwards, activity data and emissions of each individual application sector shall be presented in a comprehensible and transparent way. Therefore, the way of data collection as well as the estimation methods applied must be well documented. Moreover, data has to be prepared for appropriate importation into ZSE.

It is the objective of this study to provide the transparency demanded within 40 national application sectors of F-gases, for the period between 1995 and 2002.

- Firstly, all the activity data as well as the emissions related to them are presented and commented. This applies to manufacturing of products, F-gases banked in operating systems, and decommissioning.
- Secondly, the methodologies applied to calculate the emissions are described and all sources of information are revealed, e.g. literature, names of experts from the manufacturing industry, users, trade, and academia.
- Thirdly, reliability and safety of data are discussed.
- Fourthly, possible deviations from the IPCC default values are stated and given reasons for.

Wherever this intensive reviewing of 40 sectors through eight years of reporting uncovers gaps or inconsistencies in previous reports, later corrections can be made by means of recalculations.

17. Keywords

Fluorinated Greenhouse Gases; Emissions; Reporting; CRF, ZSE; Activity data; Emission factors; Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs); Sulphur Hexafluoride (SF_6)

Price	19.	20.	

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Emissionen, Aktivitätsraten und Emissionsfaktoren von fluorierten Treibhausgasen (F-Gasen) in Deutschland für die Jahre 1995-2002.
Anpassung an die Anforderungen der internationalen Berichterstattung und Implementierung der Daten in das zentrale System Emissionen (ZSE)</td></tr>
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08.03.2004</td></tr>
<tr><td>9. Veröffentlichungsdatum
März 2004</td></tr>
<tr><td colspan="2" rowspan="2">6. Durchführende Institution (Name, Anschrift)

Öko-Recherche, Büro für Umweltforschung und -beratung GmbH, Kaiserstr. 61, 60329 Frankfurt am Main</td><td>10. UFOPLAN - Nr.
201 41 261/01</td></tr>
<tr><td>11. Seitenzahl
X + 275</td></tr>
<tr><td colspan="2" rowspan="2">7. Fördernde Institution (Name, Anschrift)

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Vor ihrer Aufnahme ins Klimaschutzprotokoll von Kioto im Jahre 1997 erweckten die fluorierten Treibhausgase HFKW, FKW und SF_6 (F-Gase) noch wenig Aufmerksamkeit. Seitdem sind jedoch die Ansprüche an die Erhebung und Berichterstattung ihrer nationalen Emissionen erheblich gestiegen. Für die Berichterstattung an das UNFCCC-Sekretariat sind z.B. jährlich umfangreiche Angaben in vorgegebenen Formaten (common reporting format = CRF) zu melden. Wissenschaftlich formuliert werden diese Ansprüche durch die UNFCCC guidelines on reporting, die wiederum dem IPCC good practice guidance folgen.

In Deutschland wird zudem mit dem Zentralen System Emissionen (ZSE) ein Werkzeug geschaffen, welches ermöglicht, allen geforderten Anforderungen an die Qualität von Aktivitätsdaten wie von Emissionsfaktoren zu genügen. Das bedeutet, Aktivitätsdaten und Emissionsfaktoren müssen ab 1995 in jedem einzelnen Anwendungssektor in ihrem Zustandekommen und ihren Berechnungsgrundlagen nachvollziehbar und transparent dokumentiert und für die Aufnahme in das ZSE präpariert werden.

Ziel der vorliegenden Studie ist es, für 40 nationale Anwendungssektoren von F-Gasen für die Zeit von 1995 bis 2002 diese erforderliche Transparenz herzustellen.

• Erstens werden sowohl alle Aktivitätsdaten als auch die sich darauf beziehenden Emissionen selbst in Zeitreihen präsentiert und kommentiert: für Herstellung, Bestand in Produkten und Anlagen sowie Außerbetriebnahme.
• Zweitens werden die den Emissionen zu Grunde liegenden Berechnungsverfahren ausführlich dargestellt. Alle Informationsquellen (Literatur, Experten aus Anwendung, Herstellung, Handel, Wissenschaft) werden offen gelegt.
• Drittens werden Sicherheit und Aktualität der Daten erörtert.
• Viertens werden ev. Abweichungen von den IPCC-Standardwerten festgestellt und begründet.

Wo die intensive Überprüfung von 40 Sektoren durch acht Berichtsjahre hindurch Lücken oder Unstimmigkeiten aufdeckt, gestattet die Einrichtung der sog. Rekalkulation ihre nachträgliche Korrektur.</td></tr>
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Fluorierte Treibhausgase; F-Gase; Berichterstattung; CRF, ZSE; Aktivitätsdaten; Emissionsfaktoren; HFKW, FKW; SF_6 ; UNFCCC; IPCC Good Practice Guidance</td></tr>
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Contents

Summary and Note for the User

Before the 1997 Kyoto Protocol on Climate Protection, the fluorinated greenhouse gases HFCs, PFCs, and SF_6 (F-gases) aroused little public attention. Since then, the standards on surveying and reporting on national emissions have been rising constantly. Amongst others, the annual reporting to the UNFCCC secretariat makes detailed declarations on use and emissions of F-gases necessary, which have to be filled in specified formats for submission (Common Reporting Format = CRF). The scientific basis has been set out by the UNFCCC guidelines on reporting, in accordance with the instructions laid down in IPCC good practice guidance.

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- Fourthly, possible deviations from the IPCC default values are stated and reasons are given for that.

Wherever this intensive reviewing of 40 sectors through eight years of reporting uncovers gaps or inconsistencies in previous reports, later corrections can be made by means of recalculations. By that, the study contributes to a higher quality level of data reporting for the past as well as for the future.

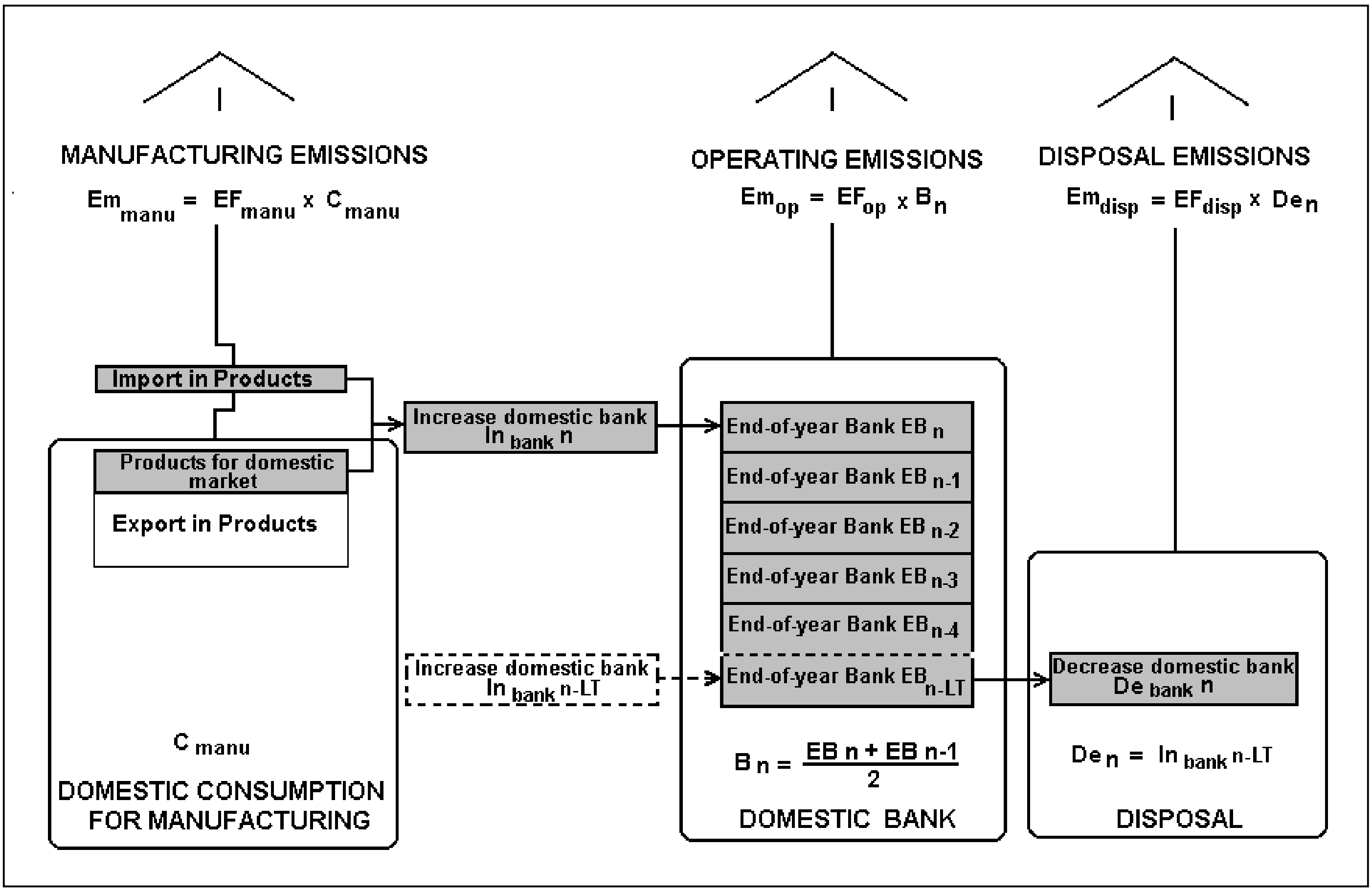
Recommendation how to use this study: Each of the 40 chapters (F-Gas-Sheets) can fairly be read and understood independently. Nevertheless, the introductory remark on the eight different emission types occurring in the study together with the graphical illustration (incl. the list of abbreviations) might make reading easier.

The sequence of the sectors in this study follows the order of sectors in the CRF data-sheet, although it is not identical to it.

Frankfurt, June 2004

Introductory Remark: Terminological Clarification of the Eight Types of Activity Data and Emissions ("Emission Types") in F-Gas-Reporting

In order to make easier the understanding of the overall 40 F-gas sectors discussed in this study regarding activity data, emission factors, and emissions, the eight most important application and emission types will be presented first in their inner connections with each other. This takes place through short descriptions which will be illustrated graphically by means of the following flow chart. (The numerous abbreviations used will be explained immediately afterwards and, additionally, at the end of the main text).



Flow chart: Connection between activity data, emissions and emission factors.

In principle, there are eight different types of emission. Some of the applications discussed in the main text include only one of them, some include two and some include even three different emission types.

Emission type 1: Manufacturing emissions

Typical cases are filling of refrigeration and air-conditioning plants, aerosol cans, switchgear equipment, sound-proof glazing, equipment for fire extinguishing, enclosure of F-gases in rigid foams and feeding of etch chambers in semiconductor manufacture.

Equation: $Em_{manu} = EF_{manu} \times C_{manu}$

This type (shown on the left side of the flow chart) refers to "domestic consumption for manufacturing" (bottom) and "manufacturing emissions" (top), whereas "import in products" is not of relevance. Activity data is domestic consumption of F-gases for manufacture of F-gas-containing products (C_{manu}), which are later divided into products for domestic market and products for export. Consumption means that quantity of gas that shall enter the product, and emission (Em_{manu}) means that part of consumption which does not reach the product, undeliberately. The relationship of emission to consumption is expressed by the emission factor (EF_{manu}). In semiconductor manufacture things are somewhat different. There, consumption is not split into emitting and filled-in quantities. All consumption (C_{manu}) is first fed into the manufacturing process, in which one part of the gas is completely destroyed and another part (Em_{manu}) is released unchanged to the atmosphere.

Emission type 2: Open application (direct)

Cases of open direct application are the use of F-gases for cleaning aluminium, for magnesium casting, in manufacture of PU integral skin foam, and for foaming XPS (only with HFC-152a) – with reservations the use of SF_6 as a tracer gas.

Equation: $Em_{manu} = EF_{manu} (100\%) \times C_{manu}$

Open applications, addressed here, have in common with emission type 1 that they also can be seen as domestic consumption of F-gases for manufacturing products (C_{manu}). However, the products themselves do not contain F-gases anymore, which is the case with emission type 1 (except for semiconductors). F-gases are completely emitting on application. The emission factor (EF_{manu}) is by definition = 100% (see equation). Domestic consumption and domestic emissions are the same ($C_{manu} = Em_{manu}$). By "direct" is meant, that F-gases in question do not emit from any interim container (e.g. aerosol cans), in which they have been filled before (→ Emission type 3).

Emission type 3: Open application (indirect)

Cases of open indirect application are all applications of cans like metered dose inhalers, general aerosols, novelty-sprays, one-component-foam.

Equation: $Em_{op} = EF_{op} (100\%) \times In_{bank}\ n$ or $(In_{bank}\ n) \times 50\% + (In_{bank}\ n\text{-}1) \times 50\%$

In indirect open applications F-gases are completely released to the atmosphere too (EF_{op} = 100%). But in distinction from direct open application (→ emission type 2) they emit from containers into which they were filled before (→ emission type 1). As long as the F-gases in question are in - domestic! - containers (mostly aerosol cans), they form a temporary domestic bank, so that emissions on application are no manufacturing emissions (Em_{manu}), but rather running emissions from the bank. (Em_{op} = operating emissions from the domestic bank). See flow chart, centre area.

The domestic bank itself is only the size of one annual input (In_{bank}). In case of short-term application the emission factor EF_{op} refers to the input of the current year. If the application is semi-prompt, which means a certain time elapsing since purchase of the container, half the input of the previous year plus half the input of the current year serve as quantity of reference (see equation: $In_{bank}\ n \times 50\% + In_{bank}\ n\text{-}1 \times 50\%$).

As the flow chart shows, it is possible that input partially (or even completely) consists of imports (import in products). This possibility is not given with emission type 2.

Emission type 4: Operating emissions from bank

"Closed" applications include all F-gas containing systems of refrigeration and air-conditioning, many insulating foams (with HFC-134a or 365mfc), fire-extinguishing equipment, switch gear and similar electrical equipment, soundproof glazing – with reservations SF_6-filled shoe soles and car tyres.

Equation: $Em_{op} = EF_{op} \times (EB\ n + EB\ n\text{-}1) \times 0{,}5$

Operating emissions from domestic banks are F-gases being released from "closed" systems. Quantitatively, they represent the bulk of F-gas emissions.

The flow chart shows that the domestic bank is made up by several layers lying on top of each other, each of which represents one entire annual input to - or increase in - domestic bank (In_{bank}). The number of annual inputs included in domestic bank depends on the lifetime (LT) of F-gas containing systems involved. The top layer in the model represents the input of the current year n; the bottom or oldest layer represents the input dating back the lifetime in years (In_{bank} n-LT). This oldest input in the bank is decommissioned over the current year n as quantity for disposal (→ emission type 5).

As the input In_{bank} runs over a whole year, its real amount is completely determined not before end-of-the-year. Then the last year's end-of-the-year bank (EB n-1) has been increased by the input's own amount. With that, the previous end-of-year bank (EB n-1) has grown to end-of-year bank of the current year n. In other words, EB n-1, i.e. the last year's domestic end-of-year bank grows over the year n by the input In_{bank} n to the end-of-year bank of the current year (EB n). The input In_{bank} n includes on its own both domestically manufactured F-gas containing products (products for domestic market) and F-gas containing products manufactured abroad (import in products). Domestic manufacturing emissions arising from "products for domestic market" are attributable to emission type 1, and are in this context out of relevance.

Emissions of the current year (Em_{op} = operating emissions) do not refer to the ready end-of-year bank of the current year n, as they arise during the entire year n. Therefore, they refer to the average of last year's end-of-year bank and this year's end-of-year bank. This is the average bank B n. The average bank follows the equation B n = (EB n-1 + EB n) x 0.5. That point is of particular importance as long as the subsequent banks are not in a balance state, but are growing or decreasing, annually.

The level of the emission factor EF_{op} depends on the operating conditions of the particular F-gas containing systems. It ranges from 0.1 to more than 25% per year. In the frame of F-gas reporting, this emission factor is the value associated with the highest degree of uncertainties.

Emission type 5: Disposal emissions

Cases of disposal emissions do not yet frequently occur in the reporting system that includes emissions from 1995 to 2002. This is because HFCs, the most important group of F-gases, have not been widely used in new systems before 1993, by that not having *reached the end of normal systems' lifetimes by 2002. Thus, cases of disposal up to 2002 are mainly SF_6 applications like switch gear, soundproof glazing, car tyres, sport shoe soles.*

Equation: $Em_{disp} = EF_{disp} \times De_{bank}\,n$ (where: $De_{bank}\,n = In_{bank}\,n - LT$)

In the model generally entire cohorts of F-gas containing products are ready for disposal, namely at the end of their physical lifetime. This simplification is necessary as long as just in a few cases direct empirical data are available on number and charge of systems being decommissioned over the year. Emissions from handling F-gases taken from existing systems during their use phase and directly given to disposal, are conceptually no disposal emissions, but operating emissions from bank (emission type 4). Likewise, this applies to emissions from handling F-gases that have become unusable in the course of manufacturing products. The latter are emissions from manufacturing (emission type 1). In the reporting system disposal is always associated with decommissioning F-gas containing products.

When the lifecycle has been completed, from the bank the input of that year retires, which dates back just a lifetime. This is in the flow chart represented by the bottom layer of the domestic bank. The quantity disposed of in year n causes a decrease in the domestic bank. Therefore, it is called $De_{bank}\,n$ (De = decrease, decommissioning, departure from bank), which is in the model the same-size as the input dating back just a lifetime ($In_{bank}\,n$ –LT). Given LT = 12 years, $De_{bank}\,n$ equals $In_{bank}\,n$-12.

How much of the charge is released on disposal to the atmosphere and how much is recovered, depends both on legal and technical conditions as well as on the care of the personnel. The un-recovered fraction of the charge is expressed by the emission factor EF_{disp}. In principle EF_{disp} and, with that, emissions on disposal Em_{disp} are not applied to the remainder of F-gas still existing in the decommissioned systems at the time n, but to the initial filling at the time n-LT. For simplicity, it is assumed that emissions during the use-phase are permanently compensated by topping-up the systems.

Emission type 6: Manufacturing plant emissions (fugitive emissions)

This is emission arising upon producing F-gases themselves. The emissions occur on chemical plants and are a certain fraction of newly produced F-gases such as HFC-134a, HFC-227ea, and SF_6 in Germany.

Emission type 7: By-product emissions

This means F-gas emissions arising on manufacturing products. Firstly, emissions of HFC-23 from production of HCFC-22, secondly, emissions of the PFCs CF_4 and C_2F_6 arising on the electrolytic production of primary aluminium.

The emission types 6 and 7 are not explained by means of the flow chart.

Emission type 8: Potential emissions

In a particular reporting year, the quantities of HFCs, PFCs, and SF_6 that are released to the atmosphere in several ways are real or "actual" emissions (A). For international reporting, up to now it is required to estimate "potential" emissions (P), additionally.

These are not so much another emission type but rather a particular view on the emissions that still have been described above in a comprehensive way.

The total amount of F-gases existing in a particular country in a reporting year forms the annual emission potential or the potential emissions. Potential emissions become actual emissions corresponding to application-specific emission factors. If the emission factor is 100% (open applications), potential and actual emissions are the same size. However, the bulk of F-gases existing in a country are contained in closed systems such as refrigeration and air-conditioning equipment, insulation foams, switchgear etc., from which just partial quantities are being released over the reporting year. These released quantities are expressed by a large number of operating and disposal emission factors. Therefore, in a given year actual emissions in a particular country are always smaller than potential emissions. The ratio of actual to potential emissions (A/P) is an admittedly rough, but meaningful measure of the retention power (leak-tightness, recovery) that a particular country practises over its F-gases in use.

The quantitative estimation of potential emissions at a certain time can be made conclusively by estimating the F-gases, which are contained in numerous banks or "stocks" (average annual stocks). This quantity banked needs to be supplemented by the quantity being used in open applications. Thus, potential emissions are arrived at by adding F-gases in open applications to F-gases enclosed in stocks. Such stocks are described mainly under the emission type 4 (closed systems), but also emission type 3 (indirect open application) is important because of the temporary stocks that this type is based on. (In terms of the Common Reporting Format [CRF], the potential emissions (P) to be entered in Table 2(II)s2 are equivalent to those "stocks“ of F-gases).

In order to estimate potential emissions it is, therefore, no longer necessary to calculate the overall F-gas quantity in a certain country the indirect way by in-depth analyses of foreign trade with F-gases. The time-consuming source-by-source determination of exports and imports of F-gases in bulk as well in products (as to date required by CRF) may cease, because estimation of domestic quantities in stocks and open applications come to the same result.

It should be noted that the stocks do not include pure storage of F-gases, although stored bottles, cylinders, and containers are part of the total bank of a country and thus are part of the potential emissions, too. These quantities are subject to large fluctuations, which make estimations nearly impossible. Establishing an average value is not possible either. The total of the potential emissions as well as the ratio of actual to potential emissions are not substantially changed by this inaccuracy.

Addendum. On frequency of sector data collection

Amongst the forty F-gas applications there are a few sectors whose emissions are determined and directly reported by manufacturers or users. These emissions are, firstly, process emissions in the semiconductor industry and, secondly, manufacturing plant emissions from aluminium production and from the production of halocarbons such as HFCs, HCFCs, and SF_6. It is understood that an annual cycle in emissions reporting is necessary there. This is because emissions of this kind vary with annual production that on its own is subject to changing conditions in economic activities of the country and of the business line.

The bulk of emissions, however, are estimated the indirect way, which is to say through combination of emission factors and activity data. In the framework of the F-gas monitoring and reporting system emission factors, mostly being technical values, stand for stability and constancy as they change very slowly with time, if at all. Although the numerous emission factors presented in the following text have constantly to be observed with respect to new findings to be incorporated as they become available, for general updating, however, a cycle of five years is deemed satisfactory.

The situation is otherwise for activity data. These are in the first instance "domestic consumption for manufacturing or filling" and "domestic bank" which in turn is a result of "annual input to the bank" and "annual output from the bank", regardless of further subdivision. Like the above-mentioned plant emissions, activity data, as the name implies, are subject to short-term influences of ever-changing economic activities as well as to varying political and legal basic conditions. Therefore, activity data have to be collected year-by-year, as a rule. This is also because of the error propagation caused by one single entry of wrong annual activity data.

That is why the national inventory agency should in the first instance endeavour to obtain every year activity data from those 34 application sectors, which do not directly report their emissions.

Thereof are some exemptions that shall be named here. Activity data in the sectors of industrial and commercial refrigeration are arrived at by means of complex refrigerant models that do not need to be elaborated repeatedly in a year-on-year basis. According to present state of knowledge, it suffices to check them up thoroughly every three years. (This includes annual controls of details). Apart from these two weighty sectors, there are some smaller end-uses, which the past eight years have proved to be constant in emissions level. These are the SF_6 sectors of particle accelerators, of military aircraft radar, and of application of tracer gas in addition to the PFC application in manufacturing printed-circuit boards. The intervals between two data collections may extend to three or even five years without jeopardising data quality.

List of Abbreviations

B_n	Average bank over the current year	Em_{disp}	Emissions on disposal
C_{manu}	Consumption for manufacturing	Em_{manu}	Ems. from manufacturing
De_{bank}	Decrease in bank (Decommissioning)	Em_{op}	Operating ems. (from bank)
EB_n	Bank at the end of the current year	In_{bank}	Input to domestic bank
EB n-1	Bank at the end of the last year	In_{bank} n	This year's input to bank
EF_{disp}	Factor of disposal emissions	In_{bank} n-1	Last year's input to bank
EF_{manu}	Factor of manufacturing emissions	LT	Life time (normal)
EF_{op}	Factor of operating emissions	n	Current year
ÖR	Öko-Recherche	ODS	Ozone Depleting Substance

F-Gas-Sheet 1: Refrigerated Vehicles

F-Gases	**HFC-134a, HFC-404A, HFC-410A, HFC-152a, PFC-218**
Application	**Refrigerated Vehicles**
Reported Years	**1995 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**

Background

According to statistics of the German Federal Office for Motor Vehicles (KBA), more than 91,000 refrigerated road vehicles were registered in 2002 compared to just 48,000 in 1993. The majority were motorised "trucks with insulated cargo hold and refrigeration", mainly being used in local and regional distribution traffic. Less of number, but greater of importance with regard to transportation capacity (distance, payload), were towed trailers, most of them being large semi mounted trailers.

Dimensions and refrigerant charges of refrigeration units vary with the cargo hold volume. Small vehicles below or not much above 2 t gross weight used for the so-called fresh-service mostly are light commercial vehicles of the VW Transporter or Mercedes Sprinter type, which are not equipped ex-works with insulation and roof-mounted refrigeration unit but are converted later-on. The vehicle engine runs the refrigeration unit with the refrigerant 134a. Larger refrigerated vehicles are from the start equipped with insulated cargo hold, on the front side of which the refrigeration set is mounted. The compressor is usually driven by an own diesel engine. Such vehicles must be able to maintain interior low temperature of - 18°C at ambient temperatures of + 30°C. The standard refrigerant is HFC-404A. To a certain degree, 410A is used, too.

I. Bank and operating emissions from bank

1 Activity data I. Domestic HFC input

1.A Annual new registrations of refrigerated vehicles by weight categories

The German Federal Office for Motor Vehicles (KBA) annually publishes for the previous year new registrations of trucks and trailers by weight and body categories. Within the body category "closed box" refrigerated vehicles are those "with insulated body and refrigeration". Based on this data it is possible to arrange a time series for newly registered refrigerated vehicles from 1993 onwards by 23 different weight categories. Table 1 shows the compilation. The 23 categories are combined into just four being of importance for the design of the refrigeration unit.

Table 1: 1993-2002 New registrations of refrigerated trucks and trailers by (gross) weight categories, in units

Gross weight	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. > 22 t	1,504	1,665	1,967	2,319	2,753	3,546	3,230	2,830	2,830	3,237
2. 9 - 22 t	1,826	1,467	1,747	1,789	1,795	2,108	2,200	1,905	1,878	1,801
3. 5 - < 9 t	1,977	1,283	1,296	1,606	1,610	1,716	1,691	1,657	1,657	1,142
4. < 2 - < 5 t	1,406	1,197	1,480	1,760	2,401	3,233	3,739	3,729	3,729	3,015
Total	6,713	5,612	6,489	7,474	8,559	10,604	10,860	10,121	10,094	9,195

Sources: KBA, Statistische Mitteilungen, Reihe 3, Kraftfahrzeuge, div. Jahresbände 1993 ff.

With the help of sector experts, the four gross weight categories have been made compatible with the division by net weight categories, which is much more common in designing refrigeration sets. (Unfortunately, this division is not used by KBA for new registrations). Table 1a shows how categories by gross weight and net weight relate to each other.

Table 1a: Recalculation of the two weight categories into each other

1. Gross weight	< 2 – < 5 t	5 t - < 9 t	9 t - < 22 t	> 22 t
2. Net weight	< 2 t	2 t – 5 t	5 t- 10 t	> 10 t

Sources: Sector experts according to section 3.

1.B Refrigerant model for refrigerated vehicles

Estimation of annual HFC input through new registrations requires three further pieces of information. Firstly, what are the typical average refrigerant charges of the refrigeration systems by vehicle weight classes? Secondly, which types of refrigerants are used? Thirdly, what are the percentage shares of refrigerant types and charges within each of the four weight categories? With the help of experts from the leading suppliers of transport refrigeration sets, a working model has been elaborated in order to reflect the present reality (since 1995) as close as possible (cf. Table 2).

Additional information: Amongst other things, Table 2 includes data of the following refrigeration sets: Class <2-<5 t: Kerstner Cool Jet 101, 161, 201, Class 5-9 t: Thermo King V 300, Class 9 t-<22 t: Thermo King TS 200-500 and Frigoblock FK 13 L, Class > 22 t: Thermo King SL 400, Carrier Vector 18, and Frigoblock HK 25.

Table 2: Model for type, charge, and share of refrigerants in refrigeration sets of refrigerated vehicles by gross weight categories in Germany, as of 1995*									
1. Weight category	< 2 – < 5 t	5 t - < 9 t		9 t - < 22 t			> 22 t		
2. Refrigerant Type	134a	134a	404A	410A	134a	404A	410A	134a	404A
3. Charge in kg	2.0	2.5	2,5	5	4	4	9	6.75	6.75
4. Share (of units)	100%	50%	50%	10%	10%	80%	10%	5%	85%

Sources: see section 3. * In 1993 and 1994 only the refrigerants 134a and 404A were available, not yet 410A. For these two years the shares of 410A (10% each, in the two upper categories) are attributed to 404A. This attribution takes place in external spreadsheet calculation.

<u>Calculation example</u>: The 2001 domestic input of HFC-410A through refrigeration sets (In_{bank}) is determined as follows: Initially, multiply the number of vehicles in the weight classes 9-22 t and >22 t (Table 1, lines 1 and 2) by 410A-shares in these weight classes (10% each, as per Table 2, line 4). The interim result is the number of 410A-sets in the two upper weight classes. The end-result is obtained by multiplying the first of the two numbers of sets by 5 kg and the second by 9 kg (Table 2, line 3). These steps are shown in the following equation for input (In_{bank} n) of 410A, where n = 2001:

$$In_{bank}\ 2001: (1878 \times 10\% \times 5\ kg) + (2830 \times 10\% \times 9\ kg) = 939\ kg + 2547\ kg = 3486\ kg$$

1.C Annual domestic HFC input through new systems

HFC input (In_{bank}) through new refrigeration sets for domestic use is as follows.

Table 3: 1993-2002 HFC-input by new refrigeration sets of refrigerated vehicles, in t/y			
	HFC-134a	HFC-404A	HFC-410A
1993	6.5	18.7	*
1994	5.1	17.6	*
1995	5.9	18.5	2.6
1996	7.0	21.0	3.0
1997	8.5	23.5	3.4
1998	10.7	29.2	4.2
1999	11.6	27.7	4.0
2000	11.2	24.4	3.5
2001	11.2	24.3	3.5
2002	10.9	25.7	3.8

Sources: Data from Table 1 and Table 2. * 410A was not used before 1995.

1.D 1996-1999 Domestic input of new HFC/PFC into old systems

In line with the German CFC-Halon-legislation, between 1996 and 1999 in a certain number of existing refrigeration systems (about 3,000 in total) CFC-12 was exchanged for new chlorine-free refrigerants or chlorine-free refrigerant components. These quantities are not yet included in the estimates of Table 3, which solely base on new registrations. According to a study for the Umweltbundesamt (Öko-Recherche 1998), roughly 10 t HFC-134a (either pure or as 88% component in 413A) and roughly 1 t HFC-152a (as 11% component in 401B) were added to the existing refrigerant bank (old systems) over those four years. Additionally, 0.7 t of PFC-218 must be considered, likewise from the use of the service refrigerant 413A, in which this PFC is contained 9%.

These quantities, which are going to retire the bank from 2003 onwards, are treated here as input of its own. Owing to higher emissions rates of old systems, these quantities need separate consideration when dealing with the bank (section 2).

Table 4 summarises the input of new HFCs and PFCs into old systems in Germany.

Table 4: 1996-1999 Input of new HFC and PFC into old refrigeration systems of refrigerated vehicles, in t/y			
	HFC-134a	HFC-152a	PFC-218
1996	2.5	0.25	0.225
1997	2.5	0.25	0.225
1998	2.5	0.25	0.225
1999	2.5	0.25	0.225

2. The HFC bank in refrigeration sets of refrigerated vehicles

Over the year n, the HFC end-of-year bank in refrigeration systems of year n-1 (EB n-1) grows to end-of-year bank n by domestic input In_{bank} n. The end-of-year bank n (EB n) is the sum of all inputs that have taken place until the end of year n, minus domestic output of HFCs due for disposal with old systems. In view of 10-year-lifetime, decrease in bank due to decommissioning will not occur before 2003.

The average domestic bank B n is half the sum of the previous end-of-year bank (n-1) and the current end-of-year bank n. This is the equation:

$$B\ n = \frac{EB\ n\text{-}1 + EB\ n}{2} \qquad \text{Where:} \quad EB\ n = EB\ n\text{-}1 + In_{bank}\ n$$

2.A Average HFC bank in new systems

The average annual bank B n in new systems shows the following time series for the three HFC refrigerants (Table 5).

Table 5: 1995-2002 Average annual HFC bank (B n) in refrigerated vehicles, in t			
	HFC-134a	HFC-404A	HFC-410A
1995	14.6	45.5	1.3
1996	21.1	65.3	4.1
1997	28.9	87.6	7.3
1998	38.4	114.0	11.1
1999	49.5	142.4	15.2
2000	60.9	168.5	19.0
2001	72.2	192.8	22.5
2002	83.2	217.9	26.1

Sources: Table 3 and above equation.

2.B Average bank in old systems and operation emissions

Because of CFC replacement in old systems with emissions rates higher than those of new systems, it seems to be appropriate to calculate separate time series for the average banks of refrigerants in old systems. Please note this is not the refrigerant bank of all old systems, but only the partial bank of old systems in which CFC refrigerants have been exchanged for CFC-free service refrigerants. For simplicity, operating emissions (EF_{op} = 25%) are entered in Table 6, too.

Table 6: 1996-2002 Average annual HFC/PFC bank (B n) in old refrigeration sets and annual operating emissions in t

	HFC-134a		HFC-152a		PFC-218	
	Av. Bank	Emissions	Av. Bank	Emission	Av. Bank	Emissions
1996	1.25	0.31	0.123	0.03	0.11	0.03
1997	3.75	0.94	0.375	0.09	0.34	0.08
1998	6.25	1.56	0.625	0.16	0.56	0.14
1999	8.75	2.19	0.875	0.22	0.79	0.20
2000	10.00	2.50	1.00	0.25	0.90	0.23
2001	10.00	2.50	1.00	0.25	0.90	0.23
2002	10.00	2.50	1.00	0.25	0.90	0.23

Sources for average bank: Table 4. Emissions estimation is based on EF_{op} = 25%.

Comment on time series of activity data

Leaving aside the only temporary time-series of old systems (Table 6), the refrigerant bank in new systems shows a steady growth. This is not surprising in the face of the ongoing substitution of CFC/HCFC by HFCs. Table 3 shows a steep rise in annual input to the domestic bank from 1994 to 1999. This indicates that input was not only used for replacement of retired systems at end-of-life, but was also used for additional purchase of new refrigerated vehicles.

The HFC segment with the sharpest growth is the category > 22 t gross weight. The main reason for that is a tripling in number of heavy semi-trailers since 1993, whereas the number of medium weight refrigerated trucks (5 - 22 t) have remained constant, and vehicles in the light segment (< 5 t) have undergone a doubling, in line with the overall trend. From 1999 to 2002, annual HFC input is slightly declining (apart from 404A in 2002). The HFC bank in refrigerated vehicles still goes on growing, however no longer with the rate of the 1990s.

Saturation of bank is conceivable at 100,000 or even fewer refrigerated vehicles (89,500 in 2002). This number will probably be met soon (2006/7). Then, the average HFC bank (340 t in 2002) will figure some 408 t, which are supposed to be split into 261 t 404A, 109 t 134a, and 38 t 410A.

3. Collection and information sources of activity data

All data such as charges of the weight-class-specific refrigeration sets, used refrigerants, details on CFC-12-replacement, etc. was collected in permanent contact with experts from the domestic branches of the two world-leading manufacturers Thermo King and Carrier, complemented by contacts with the three leading domestic players Frigoblock, Konvekta, and Kerstner. The numbers of vehicle registrations by weight categories come from written sources, i.e. from statistical KBA communications.

Information sources on activity data (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Personal Communications

Carrier Transicold Deutschland GmbH & Co., Georgsmarienhütte www.carrier-transicold.de, 18.03.98, 01.07.98, 08.02.02, 10.01.99.
Carrier Service Center Heppenheim 11.02.02.
Thermo King: Euram GmbH, Haan, 24.09.96, 19.03.98, 30.06.98.
Thermo King: Josef-Große Kracht GmbH & Co. KG, Osnabrück www.grosse-kracht.de, 21.02.02.
Thermo King: Euram GmbH, Griesheim, 10.01.99; 26.02.02, 26.02.02; 13.11.03.
FRIGOBLOCK Grosskopf GmbH, Essen www.frigoblock.de, 23.09.96; 24.06.98, 10.01.99; 21.02.02.
Konvekta AG, Schwalmstadt www.konvekta.com, 19.11.96, 22.06.98, 25.07.03.
Kestner Fahrzeugklimatechnik GmbH, Groß-Rohrheim, www.kestner.de, 13.11.03.

Written Sources

Kraftfahrt-Bundesamt, Statistische Mitteilungen, Reihe 3: Kraftfahrzeuge, Jahresbände 1993-2001: Neuzulassungen – Besitzumschreibungen - Löschungen von Kraftfahrzeugen und Kraftfahrzeuganhängern, Übersichten 19 und 32 (vor 2000: Übersichten 17 u. 27).

4. Factor of operating emissions from bank

Operating HFC emissions from refrigeration units of refrigerated vehicles are estimated at 15%/y. The same factor is applied to all weight classes and to all refrigerant types. However, it is used for new systems only, which are designed for HFC refrigerants. In old systems originally designed for CFC/HCFC use, the emission factor is estimated at 25%. This concerns chlorine-free service refrigerants (see Table 4).

Owing to the open compressor, the manual assembly of the refrigeration unit to the vehicle, and the extremely long operating time (all over the year), emissions are estimated distinctly higher than from passenger car air conditioners.

Sources of information on emission factors (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Measurements of operating emissions could not be found. Two manufacturer's experts with practical as well as scientific background estimated emissions from HFC systems at "annually at least 15%". One of them viewed the factor even at "rather 20%". The head of refrigerant applications technology at the HFC producer Solvay Fluor & Derivate GmbH took 15% for realistic in new systems. This value was presented to the professional public on expert meetings as well as through professional papers.

Concerning old systems, the emission factor of 25% was re-affirmed by each of the three experts. This value was several times mentioned in special studies and meetings on CFC-replacement arranged by the German Umweltbundesamt in the 1990s.

New Systems

Konvekta AG, Schwalmstadt www.konvekta.com, 14.02.03, 21.11.03.
FRIGOBLOCK Grosskopf GmbH, Essen www.frigoblock.de 04.03.02; Letter to ÖR 25.09.02.
Solvay Fluor & Derivate GmbH, Hannover, 26.03.03.
Christoph Meurer/Winfried Schwarz: The “Fish Cold Chain” – Basic Ecological Evaluations. Presentation at the XXI IIR International Congress of Refrigeration, August 17-22, 2003, Washington, DC.

Old Systems
FKW: Ersatz von R 502 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, im Auftrag des Umweltbundesamtes, Texte 29/97, Berlin, Juni 1997, S. 21.
Fachgespräch zum Thema "Umrüstung von bestehenden Kälte- und Klimaanlagen in Gewerbe und Industrie" mit dem Kältehandwerk (BIV und VDKF) und der Transfrigoroute, Umweltbundesamt Berlin, 8.5.1995.

5. HFC emissions from bank (new systems)

Operating emissions in a particular year n can be estimated by applying the emission factor (EF_{op}) to the average bank (B n) of that year n. The bank itself has been built up over the past years by annual domestic HFC inputs - see section 2:

$$\text{Emissions n} = EF_{op} \text{ (in \%)} \times \text{B n}$$

Because of the EF of 15% for new HFC-containing refrigeration sets of domestically registered refrigerated vehicles the specific equation of operating emissions is:

$$\text{Emissions n} = EF_{op} \text{ (15 \%)} \times \text{B n}$$

1995-2002 annual operating HFC emissions from bank (new systems) are in t/y:

Table 7: 1995-2002 Average bank and operating emissions of 134a, 404A, 410A, in t/y

	HFC-134a		HFC-404A		HFC-410A	
	Average bank	Operating Emissions	Average bank	Operating Emissions	Average bank	Operating Emissions
1995	14.6	2.2	45.5	6.8	1.3	0.2
1996	21.1	3.2	65.3	9.8	4.1	0.6
1997	28.9	4.3	87.6	13.1	7.3	1.1
1998	38.4	5.8	114.0	17.1	11.1	1.7
1999	49.5	7.4	142.4	21.4	15.2	2.3
2000	60.9	9.1	168.5	25.3	19.0	2.9
2001	72.2	10.8	192.8	28.9	22.5	3.4
2002	83.2	12.5	217.9	32.7	26.1	3.9

Sources: Table 5 and equation in this section 5.

Comment

Operating HFC emissions from banks in new systems of domestic refrigerated vehicles have constantly risen proportionally to the growth in average HFC banks. This applies to each refrigerant in use. The banks may be supposed to increase to more than 400 t (all refrigerants together) by 2006/07. Then, emissions would peak at 60 t/y (39 t 404A, 16 t 134a, and 6 t 410A).

6. Quality control and uncertainty assessment of data I

Activity data. Statistical data on annual new registrations of refrigerated vehicles by weight categories are deemed very safe, as they are based on compulsory registration to authorities. The refrigerant working model, which divides vehicles into four weight classes with representative refrigerant charges and type-shares each, is less robust. This model provides the basis for all subsequent estimations of input and bank quantities. The reliability of that model can only be kept on a reasonably high level, as long as experts from the most important suppliers of refrigeration sets are regularly interviewed in respect to the model parameters. As this has been put into practice from 1996 until today, a high degree of data safety can be assumed. Reviewing will be necessary in the future, too, as the model parameters are subject to changes. As far as details on CFC-replacement in the 1990s are concerned, reliability is deemed high. The details are based on a special study for the Umweltbundesamt.

Emission factors. There is no doubt that the persons interviewed rank among the most qualified experts in mobile refrigeration technology in Germany. Emission values other than "at least 15%" have not been communicated from serious sources. The 25% value attributed to old systems is used in relevant professional literature and has not yet been doubted in public. Both values, of which the new system value is more important, can be considered reliable in magnitude. This involves that the effective value may vary by 2 or 3 % above or below 15%, as the emission factor is no measured value but a value from experts' experience.

7. Relation to IPCC method I

IPCC GPG presents under "3.7.4 Stationary refrigeration sub-source category" the equation 3.42 for operation emissions in the framework of a bottom-up approach:

$$\text{Operation Emissions} = (\text{Amount of HFC and PFC Stock in year t}) * (x/100)$$

In the equation, x means the annual leak rate of the total charge. The default emission factor (best estimates) mentioned in Table 3.22 (% of initial charge/year) for Transport Refrigeration ranges from 15% to 50%, and the default lifetime is 6-9 years.

The country-specific parameter of 15% (emission factor for Germany), which should be used preferentially acc. to Box 3 of the Decision Tree for Actual Emissions (Tier 2), is situated at the lower bound of the default value (15% - 50%).

8. Entry in CRF I

The CRF Table to enter data on "Average annual stocks" and "Emissions from stocks" is Table 2(II).Fs1, row 29 for 134a, rows 32-34 for 404A, rows 40-44 for 410A and the substitutes for CFC-12. Each time the respective columns are C and I.

II. Domestic HFC consumption and manufacturing emissions

Filling of new refrigeration sets, the annual number of which was determined by charge and refrigerant type in Part I, takes place inside Germany. Therefore, domestic input to the bank (In_{bank}) and domestic consumption for manufacturing (C_{manu}) are in principle the same. There is one significant exception: Of the new 404A-sets, about 60% are filled abroad and then imported. This applies to systems from the two world market leaders Thermo King and Carrier.

This should be kept in mind when determining domestic filling emissions. In addition, it should be taken account of the fact that during the years of R-12 replacement new HFCs (including small PFC quantities) were filled into still existing old equipment.

9. Activity data II. Number of domestically filled systems

Table 9 lists the annual domestic numbers of old and new refrigeration sets that were filled with HFCs and PFCs in 1995-2002 for the first time. The number of new 404A-units is already reduced to 40% in order to represent domestically filled systems only. This is the only alteration to the respective Tables in Part I.

Table 9: 1995-2002 Number of domestically filled vehicle refrigeration sets, by refrigerant type and year

Refrigerant	404A	134a	410A	152a	218	134a II
1995	1,487	2,401	371			
1996	1,682	2,858	411	75	75	800
1997	1,832	3,523	455	75	75	800
1998	2,224	4,480	565	75	75	800
1999	2,140	4,966	543	75	75	800
2000	1,903	4,890	474			
2001	1,895	4,887	471			
2002	1,905	3,928	504			

Explanation: 134a II means that part of HFC-134a that was filled into old systems, be it as a component of a service refrigerant or pure.

Approach of estimation, information sources, and appraisal of data quality has already been dealt with in Part I.

10. Factor of filling emissions

Refrigerant loss on filling is estimated at 5 grams per system whatever its size is.

The filling loss of 5-g/system is a default value standing for the losses from charging hoses during on-site filling. Vehicle refrigeration experts have confirmed this value.

11. Annual filling (manufacturing) emissions

Compared to operation emissions from bank, filling emissions are relatively small. Their significance is even lowered by the fact that they definitely occur only once during a system lifetime. Moreover, losses of 404A arise only 40% domestically and 60% abroad. In Table 10, filling emissions are put in relation to domestic consumption (C

$_{manu}$) according to CRF requirements, albeit emissions are not yet recalculated to percentages of consumption (implied emission factor).

Table 10: 1995-2002 Domestic consumption and filling emissions of 404A, 134a, 410A, in kg/y

	HFC-134a		HFC-404A		HFC-410A	
	Con-sumption	Filling-Emissions	Con-sumption	Filling-Emissions	Con-sumption *	Filling-Emissions
1995	5,942	12	7,397	7	2,643	2
1996	7,026	14	8,414	8	2,981	2
1997	8,462	18	9,419	9	3,375	2
1998	10,652	22	11,696	11	4,246	3
1999	11,562	25	11,074	11	4,007	3
2000	11,246	24	9,762	10	3,500	2
2001	11,236	24	9,727	9	3,486	2
2002	10,863	20	10,305	10	3,814	3

Sources for domestic consumption: Table 3 in Part I.
* Domestic consumption of 404A includes only 40% of domestic HFC-input (In $_{bank}$).
Notice: The quantities are not indicated as tonnes, but as kilograms.

In addition, emissions from filling of old R-12 systems over the years 1996-1999 figured for:

- HFC-134a 4.0 kg per year,
- HFC-152a 0.4 kg per year,
- PFC-218 0.4 kg per year.

When filling emissions shown in Table 10 (5-g/system) are related to annual consumption listed in the same Table, an implied emission factor of manufacturing (EF $_{manu}$) emerges as a percentage of 0.2 for 134a and of 0.05% for 410A. This relatively (not absolutely) large difference in implied emission factors is an outcome of the fact that HFC-134a is predominantly filled into small sets of about 2 kg charge, whereas 410A is typical of systems charged with refrigerant up to 9 kg.

12. Data quality and uncertainty assessment II

There is nothing to say about the activity data, which goes beyond the details given in Part I. The emission factor 5-g/system results from interviews with several refrigeration experts, and it can therefore be seen as reasonably reliable.

13. Relation to IPCC method II

In Table 3.22, IPCC GPG reproduces "best estimates" for relative filling emissions, i.e. "initial emission" in % of initial charge. The magnitude ranges from 0.2 to 1 percent. With 0.05 and 0.2%, the country-specific data of the inventory agency Öko-Recherche (ÖR) are situated at the very bottom of those best estimates (or even underneath).

Incidentally, the ÖR value is no percentage of filling but a fixed quantity of 5 grams that are assumed to be lost on charging one system. This value is deemed closer to reality, as filling loss is no linear function of the charge.

14. Entry in CRF II

The CRF-Table where data on fluids "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered for transport refrigeration is Table 2(II).Fs1, row 29 for 134a, rows 32-34 for 404A, rows 40-44 for 410A and the substitutes for CFC-12. Each time the columns in question are B and H.

F-Gas-Sheet 2: Refrigerated Containers

F-Gases	**HFC-134a, HFC-404A**
Application	**Refrigerated (Reefer) Containers**
Reported Years	**1995 - 2002**
Emission Type 4	**Operating Emissions from Bank**

Remark on method

Refrigerated containers are mainly used for transportation of perishable goods on sea-ships. Losses of refrigerant predominantly occur in international waters, which none of the nation states are legally responsible for. As the states are involved in world trade, which cannot go well without a worldwide merchant fleet, it seems to be plausible to distribute refrigerant emissions according to the share of each country in world trade. The German EPA holds this opinion. According to Germany's share of about 10% in world trade, emissions from the worldwide fleet of reefer containers are attributed to national emissions, no matter where they actually arise and whom the ships or the containers on the ships legally belong to.

Background

New reefer containers are almost exclusively "integrated". To their front wall, a refrigeration set is mounted, which runs on board electrically. A typical container ship has some 6,000 storing positions (6 layers on deck, 6 layers below deck), of which roughly 10% are equipped with a power socket from the on-board electrical system. The worldwide stock of reefer containers is still growing and figures about 1 million TEU (Twenty Feet Equivalent Units), which means some 600,000 container boxes. The difference in numbers results from the fact that units with 20 ft. as well as units with 40 ft. length are available. One 40 ft. container is recalculated to two TEU.

A typical refrigeration unit with a reciprocating compressor from the world market leader Carrier contains 6 kg (5 litres) HFC-134a. On grounds of universal availability in the harbours all over the world, in the course of CFC displacement HFC-134a was introduced as uniform refrigerant in 1993. Thermo King, the second on the world market (besides, there are only two more manufacturers, namely the Japanese companies Mitsubishi and Daikin), has additionally been using 404A since 1997. This blend is deemed energetically superior in freezing and needs only 4 kg refrigerant charge thanks to its scroll compressor. Nevertheless, there is no general trend to lower refrigerant charges per container, because more and more containers need two refrigeration sets to cool their enlarged interior.

Bank and operating emissions from bank

1 Activity data. Annual worldwide HFC input

1.A Annual worldwide production of reefer containers

Normally, a reefer container has only one refrigeration set, no matter if the container is 20 or 40 ft. long. Though the annual worldwide production of reefer containers is surveyed in measures of length of 20 ft. each, here are not measures of interest but physical units. The number of units from 1993 onwards is entered in Table 1. Despite of fluctuations, it shows a clear year-on-year up-trend.

Table 1: 1993-2002 World production of reefer containers with HFC refrigeration

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Units	32,750	37,000	46,250	44,750	50,750	51,750	50,250	55,000	53,000	65,000

Source: World Container Census.

1.B The refrigerant model for reefer containers

Table 2: Typical HFC refrigerants in reefer containers by charges and shares

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. Charge 134a kg	6	6	6	6	6	6	6	6	6	6
2. Charge 404A kg					4	4	4	4	4	4
3. Share HFC	30%	60%	90%	100%	100%	100%	100%	100%	100%	100%
- Thereof 134a	100%	100%	100%	100%	90%	88%	86%	84%	82%	80%
- Thereof 404A					10%	12%	14%	16%	18%	20%

Sources: Section 3. Notice: HFC-404A was not used before 1997.

In Table 2, the two important refrigerants 134a and 404A are entered by charges and market shares in reefer-container refrigeration-sets. The average HFC charges have remained constant since 1993 and 1997, respectively. A 134a-set contains 6 kg, and a 404A-unit contains 4 kg. In line 3, the gradual introduction of HFC as refrigerant for new refrigeration systems is shown. It started in 1993 with 30% (remainder: R-12 or -22) and was completed in 1996 (100%). The next line shows that 134a was the only HFC (100%) for reefer containers just four years long; from 1997 onwards the HFC 404A has additionally been used. The share of 404A (bottom line) has been rising slowly from initially 10% to 20%, but this refrigerant blend has not yet endangered the leading position of 134a (80% in 2002).

1.C Annual worldwide HFC input through reefer-container refrigeration sets

By means of the annual number of manufactured units in Table 1, together with the refrigerant charges and market shares in Table 2, the HFC input (first fills) can be estimated for each year in tonnes, from 1993 to 2002.

Calculation of input of HFC-134a in year n (In_{bank} n) is a two-step procedure: First, weight the number of units in year n (Table 1) with the percentage share of 134a in the same year (Table 2). Secondly, multiply this weighted number of units by 6 kg charge (likewise in Table 2). The same approach serves to estimate 404A input.

Table 3 shows the worldwide annual input of new HFCs to that HFC quantity which has already been banked in reefer container refrigeration units.

Table 3: 1993-2002 Worldwide HFC input through new reefer containers, in t/y		
	HFC-134a	HFC-404A
1993	59.0	
1994	133.2	
1995	249.8	
1996	268.5	
1997	274.1	20.3
1998	273.2	24.8
1999	259.3	28.1
2000	277.2	35.2
2001	260.8	38.2
2002	312.0	52.0

Sources: Number of units and shares of the refrigerant types according to Table 1. The refrigerant charges per refrigeration set are 6 kg (134a) and 4 kg (404A), respectively.

2. Worldwide HFC bank in reefer-container refrigeration sets

The HFC end-of-year bank (EB) in container refrigeration sets in year n-1 increases to the end-of-year bank in year n by the HFC input through new systems (In_{bank}) during the current year n. The average worldwide bank B n is half the sum of the end-of-year banks of the previous year n-1 and of the current year n. The equation is:

$$B\ n = \frac{EB\ n-1 + EB\ n}{2} \quad \text{Where:} \quad EB\ n = EB\ n-1 + In_{bank}\ n$$

The average annual bank B n in reefer containers exhibits following time series.

Table 4: 1995-2002 Average annual HFC bank (B n) in reefer containers, in t		
	HFC-134a	HFC-404A
1995	317	
1996	576	
1997	847	10
1998	1,121	33
1999	1,387	59
2000	1,656	91
2001	1,925	128
2002	2,211	173

Sources: Table 3 and the above equation.

Comment on time series

Worldwide input of HFC-134a was steadily rising until 1997. Since then, input is stagnating, because 134a has to share the growth in quantity with HFC-404A. The average annual banks of both refrigerants have been growing quickly since 1993 and 1997, respectively. Saturation seems to be possible for the time, when all chlorine-containing refrigerants in systems are replaced, and some 800,000 reefer container units are in use. HFC-134a is conceived to peak in 2012, at 3,800 t; 404A might peak in

2016, at 640 t, if its share of 20% in annual consumption of HFC refrigerants continues to be stable.

Exchange of R-12 in existing refrigeration sets virtually did not take place. Thus, the time series for the 1990s does not need to be modified.

3. Collection and information sources of activity data (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

The data on annual numbers of new reefer containers was provided by the information service World Cargo News (UK), which periodically publishes the results of the World Container Census. Annually, these figures are also presented on the Internet (for the previous year), in "Containerhandbuch des Gesamtverbands der Deutschen Versicherungswirtschaft". Data on transition from CFCs to HFCs are based on written sources as well as on interviews with European experts from the world-market leader in container refrigeration, Carrier Transicold (Rotterdam), and with the German expert on the field of container refrigeration, Karl-Heinz-Hochhaus (TU Hamburg-Harburg). Experts from the leading German container line Hapag-Lloyd (Hamburg) gave information on refrigerant charges and on market shares of the refrigerants.

Personal Communications

Carrier Transicold, Rotterdam, www.container.carrier.com, 23.09.96, 23.09.96, 22.06.98, 12.09.02.

TU Hamburg-Harburg, Arbeitsbereich Hilfsmaschinen und Automation, 30.09.96; 06.12.96; 08.06.99, 12.09.02.

Verband Deutscher Reeder, Hamburg, 24.09.96.

World Cargo News June 2002: Jahresproduktion von Kühlcontainern 1990-2002 nach Größe und Typ www.worldcargonews.com/htm/n_wcn20030615.776248.htm

Yves Wild, Kühlcontainer und CA-Technik, in: Gesamtverband der Deutschen Versicherungswirtschaft (GDV), Berlin 2003: www.containerhandbuch. Darin www.containerhandbuch.de/chb/wild/index.html.

Hapag-Lloyd Container-Linie GmbH, Hamburg, 15.08.02, 02.10.02.

Written Sources

IICL report finds leasing industry getting greener, in: Container Management, November 1994, S. 29.

An end to cold fleet? (Steve Coulter), in: Container Management, November 1994, S. 33.

Hochhaus, K.H., Entwicklungen in der Kühlcontainer-Transporttechnik, in: euromodal (Basel), 1/94, S. 15-19.

Containerisation International, Sonderheft Market Analysis: More Cool Growth, January 1996, S. 29-32.

Dr. Yves Wild, Hamburg: Kühltransport und Kühllagerung unter Einsatz von "Kontrollierter Atmosphäre" (CA) und "Modifizierter Atmosphäre" (MA), http://www.tis-gdv.de/tis/vortraeg/wild/wild.htm

4. Factor of operation emissions from bank

Operation HFC emissions from refrigeration sets of reefer containers are estimated at 10%/y. This value is low compared to refrigerated road vehicles, which is attributable to the semi-hermetic and, increasingly, hermetic design of the compressor as well as to the lower mechanical stress on sea-ships.

5. Sources of information on emission factor (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

There are no systematic measurements of operating emissions available. Experts from the German shipping company Hapag-Lloyd estimated emissions from new refrigeration sets of reefer containers at 5%/y (for their own systems). They attribute this very low value to the hermetic design of the compressor, which is driven electrically from the on-board grid, as well as to little mechanical stress on sea-ships. However, taking into account ageing of refrigeration units over the lifetime of 15 years, the emission rate of 10%/y presented in the 2002 UNEP RTOC Assessment seems to be more appropriate. By Danish experts (Kauffeld/Christensen), even 20%/y was assumed in 1998. It should be kept in mind that in case of reefer containers country-specific emission factors are inappropriate, as the reference quantity for emissions is the worldwide container fleet.

Hapag-Lloyd Container-Linie GmbH, Hamburg, 15.08.02, 02.10.02.
Christoph Meurer/Winfried Schwarz: The "Fish Cold Chain" – Basic Ecological Evaluations. Presentation at the XXI IIR International congress of Refrigeration, August 17-22, 2003, Washington, DC.
Kauffeld, M., and Christensen, K.G.: A new energy-efficient reefer container concept using carbon dioxide as refrigerant. Proceedings of the IIR conference: Natural Working Fluids, Trondheim, 1998, pp. 1-10.
UNEP (United Nations Environment Programme); 2002 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC); Nairobi, January 2003.

6. Operating HFC emissions from bank (only German share)

Operating emissions in a particular year can be estimated by applying the emission factor (EF_{op}) to the average bank (B n) of that year. The bank itself has been built up over the past years by annual HFC inputs - see section 2:

$$EF_{op} \text{ (in \%)} \times B\ n$$

Because of the EF of 10% for HFC containing refrigeration sets of reefer containers the specific equation of operating emissions is as follows:

$$\text{Emissions } n = EF_{op} \text{ (10 \%)} \times B\ n$$

Table 5 presents annual operating HFC emissions from bank by refrigerant types in t/y. Please note that only the German share of 10% of the worldwide average bank as well as of operating emissions is listed.

Table 5: 1995-2002 German share (10%) in average bank and operating emissions from bank of 134a and 404A in worldwide reefer containers, in t/y				
	HFC-134a		HFC-404A	
	Average bank	Emission	Average bank	Emission
1995	31.7	3.17	-	-
1996	57.6	5.76	-	-
1997	84.7	8.47	1.02	0.10
1998	112.1	11.21	3.27	0.33
1999	138.7	13.87	5.92	0.59
2000	165.6	16.56	9.09	0.91
2001	192.5	19.25	12.76	1.28
2002	221.1	22.11	17.26	1.72

Comment

Operating emissions from the banks rose constantly in pace with the steady growth in average annual banks of both refrigerants. Provided the worldwide bank of 134a keeps rising until 2012 to more than 3,800 t and the bank of 404A increases until 2016 to more than 640 t, the 10% operating emissions attributable to Germany will peak at 38 t and 6.4 t, respectively.

7. Quality control and uncertainty assessment of data

Activity data. The basic statistical data from the World Container Census is robust, albeit the number of units generally is rounded up or down to the next 500. Transition from CFCs to HFCs over the 1993-1996 period has been well examined. Nevertheless, in individual years the effective HFC-share might amount to 10% more or less than indicated. Several experts involved estimated the market share of 404A compared to 134a in unison. The charges of refrigeration sets are mean values, which may deviate from the true values by ±10% at most. All these data (especially charges and market shares of the refrigerants) should be reviewed periodically in the future, as they are subject to changes.

Emission factor. The Hapag-Lloyd experts interviewed about emission factors count amongst the most competent specialists in Germany without doubt. Up to now, values other than "5% at the maximum" have not been mentioned anywhere else for German shipping companies. This value is based on actual top-ups, which were partly recorded (company-internally). Because emissions in question, however, are in principle emissions of the worldwide fleet, country-specific emission factors do not matter here. No doubt, UNEP experts are rightly to be expected to provide data reliable under a worldwide aspect.

8. Relation to IPCC method

In IPCC manual GPG, recommendations refer exclusively to road vehicles transport refrigeration. In principle, ÖR estimates country-specific data in the frame of a bottom-up approach. This, however, makes no sense for emission factors of refrigerated containers because reference quantity is the worldwide fleet, not the national one. IPCC GPG does not propose any default values for refrigerated containers.

9. Entry in CRF

The CRF Table to enter data on "Average annual stocks" and "Emissions from stocks" is Table 2(II).Fs1, row 30 for 134a and rows 35-38 for 404A. The columns in question are C and I.

10. Remark on filling emissions and domestic HFC consumption

In Germany, neither refrigerated containers nor special refrigeration sets are manufactured/first-filled. Refrigerated containers come more than 80% from China and just 15% from Europe outside Germany. This is why emissions from first filling do not occur domestically. The conceivable approach, to attribute filling losses, like operating emissions, to individual countries, according to their shares in world trade, has been rejected because of the very small quantities in question and, additionally, the dubiousness of such an approach. Different from operating emissions, manufacturing emissions are clearly attributable to particular countries.

F-Gas-Sheet 3: Domestic Heat Pumps

F-Gases	**HFC-134a, HFC-404A, HFC-407C, HFC-410A**
Application	**Domestic Heat Pumps**
Reported Years	**1995 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**

Background

By means of an electrically driven refrigeration cycle heat pumps produce useful heat from ambient heat. The refrigerant absorbs ambient heat of low temperature and changes it to heat of higher temperature. According to the energy sources used, there are three different categories of heat pumps for heating: The most frequent systems obtain energy stored in the ground by means of brine (ground/water). They work similar to systems obtaining energy stored in the ground water (water/water). The third way to obtain heat is the use of energy in the ambient inside or outside air (air/water).

Heat pumps are predominantly used for heating one-family and apartment houses. Although this heating system is gaining in importance, it is not widely used yet.

Apart from heating, heat pumps can also be used for simple hot water supply. In this case, mostly the energy provided in the air is used to heat up water.

In Germany, there are some 20 manufacturers of heat pumps. They are using four different HFC refrigerants and to a certain part propane (R-290).

I. Bank and operating emissions from bank

1 Activity data I. Domestic HFC-input

1.A Annual domestic sales of heat pumps by energy source

The Federal Association Heat Pump (BWP) annually publishes the number of new domestically installed heat pumps by type and energy source, as far as sold by member companies. Table 1 shows these numbers after extrapolation, with the BWP members representing 90% of the total market.

Table 1: 1995-2002 Domestic sales of heat pumps, in units

Type	1995	1996	1997	1998	1999	2000	2001	2002
1. Hot water HP	3,111	3,333	3,889	4,111	4,444	4,778	5,000	4,536
2. Heating-HP - Air	556	576	768	719	860	1,103	1,736	1,693
3. Heating-HP - Water	222	303	647	627	597	660	1,376	1,599
4. Heating-HP - Ground	1,667	1,688	2,563	3,507	3,787	4,610	6,017	5,959
Number of units total	5,556	5,900	7,867	8,963	9,688	11,151	14,128	13,787

Sources: Bundesverband Wärmepumpe (BWP), München. Extrapolation from 90% to 100%.

As of 1995, the first year of general use of chlorine-free refrigerants (apart from some remainder of HCFC-22), domestic sales of all four heat pump types had been growing constantly. For the first time, there was a drop in sales in 2002, which the BWP put down to falling building-activity.

1.B The refrigerant model for heat pumps

In order to determine domestic refrigerant input from 1995 onwards a model is used, which has been elaborated with the assistance of sector experts (Table 2). This model shows for three categories of heat pumps (systems with energy source ground and ground water are subsumed under one heading) the charges (in case of HFCs) as well as the refrigerant types used by percentage shares.

Table 2: Typical refrigerants in heat pumps by charges, shares, and years

Type	1. HotW-HP	2. Heating-HP Air			3. Heating-HP Ground/Water				
Charge	0.8 kg	3.0 kg (when HFC)			1.9 kg (when HFC)				
Refriger	134a	404A	407C	R-290	407C	410A	404A	134a	R-290
1995	100%	48%	48%	4%	15%	-	5%	5%	50%
1996	100%	48%	48%	4%	20%	-	5%	5%	60%
1997	100%	48%	48%	4%	20%	-	5%	5%	70%
1998	100%	48%	48%	4%	35%	15%	5%	5%	40%
1999	100%	48%	48%	4%	45%	15%	5%	5%	30%
2000	100%	48%	48%	4%	55%	15%	5%	5%	20%
2001	100%	48%	48%	4%	60%	15%	5%	5%	15%
2002	100%	48%	48%	4%	60%	15%	5%	5%	15%

Sources: See section 2 (sources of information). The model here presented traces back to Kai Schiefelbein (Working group techniques in BWP) to a high extent.

<u>Explanation</u>: R-290 is the term for propane as a refrigerant. In 1995 and 1996, the sum of the refrigerant shares for type 3 is less than 100%, because a remainder was held by HCFC-22.

1.C Annual HFC input through new domestic heat pumps

The annual input (In_{bank}) of a particular refrigerant in year n is arrived at in two steps. Firstly by weighting the number of units of a particular heat pump type in year n (Table 1) with the percentage share of the refrigerant for the respective type – according to Table 2, line "refrigerant". Secondly, by multiplication of the refrigerant-weighted number of units by the attributed charge in kg – according to Table 2, line "charge". From this, the HFC input can be derived as shown in Table 3.

Table 3: 1995-2002 HFC input through domestically installed new heat pumps, t/y

	HFC-134a	HFC-404A	HFC-407C	HFC-410A
1995	2.7	1.0	1.3	- *
1996	2.9	1.0	1.6	- *
1997	3.4	1.4	2.3	- *
1998	3.7	1.4	3.8	1.2
1999	4.0	1.7	5.0	1.2
2000	4.3	2.1	7.1	1.5
2001	4.7	3.2	10.9	2.1
2002	4.3	3.2	11.1	2.2

Sources: Number of units as per Table 1. Refrigerant shares and charges as per Table 2.
* In these years, 410A was not used yet, instead of it, however, more propane (R-290).

2. The HFC bank in heat pumps

The HFC end-of-year bank in year n (EB n) in domestic heat pumps increases by the next annual domestic input (In_{bank} n+1), as long as no considerable departures occur, which is not yet systematically the case in the face of a 15-year-lifetime.
The average annual bank (B n) is half the sum of the last year's end-of-year bank (EB n-1) and the current year's end-of-year bank (EB n). This is the equation:

$$B\,n = \frac{EB\,n\text{-}1 + EB\,n}{2} \qquad \text{Where:} \quad EB\,n = EB\,n\text{-}1 + In_{bank}\,n$$

The average annual bank (B n) exhibits the following time series (Table 4):

Table 4: 1995-2002 Average annual HFC bank (B n) in heat pumps, in t/y

	HFC-134a	HFC-404A	HFC-407C	HFC-410A
1995	1.3	0.5	0.7	-
1996	4.1	1.5	2.1	-
1997	7.2	2.7	4.1	-
1998	10.8	4.1	7.1	0.6
1999	14.6	5.7	11.5	1.8
2000	18.8	7.5	17.6	3.2
2001	23.3	10.2	26.2	5.0
2002	27.8	13.4	37.6	7.1

Sources: Table 3 and the equation in this section.

Comment on time series of activity data I

The input of HFC-134a, which is used 95% for hot water heat pumps, steadily grew in accordance with the overall trend until 2001, after then it dropped slightly.

Consequently, the bank has grown constantly. Similar can be said about 404A, which is mainly used in air-based heat pumps for heating. The input of 407C has experienced a marked acceleration since 1998. From 1999 onwards, it has been the strongest refrigerant on the market; from 2001 onwards, it is the strongest refrigerant in the bank, too. The background is the collapse of propane (R-290), which had lost three quarters of its 1997 market share of 70% in ground/groundwater heat pumps by 2001. 407C and – to a lesser degree – 410A have overtaken its shares (cf. Table 2).

Replacement of R-12 in existing plants did virtually not occur in the field of heat pumps, because long before 1995 HCFC-22 had been the standard refrigerant.

Compared with other applications, HFC input and bank in heat pumps are not large. The overall bank of the four HFC refrigerants amounted in 2002 to 86 t, filled in 77,000 HFC containing systems. Under the assumption of constantly high growth rates of 3% for heating heat pumps and of 2% for hot water heat pumps, in 2020 about 280,000 systems will be installed with an HFC bank of 420 t, thereof 220 t 407C.

3. Collection of activity data and sources of information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

The annual number of units trace back to reports of member companies to the BWP. Data on charges and shares of the refrigerants in the different heat pump segments have been provided for the refrigerant model by direct interviews with experts from the six leading German manufacturers. Information on transition from CFC/HCFC to chlorine-free refrigerants and on the difficulties of propane originates from direct enquiries having been conducted since 1995.

KKW Kulmbacher Klimageräte-Werk GmbH, Kulmbach, 04.04.95, 13.06.96, 19.03.99, 18.11.03.
Brandt Group Hausgeräte GmbH (Blomberg), Ahlen, 19.03.99; 23.10.02, 12.06.96; 19.11.03.
Waterkotte Wärmepumpen GmbH, Herne, 21.10.02.
Stiebel-Eltron GmbH & Co. KG, Holzminden, 19.03.99, 21.10.02, 18.11.03.
Alpha-InnoTec GmbH, Kasendorf, 19.11.03.
HAUTEC AG, Bedburg-Hau, 19.11.03.
Bundesverband WärmePumpe (BWP) e.V. (vorm. Initiativkreis WärmePumpe e.V.), http://www.waermepumpe-bwp.de München, 21.10.02, 18.11.03, 21.11.03.

4. Factors of operating emissions from bank

Operating HFC emissions from heat pumps for heating are estimated at 2.5% per year. The EF_{op} of heat pumps for hot water supply is somewhat lower, with 2.0%.

5. Sources of information on emission factors (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

For a long time the only published emission factors had been 2.5% for heating heat pumps and 1.5% for hot water systems. These values date back to a direct enquiry carried out by ÖR in 1995, which was published in a Greenpeace study, and was adopted the same year by the status report for the Umweltbundesamt "Ersatz von R-12" ("Replacement of R-12").

In 2003, these figures were subject to an expert review. Among others, the fruitful interview with Dr. Kai Schiefelbein (Stiebel-Eltron and Working group techniques with

BWP) should be pointed out. Five years long, he had evaluated customer-service records with respect to causes and quantities of topping-up. He arrived at a value of 1% for gradual and service-induced emissions and of additional 1% for emissions from individual breakdowns.

Schiefelbein takes 2.5% adequate for the totality of the installed heat pumps, so that this value should be used further. From manufacturers of heat pumps for hot water supply a higher leak-tightness was claimed for these systems, which do not even have any service connections as potential sources of refrigerant loss. Considering this fact, the emission rate of heat pumps for hot water supply is assessed at 2.0% and thus by 0.5% lower.

KKW Kulmbacher Klimageräte-Werk GmbH, Kulmbach, 04.04.95; 19.03.99.
Öko-Recherche: No "all-clear" for ozone and climate. 1995 German consumption forecast for CFCs, HCFCs and HFCs (in German), Study for Greenpeace e.V. Hamburg, S. 14. http://www.oekorecherche.de/english/berichte/volltext/keine-entwarnung.pdf
FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz von R 12 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, im Auftrag des Umweltbundesamtes, Statusbericht im Auftrag des Umweltbundesamtes, Berlin, Hannover, November 1995. S. 96.
Arbeitsgruppe Technik im BWP, Dr. Kai Schiefelbein, 18.11.03.
Brandt Group Hausgeräte GmbH (Blomberg), Ahlen, 19.11.03.

6. Operating HFC emissions from bank

Operating emissions in a particular year can be estimated by applying the emission factor (EF_{op}) to the average bank (B n) of that year. The bank itself has been built up over the past years by a number of annual HFC inputs (cf. section 2):

$$EF_{op}\ (\text{in }\%) \quad \times \quad B\ n$$

Because of EF 2.5% for heating heat pumps, the specific equation for operating emissions is:

$$EF_{op}\ (2.5\ \%) \quad \times \quad B\ n$$

EF of 2.0% applies to heat pumps for hot water supply (only 134a). For simplicity, the same emission factor applies to the few heating heat pumps with HFC-134a.

Table 5 shows annual HFC emissions from the average bank by refrigerants in t/y.

Table 5: 1995-2002 Operation HFC emissions from banks in heat pumps, in t/y

	HFC-134a	HFC-404A	HFC-407C	HFC-410A
1995	0.03	0.01	0.02	-
1996	0.1	0.04	0.05	-
1997	0.1	0.07	0.1	-
1998	0.2	0.1	0.2	0.01
1999	0.3	0.1	0.3	0.05
2000	0.4	0.2	0.4	0.1
2001	0.5	0.3	0.7	0.1
2002	0.6	0.3	0.9	0.2

Sources: Operating emission factors (2.5%/2%) related to the figures in Table 4.

Comment

Operating emissions from banks totalled 2.0 t in 2002. Simultaneously with the steady rise in average banks of 134a and 404A, emissions increased evenly, whereas in 407C and 410A a rapid development of emissions can be seen. The overall level of emissions is rather low, compared to other refrigerant applications. Should the bank grow to 420 t by 2020, the then emissions would total some 10 tonnes.

7. Quality control and uncertainty assessment of data I

Activity data. The basic statistical data of the BWP can be judged robust like any data based on sales records. The extrapolation made by ÖR from 90% market share represented by BWP to 100% cannot fail the effective values considerably. The uncertainties of the model-integrated data on charges and refrigerants by heat pump types should be seen in the range of ± 10% in the face of the sector's real variety. The transition period from chlorine containing to chlorine-free refrigerants as well as the changing shares of propane are well documented by expert interviews. Errors are to be situated within a range of ± 10% of indicated quantities.

Emission factors. The EF for heat pumps was confirmed in 2003. It is deemed certain. The estimation method is of high quality, because it is based on real field-observations over a 5-year-period, in addition to expert judgements. Moreover, it distinguishes between regular and irregular refrigerant loss, a very fruitful distinction that researchers had not made before recent time. An emission bonus of 0.5% for heat pumps for hot water supply seems to be justified.

8. Relation to IPCC method I

IPCC manual GPG provides for heat pumps under "stationary refrigeration" (3.7.4) best estimates for lifetime emissions which range "between 1 and 5 percent" (Table 3.22, A/C including Heat Pumps). The 2.5% country-specific value by ÖR is localized in the centre of these expert judgements.

9. Entry in CRF I

The CRF-Table where data on "Average annual stocks" and "Emissions from stocks" are primarily entered is Table 2(II).Fs1. To date, 134a is entered in row 71, 407C in rows 72-75, 404A in rows 76-79, 410A in rows 80-82. The columns are C and I.

II. Domestic HFC consumption and manufacturing emissions

10. Activity data II

CRF calls for estimation of consumption for domestic manufacturing (C_{manu}) and for HFC emissions arising on that. Consumption does not correspond to domestically installed, but to domestically manufactured systems, on which statistical data open to the public, are not available.

The sector experts interviewed in 2003 (see Part I, 2) were asked for estimates of the number by which domestically manufactured heat pumps exceed the (published) domestic sales. (Germany is a net exporter, and imports are of secondary importance). The answers given to ÖR come almost consistently with each other down to a factor of 1.5 for each of the four heat pump categories. This means that in line with the estimations the quantity of manufactured heat pumps in each of the four segments amounts to the 1.5 fold of the number of domestically sold systems.

Thus, from the line "number of units, total" in Table 1 (Part I) a rough estimation of annually manufactured heat pumps can be derived. It needs to be taken care to exclude from that Table those systems that work with propane or HCFC-22. The result of this exercise can be seen in Table 6, line 1.

11. Factor of filling emissions

The interviewed experts (see Part I. 2) indicated either 1 or 2 grams as filling loss per heat pump irrespectively of the type and the charge. In automatic filling (which is common practice), from a filling hose the HFC content does not escape in that the hose end closes of itself when being withdrawn (the coupling cannot be removed unless the cut-off valve is closed). Nevertheless, a partial quantity from inside the service coupling is released. ÖR estimates this loss at two grams, because apart from these small hose-losses there are some more sources of gas loss in a factory (storage tanks, interim containers, etc.).

12. Filling emissions in kg

In addition to the number of domestically manufactured HFC-containing heat pumps, Table 6 shows the specific loss per system in grams (generally 2 grams) and in the bottom line the filling emissions in kg per year. These emissions range between 12.4 kg (minimum) and 38.9 kg (maximum).

Table 6: 1995-2002 Domestic production of heat pumps and filling losses, per system and in total, in kg

	1995	1996	1997	1998	1999	2000	2001	2002
Heat Pumps number	6,175	6,725	8,383	10,922	12,508	15,079	19,428	18,878
Loss per system in g	2	2	2	2	2	2	2	2
Filling emissions in kg	12.4	13.5	16.8	21.8	25.0	30.2	38.9	37.8

13. Filling emissions by refrigerants, and in relation to HFC consumption

CRF additionally requires a breakdown of refrigerant emissions into HFC types and for a relation of these emissions to the quantity consumed for manufacturing (Table 7).

Firstly, by means of Table 2 (Part I) the manufactured heat pumps are compiled by refrigerants and by years of manufacture. Systems with R-290 and R-22 are excluded. The multiplication of the number of HFC systems by two grams gives the filling loss. This refrigerant-specific loss is entered in Table 7 in the right columns (Loss g).

The left columns in Table 7 show under "C_{manu} kg" the consumption per refrigerant. This figures are calculated by means of the equation "In_{bank} (as per Table 3) times 1.5", where 1.5 is a factor expressing the quantitative relation of domestically manufactured to domestically installed heat pumps (Part II, section 10), which ÖR was given by sector experts.

Table 7: 1995-2002 HFC consumption for manufacturing (C_{manu}) of heat pumps, in kg, and filling loss, in g

	1. HFC-134a		2. HFC-404A		3. HFC-407C		4. HFC-410A	
	C_{manu} kg	Loss g	C_{manu} kg	Loss g	C_{manu} kg	Loss g	C_{manu} kg	Loss g
1995	4,003	6,412	1,469	722	2,008	550	-	-
1996	4,284	6,866	1,527	752	2,378	674	-	-
1997	5,124	8,098	2,116	1,058	3,488	1,011	-	-
1998	5,522	8,636	2,142	1,104	5,676	1,792	1,767	1,240
1999	5,958	9,328	2,482	1,264	7,479	2,385	1,874	1,316
2000	6,484	10,082	3,134	1,586	10,644	3,428	2,253	1,582
2001	7,053	10,740	4,802	2,406	16,390	5,268	3,160	2,218
2002	6,520	9,926	4,735	2,382	16,581	5,347	3,231	2,268

Notice: Consumption (C_{manu}) is measured in kilograms, filling loss in grams.

14. Implied emission factors of filling

After calculation of filling loss in grams (Loss g), the latter can be placed to the HFC quantity consumed for manufacturing (C_{manu}). This results in the implied emission factors, ranging in the order of magnitude of from approx. 0.15% (for small systems with 134a) to 0.05% (for larger systems with 404A).

15. Quality control and uncertainty assessment of data II

Safety of activity data on domestic filling is mainly based on safety of data that operating emissions are based on. This issue has already been discussed. New uncertainties arise from the fact that the number of domestically manufactured heat pumps is not only based on surveys or reports, but depends to a large degree on expert judgements regarding the production-factor of 1.5.

The emission factor (EF_{manu}) of two grams per system, however, is a reliable value, which is also reported from mobile air conditioners. It should be mentioned that emissions are not estimated as linear functions of consumed quantities, but as constant figures per filled system.

16. Relation to IPCC method II

There are "best estimates" in Table 3.22 (IPCC GPG) for the estimation of "initial emission" in percentage of the initial charge. They range between 0.2 and 1 percent. Country-specific data of ÖR of from 0.15 to 0.05% are situated below the range of those best estimates, which go back to the expert Denis Clodic (1999).

Incidentally, the ÖR value is no percentage of the initial charge, but a constant loss of two grams per system. This value is seen more realistic as filling loss is no linear function of charge.

17. Entry in CRF II

The CRF Table where "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered is Table 2(II).Fs1. To date, 134a has been entered in row 71, 407C in rows 72-75, 404A in rows 76-79, and 410A in rows 80-82. The respective columns are B and H.

F-Gas-Sheet 4: Domestic Refrigerators and Freezers

F-Gas	**HFC-134a**
Application	**Domestic Refrigerators and Freezers**
Reported Years	**1995 - 2002**
Emission Type 4	**Operating Emissions from Bank**

Background

Replacement of CFC-12 by HFC-134a in household refrigerators and freezers started in the late 1993s, but did not last a long time. Because of intensive efforts triggered by Greenpeace, still in 1994 the German manufacturers switched over to iso-butane (R-600a) as new and general refrigerant. Since then, the German manufacturers have been using only this refrigerant.

In other European and in North-American countries this second replacement has not taken place, at least not within such a short time frame. According to investigations carried out by Greenpeace, it can be said that annually at least one percent of the domestically sold household refrigerators and freezers (sales per year average at 4 million units) are imported appliances running on HFC-134a.

This applies to simple models (just one star) as well as to large models (refrigerator-freezer-combinations with two front doors).

Given an average appliance filling of 0.1 kg, the annual HFC quantity imported through some 40,000 household refrigerators and freezers is of minor importance.

Bank and operating emissions from bank

1 Activity data. Annual domestic HFC input

Due to the fact that from 1995 onwards filling with HFC-134a occurs solely abroad, neither domestic consumption (C_{manu}) nor domestic manufacturing emissions (Em_{manu}) need to be estimated. Since 1995, HFCs in imported appliances must be understood as input to domestic HFC bank (In_{bank}). The bank increases by the amount of this input, as long as considerable HFC quantities are not disposed of, which is not expected to happen before 2005.

Table 1 shows to the left the annual HFC input since 1993 (before 1995 mainly from domestic manufacture), and to the right the average annual bank, which is easy to determine because of the constant input figures. The average bank of a particular year (B n) is half the sum of the last year's end-of-year bank (EB n-1) and the current year's end-of-year bank (EB n). The equation is as follows:

$$B\ n = \frac{EB\ n\text{-}1 + EB\ n}{2} \qquad \text{Where:} \quad EB\ n = EB\ n\text{-}1 + In_{bank}\ n$$

Table 1: 1993-2002 HFC-134a input and average HFC-134a bank in household refrigerators and freezers

	Annual input in t/y	Average bank in t
1993	2	1
1994	400	202
1995	4	404
1996	4	408
1997	4	412
1998	4	416
1999	4	420
2000	4	424
2001	4	428
2002	4	432

Sources: See section 2.

2. Collection of activity data and sources of information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

The annual number of roughly 40,000 household refrigerating appliances goes back to information given by Greenpeace Germany ("Greenfreeze-Group"), who were periodically carrying out inspections in large department stores in addition to interviews with the big four German manufacturers (Bosch-Siemens-Hausgeräte, Liebherr, AEG, Foron).

At the beginning of 2004, the manufacturer Liebherr confirmed the Greenpeace estimation of one percent market share for HFC containing appliances.

Greenpeace Deutschland, Hamburg, lfd., Greenpeace-Kühlschrankgruppe, Kühlschrank-Recherche für Hamburg, 19.02.00.
Liebherr Machines Bulle S.A, Bulle (Switzerland), 05.03.04.

ILK Dresden/FKW Hannover, Aktuelle TEWI-Betrachtung von Kälteanlagen mit HFKW- und PFKW-Kältemitteln unter Berücksichtigung der unterschiedlichen Rahmenbedingungen für verschiedene Anwendungsgebiete, im Auftrag des Forschungsrats Kältetechnik e.V., FKT 96/03, Frankfurt, November 2003.

3. Factor of operating emissions from bank

Operating HFC emissions from household refrigerators and freezers are estimated at 0.3% per year.

4. Sources of information on the emission factor

Publications about emissions from household refrigerating appliances date back to the mid 1990s. In 1993 Lotz, himself being a member of a German manufacturer's senior staff estimated emissions optimistically at just 0.15% (for R-12 and R-134a). Incidentally, he estimated the lifetime at 20 years.

In 1995, the FKW-Hannover assumed an emission rate of 0.36% (20 t emission from 5,500 t bank) for R-12 appliances. In all likelihood, emissions are somewhat lower in case of HFC-134a. Therefore, ÖR has calculated with a rate of 0.3%, not including the rather high disposal emissions on scrapping.

Hans Lotz, Beitrag der deutschen Kälte-, Klima- und Wärmepumpentechnik zur Verringerung der Treibhausbelastung bis zum Jahre 2005, DKV-Statusbericht Nr. 13, Stuttgart, April 1993.
FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz von R 12 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, im Auftrag des Umweltbundesamtes, Statusbericht im Auftrag des Umweltbundesamtes, Berlin, Hannover, November 1995. S. 96.

5. Operating HFC emissions from bank

Operating emissions in a particular year n are arrived at by applying the factor of operating emissions (EF_{op}) to the average bank of year n (B n), which itself has been built up by a number of preceding annual inputs to the bank (In_{bank}) - see section 1:

$$EF_{op} \text{ (in \%)} \quad \times \quad B\ n$$

Because of the EF of 0.3% for household refrigerators and freezers, the specific equation of operating emissions is:

$$EF_{op} \text{ (0.3 \%)} \quad \times \quad B\ n$$

Table 2 presents annual HFC emissions from the average bank in household appliances.

Table 2: 1995-2002 Operating HFC-134a emissions from bank in household refrigerators and freezers, in t/y

	1995	1996	1997	1998	1999	2000	2001	2002
Emissions in t/y	1.21	1.22	1.24	1.25	1.26	1.27	1.28	1.30

Sources: EF_{op} (0.3%) related to the banks as per Table 1.

Comment

The overall operating emissions from household refrigerating appliances are low. More than 90% of today's emissions go back to refrigerant stocks that had been built up before 1995.

6. Quality control and uncertainty assessment of data

Activity data. The estimation of roughly 40,000 HFC containing appliances being imported annually can be considered robust, the more so as this number originates from several sources of information.

Emission rate. Results from measurements on household appliances are not available. The value of 0.3%, however, seems to be close to reality, if a margin of error of ± 0.1% is made allowance for.

7. Relation to IPCC method

The IPCC manual GPG provides in Table 3.22 best estimates for lifetime emissions from "domestic refrigeration", which range between 0.1 and 0.5 percent. The value of 0.3%, which is used by ÖR, is within the scope of that estimation.

8. Entry in CRF

The CRF Table where figures on "Average annual stocks" and "Emissions from stocks" for domestic refrigeration are primarily entered is Table 2(II).Fs1, row 12, columns C and I.

F-Gas-Sheet 5: Stationary Air Conditioning

F-Gases	**HFC-134a, HFC-407C**
Application	**Stationary Air Conditioning**
Reported Years	**1995 – 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**

Background

Inside buildings, stationary air-conditioning can provide comfortable temperatures at any time. For single rooms or even single storeys, room air conditioners (RAC) with directly evaporating refrigerant may be sufficient. However, for air-conditioning of whole buildings (department stores, factories, hotels) or large halls (cinemas, sports complexes, computer centres) mostly centrally positioned systems are used which work the indirect way: The refrigeration circuit cools a liquid (mostly water) down to + 5 or + 6°C, which is pipelined through the building as a coolant. Such systems are called liquid chillers.

Stationary systems of air-conditioning can be discerned by three compressor types, which on their part are typical of particular refrigerating capacities. The topmost region of refrigerating performance (from 700 kW to three MW) is dominated by centrifugal compressor chillers. For medium performance (from 200 to 1,000 kW), mainly systems with screw compressors are used. In the range of 20 to 200 kW, systems with reciprocating and – increasingly – scroll compressors prevail. Underneath is the area of application of so-called room air conditioners, RACs - see special F-Gas sheet.

The vast majority of stationary systems are liquid chillers cooling the indirect way. Directly evaporating systems, however, are also common, particularly in the performance range below 200 kW, where direct systems account for almost 30%.

Today the most important HFC for stationary air-conditioning is the blend 407C. However, centrifugal compressor chillers exclusively use HFC-134a. For technical and physical reasons they can only run with single-component refrigerants.

I. Domestic HFC consumption and manufacturing emissions

1 Activity data I. Annual domestic HFC consumption

Systems of stationary air-conditioning above the performance range of RACs, i.e. above 20 kW, are assembled on site. Admittedly, there are very large systems, above all centrifugal compressor based chillers, which are being manufactured for the world market on a large scale outside Germany. Indeed, this manufacturing is rather a pre-assembly that shortens the final on-site assembly including the connection to the cold-liquid circulation, but cannot replace it. The refrigerant is first filled-in on site, anyway. That means there is no need to consider foreign trade with HFC containing systems. This is why domestic HFC consumption (C_{manu}) is the same size as HFC input to the domestic HFC bank (In_{bank}). The latter (input) is only a little bit lower than the former (consumption), namely by the amount of manufacturing emissions (Em_{manu}). This is generally the case with any refrigeration or air-conditioning system.

1.A Annually new-installed systems of stationary air-conditioning

Expert interviews provided the number of new installed systems of stationary air-conditioning (without RACs) as of 1993. Three types of compressors they are driven with distinguish these: Centrifugal compressors (700-3000 kW), screw compressors (200-1000 kW), and reciprocating or scroll compressors (20 - 200 kW). The number of units is shown in Table 1.

Table 1: 1993-2002 Number of new installed stationary HFC air-conditioning systems above 20 kW refrigerating capacity, by compressor type

Compressor type	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. Centrifugal	10	50	100	100	100	100	100	100	100	100
2. Screw	83	166	248	330	423	550	688	825	865	865
3. Scroll/Recip	n.o.	n.o.	420	420	430	1.540	2,660	4,200	4,325	4,433
Total	93	216	768	850	953	2,190	3,448	5,125	5,290	5,398

Sources: Sector experts. Explanation of performance ranges: Centrifugals >700 kW; screws 200-1000 kW; scrolls and recips: 20-200 kW. The low values before 1997 and the indication "n.o." (not occurring) result from the prolonged use of non-HFC refrigerants, above all HCFC-22 and HCFC-123.

1.B The refrigerant model for stationary air conditioning

In order to determine domestic refrigerant consumption since 1993, with the help of sector experts a model (Table 2) was elaborated, which contains for each of the three categories (compressor designs) of air-conditioning systems both the average refrigerant charge and the typically used refrigerant (by percentages).

Table 2: Typical HFC refrigerants in stationary air-conditioning by average charge, percentage and years (1993-2002)					
Design	1. Centrifugal compressor	2. Screw compressor		3. Scroll and reciprocating compressor	
Charge	500 kg [1000 kW]	160 kg [400 kW]		27 kg [120 kW]	
Refrigerant	R-134a	R-134a	R-407C	R-134a	R-407C
1993	100%	100%	-	-	-
1994	100%	100%	-	-	-
1995	100%	100%	-	100%	-
1996	100%	100%	-	100%	-
1997	100%	97.64%	2.36%	97.67%	2.33%
1998	100%	72.73%	27.27%	27.27%	72.73%
1999	100%	50.00%	50.00%	15.79%	84.21%
2000	100%	50.00%	50.00%	10.00%	90.00%
2001	100%	33.33%	66.67%	10.00%	90.00%
2002	100%	33.33%	66.67%	10.00%	90.00%

Sources: see section 3. Explanation: Percentages refer only to the actually used HFC refrigerants, not to the total of halogenated refrigerants. Up to 1999, HCFCs (22, 123) were filled into new systems, particularly into reciprocating and scroll systems.

1.C Annual HFC consumption for new systems of stationary air-conditioning

The annual consumption (C_{manu}) of a particular refrigerant in year n is achieved in two steps: Firstly, multiply the number of a particular system of stationary air-conditioning (Table 1) by the respective charge in kg – as per Table 2, line "charge". Further, multiply this product by the refrigerant percentage for the respective system in year n – likewise according to Table 2. This exercise results in the HFC consumption listed in Table 3.

Table 3: 1993-2002 HFC consumption for new systems of stationary air-conditioning, in t/y		
	HFC-134a	HFC-407C
1993	18.3	-
1994	51.6	-
1995	101.0	-
1996	114.1	-
1997	127.4	1.9
1998	125.3	54.2
1999	116.4	115.5
2000	127.3	168.1
2001	107.8	197.4
2002	108.1	200.0

Sources: Number of units as per Table 1. Refrigerant percentages and charges as per Table 2. Empty columns (-) mean that the refrigerant (407C) was not yet in use.

1.D Domestic consumption of HFC-134a for old systems, 1995-1998

Following the CFC-Halon Ban Ordinance, between 1995 and 1998 a considerable number of centrifugal chillers (some 700) were retrofitted from CFC-12 to HFC-134a. In addition, centrifugal chillers with CFC-11 (running at low pressure below the atmospheric pressure) were retrofitted, albeit predominantly to HCFC-123. (The other stationary air-conditioning systems with screw, scroll, and reciprocating compressors hardly contained fully halogenated CFCs). The estimations of the above Table 3 take only account of new-installed systems, so that they exclude CFC replacement by HFCs in old systems. According to an Umweltbundesamt study (Öko-Recherche 1998), roughly 350 tonnes of HFC-134a were additionally used for old air-conditioning systems over those four years.

Table 4 presents the number of centrifugal chillers that were retrofitted in 1995-1998 and, additionally, the quantity of HFC-134a that was consumed to fill those old systems.

Table 4: 1995-98 Consumption of HFC-134a for retrofitted centrifugal chillers, in t/y			
	Retrofit cases	134a per case in t	Consumption 134a in t/y
1995	100	0.5	50
1996	200	0.5	100
1997	200	0.5	100
1998	200	0.5	100

Sources: Öko-Recherche 1998.

By adding the HFC consumption for new installed stationary A/C systems (as of 1993, as per Table 3) to the HFC consumption for old systems (1995-1998, as per Table 4), the total HFC consumption over the 1993-2002 period is arrived at (Table 5).

1.E Total HFC consumption for old and new air-conditioning systems

Table 5: 1993-2002 Total HFC consumption for old and new stationary air conditioning systems, in t/y		
	HFC-134a	HFC-407C
1993	18.3	-
1994	51.6	-
1995	**151.0**	-
1996	**214.1**	-
1997	**227.4**	1.9
1998	**225.3**	54.2
1999	116.4	115.5
2000	127.3	168.1
2001	107.8	197.4
2002	108.1	200.0

Sources: Tables 3 and 4. Alterations in respect to Table 3 are shown in bold type.

Table 5 differs from Table 3 in the lines of the years from 1995 to 1998, i.e. only in column "HFC-134a". Here, additionally the consumption for replacing CFC-12 is taken into account.

Comment

Since 1992, which is the first year of the CFC ban for new stationary plants with more than 5 kg refrigerant charge, HFCs are in use. The rise in new HFC systems, however, was rather slow over the first years. Only from 2000 onwards, new systems have been assembled in a constant annual number of over 5,000. Main reason for this delay was the prolonged use of HCFC-22, particularly in scroll and reciprocating compressor systems, to a certain degree in screw systems. It was the use of 407C, which provided an upswing in favour of HFCs as of 1999.

The early CFC ban affected in the first line centrifugal chillers, which ran on CFC-11 and CFC-12 before 1992. From 1992 to 1995, there was no clear guidance for manufacturers which refrigerant to use. First, the Umweltbundesamt announcement on CFC-12 replacement at the end of the year 1995 changed the situation. However, in between many a new system was built, which made use of the refrigerants HCFC-123 or ammonia or, in the case of absorption chillers, used another technology, when eventually HFC-134a became the main refrigerant in this application.

2. Emissions on filling of stationary air-conditioning systems

Though filling emissions (Em_{manu}) in case of refrigeration or air-conditioning plants are generally low, CRF requires their estimation from 1995 onwards.

2.1 Filling emission factor

Considering the variety of system sizes, the average refrigerant loss per filling amounts to some 20 grams, i.e. per system being filled (EF_{manu} = 20 g/system).

With 20 to 1,000 kg, the refrigerant charges per system are large, so that mostly an array of refrigerant containers is necessary for filling. This is why on filling one system small losses from the filling hose and valves occur several times and add up each other.

2.2 Number of annually filled systems by HFC refrigerant

In Table 1, the number of annually new installed systems was not yet subdivided by refrigerants. This division is presented in Table 6. The number of retrofitted old systems shown in Table 4 is included here.

Table 6: 1995-2002 Number of stationary air-conditioning systems filled with HFCs the first time, by refrigerants

Year	HFC-134a			HFC-407C
	New systems	Retrofitted systems	All systems	New systems
1995	768	100	868	-
1996	850	200	1,050	-
1997	933	200	1,133	20
1998	920	200	1,120	1,270
1999	864	-	864	2,584
2000	933	-	933	4,193
2001	821	-	821	4,469
2002	832	-	832	4,566

In Table 7, the emission factor (EF_{manu}) of 20 grams per system is multiplied by the number of systems, separately for 134a and 407C. The two columns to the right show the resulting figures of filling emissions of 134a and 407C in kg per year.

Table 7: 1995 to 2002 Filling loss per system, filled systems, and filling emissions by refrigerant 134a and 407C					
Year	Loss in g per system	Systems 134a Number	Systems 407C Number	Emission 134a in kg	Emission 407C in kg
1995	20	868	n.o.	17.4	n.o.
1996	20	1,050	n.o.	21.0	n.o.
1997	20	1,133	20	22.7	0.4
1998	20	1,120	1,270	22.4	25.4
1999	20	864	2,584	17.3	51.7
2000	20	933	4,193	18.7	83.9
2001	20	821	4,469	16.4	89.4
2002	20	832	4,566	16.6	91.3

Sources: Number of systems in Table 6. n.o. = not occurring.

Comment

As expected, the absolute level of filling emissions is not high with 16.6 and 91.3 kg respectively (in 2002). Compared to the same year's 134a consumption with 108.1 tonnes (Table 3 and 5), the implied emission factor is just 0.015 %. In case of 407C (200 tonnes consumed for generally smaller systems) filling emissions of 91 kg stand for a bit higher implied emission factor: 0.045 %.

3. Collection of activity data and sources of information

In the absence of public statistical data on annual HFC consumption for stationary air-conditioning systems of different types, all information about this application depends on experts. Since 1998, ÖR has regularly inquired the world market leaders as well as regionally active workshops for air-conditioning. Of particular importance was the specialised knowledge of the refrigerant producer Solvay. In this way, a reasonably reliable overall picture of activity data could be formed from numerous single data such as initial year of HFC use, quantitative relationship between individual refrigerants, details on CFC replacement in old systems, annual number of new installed systems by compressor type and by refrigerating capacity, representative figures for refrigerating capacities, refrigerant charges, lifetime, and suchlike.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Carrier LTG Service GmbH, Unterschleissheim, 18.05.98; 17.07.98, 17.07.98.
Trane Deutschland GmbH, Duisburg, 22.07.98; 12.03.98, 15.07.98, 16.10.02.
LTB Schiewer, Oberursel, 29.05.98, 17.03.99.
WRK Schenk, Barsinghausen, 05.06.98, 17.03.99.
Öko-Recherche: No "all-clear" for ozone and climate. 1995 German consumption forecast for CFCs, HCFCs and HFCs (in German), Study for Greenpeace e.V. Hamburg, S. 26. http://www.oekorecherche.de/english/berichte/volltext/keine-entwarnung.pdf
Öko-Recherche: R 12 replacement in existing equipment from 1996 to middle of 1998. Report on the Umweltbundesamt (in German), August 1998. http://www.oekorecherche.de/deutsch/berichte/volltext/vollR12.pdf
FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz der FCKW R11, R13, R503, R13B1, R113, R114 und R12B1 in bestehenden Kälte-, Klima- und Wärmepumpen-anlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, Statusbericht für das Umweltbundesamt, Berlin, Hannover, Mai 1998. S. 33 ff.
Daikin Airconditioning Germany GmbH, Unterhaching, 16.10.03.

Solvay Fluor & Derivate GmbH, Hannover: HFC chillers sold to the German market and key figures for the estimation of their lifetime, average capacities in kW and charge in kg/kW. Internal Compilation, 27.03.03.
Öko-Recherche/Solvay Fluor: Conference on basic data and sales quantities of HFCs for refrigeration and air conditioning. Participants: Winfried Schwarz (ÖR), Christoph Meurer (Solvay) and Felix Flohr (Solvay), Hannover, 26.03.03.

4. Estimation and source of information on manufacturing emission factor

The emission factor EF_{manu} of 20-g/system is based on ÖR estimation.

5. Quality control and uncertainty assessment of data I

Activity data. The various pieces of information based on which annual consumption of HFC refrigerants is estimated, were throughout given by experts, each of which is indisputably qualified in his particular sphere. However, concerning data on the countrywide market of stationary A/C, indications of the number of new installed systems and their average charges and refrigerating capacities, deviate from each other, in that each expert has his particular business focus influencing his view of the entire market. Therefore, in a given year estimated HFC quantities in new installed systems might deviate by ± 20% from the effective values in the segments of systems with centrifugal or screw compressors. As to smaller air-conditioning systems with reciprocating and scroll compressors the data accuracy is higher (error band estimated at ± 10%), since the major suppliers inform each other on their annual sales data, regularly.

Emission factor. The emission factor (EF_{manu}) of 20-g/system is estimated by Öko-Recherche based on plausibility. The assumption is that on average four refrigerant containers are used to fill one system and that from each container one hose filling of 5 grams escapes. The five-gram-loss is a default value to estimate emissions on filling of on-site assembled systems.

6. Relation to IPCC method I

In Table 3.22 (IPCC GPG) best estimates for charge, lifetime and emission factors are presented for chillers. The charges indicated range from 10 to 2000 kg, which reasonably complies with the three representative figures of ÖR (Table 2), namely 500 kg, 160 kg, and 27 kg.

In IPCC GPG, the chiller lifetime is estimated at between 10 and 30 years. ÖR assumes 12 years for reciprocating and scroll systems, 20 years for screw and 25 years for centrifugal systems, which likewise match the IPCC frame. IPCC GPG estimates "initial emission" at 0.2 to 1 percent of the first charge. The country-specific factor of ÖR, which is derived from a fixed loss of 20 grams per system, comes to much lower percentages of just 0.015/0.045.

7. Entry in CRF I

The CRF Table where data on fluids "Filled in new manufactured products" and on "Emissions from manufacturing" are primarily entered is Table 2(II).Fs1. Data for 134a are put in row 59, data for 407C are put in rows 60-63. The respective columns are B and H.

II. Bank und operating emissions from bank

As mentioned at the beginning of Part I, for lack of foreign trade with HFC containing stationary air-conditioning, annual input to domestic HFC bank (In_{bank}) is basically the same size as domestic HFC consumption (C_{manu}) described in Part I. Therefore, annual input, necessary for estimation of the bank, can be taken over from Part I, Table 5. These values are shown again in Table 8.

Table 8: 1993-2002 Total HFC input in retrofitted and new systems of stationary air-conditioning, in t/y

	HFC-134a	HFC-407C
1993	18.3	-
1994	51.6	-
1995	151.0	-
1996	214.1	-
1997	227.4	1.9
1998	225.3	54.2
1999	116.4	115.5
2000	127.3	168.1
2001	107.8	197.4
2002	108.1	200.0

Sources: Table 5 on consumption, which equals input.

8. The HFC bank in stationary air conditioning systems

The HFC end-of-year bank (EB n) in domestic systems of stationary air-conditioning has grown every year since the start in 1993 by annual domestic inputs (In_{bank}), as to date departures of HFC containing systems have not yet occurred systematically. Decommissioning is not expected to take place before 2007 in view of a lifetime of 12 years of systems with reciprocating or scroll compressors. The residual lifetime of retrofitted centrifugal compressor systems will not end before 2007 either.

The <u>average</u> annual bank (B n) is half the sum of the last year's end-of-year bank (EB n-1) and of the current year's end-of-year bank (EB n). This is the equation:

$$B\,n = \frac{EB\,n\text{-}1 + EB\,n}{2} \qquad \text{Where:} \quad EB\,n = EB\,n\text{-}1 + In_{bank}\,n$$

The average annual bank (B n) shows the following time series (Table 9):

Table 9: 1995-2002 Average annual HFC bank (B n) in stationary air-conditioning systems (new and retrofitted), in t/y

	HFC-134a	HFC-407C
1995	145.4	-
1996	327.9	-
1997	548.7	0.9
1998	775.1	29.0
1999	945.9	113.9
2000	1067.8	255.7
2001	1185.3	438.4
2002	1293.3	637.0

Sources: Table 8 and the above equation.

Comment on time series of input and bank

Although since 1997 HFC-407C has been growing faster than HFC-134a, the 407C bank is not yet half the size of the 134a bank, by 2002. This is because 134a has been used much earlier (as from 1993) in new systems and additionally (from 1995 to 1998) in existing systems of the centrifugal compressor type, as a CFC replacement. The input of 407C can be assumed to keep the 2002 level in the future. The 407C bank, however, should go on increasing for a long time because of the long lifetime of screw compressor systems (20 years), which means more input than departures of HFC refrigerants. Saturation may be supposed at 3,000 tonnes. In case of 134a, a similar trend is to be expected, as its use focuses on very long-lasting centrifugal compressor systems. Saturation of the 134a bank can be expected to take place just before 2020, at some 2,400 tonnes. Then departures will be balance out inputs of about 110 tonnes, which already was the size by 2002.

9. Factor of operating emissions from bank

Operating HFC emissions from stationary air-conditioning systems are estimated at 6% per year. That means, an emission factor (EF_{op}) is assumed, which is same-sized for all categories of refrigerating capacities and compressor types, at any age of the systems and for any refrigerants used.

10. Estimation of the operating emission factor

The authors of the 1998 FKW status report for the Umweltbundesamt came across expert estimations of CFC-11 emissions from centrifugal chillers, namely 7.1% (Lotz for 1996) and 7.0% (York for 1996). These 7.0%, also being used by Öko-Recherche for 1995, were adopted by the 1998 FKW report. Aside from this data, there are practically no usable statements on emission rates in stationary air-conditioning all over the specialised literature, be it CFC (R-12), HCFC, or HFC emissions.

The experts interviewed by ÖR about centrifugal chillers with HFC-134a, uniformly claimed significant improvements of leak tightness. The emission rate was no longer estimated at 7% but by "much less". The lowest value indicated amounted even just 2%. On the other hand, 7% were declared as usual values for systems with screw, reciprocating, and scroll compressors. In contrast, emissions from liquid chillers were estimated lower, namely at 5%, in comparison with 8% for direct evaporating condensing units with long refrigerant pipes.

If we weight the shares of the respective systems in the total refrigerant bank with these three different emission rates (2 to 7%, 5%, and 8%), a "weighted" emission rate of about 6% is arrived at. In 2003, this order of magnitude met approval also by the expert for refrigeration and air-conditioning at the HFC producer Solvay Fluor & Derivate, Mr Christoph Meurer. The collective value of 6% has already been presented to the specialised public by ÖR in the two leading German journals for refrigeration and air-conditioning (Ki and KK), in 2000.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Hans Lotz, Beitrag der deutschen Kälte-, Klima- und Wärmepumpentechnik zur Verringerung der Treibhausbelastung bis zum Jahre 2005, DKV-Statusbericht Nr. 13, Stuttgart, April 1993.

Öko-Recherche: No "all-clear" for ozone and climate. 1995 German consumption forecast for CFCs, HCFCs and HFCs (in German), Study for Greenpeace e.V. Hamburg, S. 26. http://www.oekorecherche.de/english/berichte/volltext/keine-entwarnung.pdf
York International GmbH, Mannheim, 22.11.96.
Carrier LTG Service GmbH, Unterschleißheim, 18.05.98; 17.07.98, 17.07.98.
FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz der FCKW R11, R13, R503, R13B1, R113, R114 und R12B1 in bestehenden Kälte-, Klima- und Wärmepumpen-anlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, Statusbericht im Auftrag des Umweltbundesamtes, Berlin, Hannover, Mai 1998. S. 34.
Winfried Schwarz, HFKW-Emissionen aus Kälte- und stationären Klimaanlagen. Aus einer neuen Studie des Umweltbundesamts zu Minderungspotentialen fluorierter Treibhausgase in Deutschland, in: DIE KÄLTE & Klimatechnik 4/2000, S. 16.
Winfried Schwarz, HFKW-Emissionen aus Kälte- und Klimaanlagen bis 2010, in: KI Luft- und Kältetechnik 4/2000, 164-170.
Trane Deutschland GmbH, Duisburg, 16.10.02.
Öko-Recherche/Solvay Fluor: Conference on basic data and sales quantities of HFCs for refrigeration and air conditioning. Participants: Winfried Schwarz (ÖR), Christoph Meurer (Solvay) and Felix Flohr (Solvay), Hannover, 26.03.03.

11. Operating HFC bank emissions

Operating emissions in a particular year n are arrived at by applying the operating emission factor (EF_{op}) to the average domestic HFC bank of year n (B n), which itself has been built up by annual inputs over the previous years. (See section 8):

$$EF_{op} \text{ (in \%)} \quad \times \quad B\ n$$

With an emission factor of 6% for any HFC containing systems of stationary air-conditioning, whichever compressor type is used, the specific equation for operating emissions is as follows:

$$EF_{op} \text{ (6 \%)} \quad \times \quad B\ n$$

Operating annual HFC emissions from bank are listed in Table 10 (in t/y):

Table 10: 1995-2002 Average banks and operating emissions of 134a and 407C from stationary air-conditioning, in t/y

	HFC-134a		HFC-407C	
	Average bank	Operating emissions	Average bank	Operating emissions
1995	145.4	8.7	-	-
1996	327.9	19.7	-	-
1997	548.7	32.9	0.9	0.1
1998	775.1	46.5	29.0	1.7
1999	945.9	56.8	113.9	6.8
2000	1067.8	64.1	255.7	15.3
2001	1185.3	71.1	438.4	26.3
2002	1293.3	77.6	637.0	38.2

Sources: Table 9 and equation in this section.

Comment

Emissions from banks in stationary air-conditioning systems increase constantly in step with the growth in average banks. This applies to both refrigerants. Saturation for 134a can be expected as of 2020 (peaking at 140 t). The same time horizon is to be expected for 407C emissions (peaking at 190 tonnes).

12. Quality control and uncertainty assessment of data II

Emission factor. There are no new activity data on the bank to be evaluated in addition to Part I. The situation is otherwise for operating emissions in that the emission factor is based on controversial expert judgements. Only for centrifugal compressor systems, written sources are available, albeit just with respect to CFC-11 systems. At the same time in modern centrifugal chillers, one expert maintained a value of 2%, which strongly differs from all the other indications.

Despite of this somewhat unclear data situation ÖR decided to apply a uniform factor of 6% to all systems of stationary air-conditioning. The possible error band for 134a emissions is estimated at ± 30% relatively, which means 6% ± 2% in "absolute" terms. It should be noted that centrifugal chillers exclusively run with 134a. The error band for systems predominantly run by 407C is seen lower with 6% ± 1%.

13. Relation to IPCC method II

IPCC manual GPG presents under "3.7.4 Stationary refrigeration sub-source category" the general equation (3.42) of operating emissions within the framework of a bottom-up-approach:

Operating Emissions = (Amount of HFC and PFC Stock in year t) * (x/100)

In this equation, x/100 is the emission factor. In Table 3.22 (best estimates), a default emission factor (% of initial charge/year) for "Chillers" is proposed in the order of from 2 to 15. According to Box 3 of the "Decision Tree for Actual Emissions (Tier 2)", country-specific values shall be used preferably. This study's country-specific 6% value is situated in the lower range of the IPCC default value dating back to 1999.

14. Entry in CRF II

The CRF Table where data on "Average annual stocks" and "Emissions from stocks" primarily are entered is Table 2(II).Fs1, with row 59 for 134a, and rows 60-63 for 407C. The columns are C and I.

F-Gas-Sheet 6: Room Air Conditioners

F-Gases	**HFC-407C, HFC-410A**
Application	**Room Air Conditioners, RACs**
Reported Years	**1998 - 2002**
Emission Type 4	**Operating Emissions from Bank**

Background

Room Air Conditioners (RACs) are used to produce comfortable temperatures inside individual living and working rooms or whole storeys. The refrigerating capacity generally ranges below 20 kW, in case of larger sets, however, up to 60 kW. There is no circulating liquid chilled, but the refrigerant evaporates directly.

RACs can be distinguished into mobile and fixed devices.

Mobile systems are mostly compact, i.e. they contain all components of the refrigeration cycle in one device. The heat taken from the room is removed to the outer air by means of hoses. Mobile devices in split-design are subdivided into two units. The refrigerating set with condenser is placed outside; the air conditioner with evaporator and fan is inside. The refrigerating capacity of split-systems is higher, and ranges to 5 kW. The advantage of split-systems is the lower noise level in the room inside.

Fixed systems are always split-devices. The inside part of these wall, ceiling or case systems consists of evaporator, ventilator and regulation. With the aid of a refrigerant pipeline, the room heat is transported outwards and delivered to the outer air through a condenser in the outside part, where the compressor is placed, too.

An increasingly important special version of fixed split systems is Multi-Split systems, where the outside part is connected to five and more inside devices. With that, such systems are suited for air-conditioning of larger rooms or of several rooms at the same time. Because of refrigerating capacities up to 60 kW, they compete with the more expensive stationary air-conditioning chillers working the indirect way.

Unlike compact mobile systems, in case of split and Multi-Split systems a refrigerant pipeline must be laid on site. This piping may be of considerable length.

In Germany, room air conditioners are not being manufactured. All devices are imported, the refrigerant already filled in.

Bank and operating emissions from bank

1 Activity data. Annual HFC input

As mentioned in the introduction, in Germany room air conditioners are neither manufactured nor initially charged with refrigerant. Therefore, consumption for manufacturing (C_{manu}) and emissions from manufacturing (Em_{manu}) do not need to be estimated. When split-systems are installed, refrigerant pipes are laid and must be charged with some additional refrigerant on site (about 15 grams per metre). This domestic filling, however, is so small in quantitative terms that it will be left out of further consideration. Thus, activity data to be estimated are only annual refrigerant input through new devices (In_{bank}), and refrigerant banks (EB and B), which have been built up by these inputs since the first year of HFC usage.

1.A Annual sales of RACs containing chlorine-free refrigerants

Via enquiries of domestic suppliers, the number of RACs that have been sold in Germany could be estimated by the three designs "mobile", "split", and "Multi-Split". The rather late start in 1998 is an outcome of the fact that until 1997 virtually exclusively systems with HCFC-22 came on the market.

In 1998, the first systems with 407C emerged, followed by the first systems with 410A in 2000. The year 2000 is the first year without new HCFC-containing systems on the domestic market. The annual numbers of systems are shown in Table 1.

Table 1: 1998-2002 Annual numbers of new systems of room air conditioners with chlorine-free refrigerant sold in Germany, by design

Design	1998	1999	2000	2001	2002
1. Mobile	5,000	20,000	46,600	57,700	56,400
2. Split	8,160	24,510	46,841	50,630	47,730
3. Multi-Split	1,440	4,300	9,400	8,900	8,400
Total	14,600	48,810	102,841	117,230	112,530

Sources: Sector experts. The low values in 1998 and 1999 are a result of the considerable circulation of new devices with HCFC-22, which contains chlorine.

1.B The refrigerant model for room air conditioners

In order to determine refrigerant input from 1998 onwards, with the help of sector experts a model has been elaborated, and is presented in Table 2.

It shows for the three categories of RACs the average refrigerating capacity in kW, the average charge in kg, and the used HFC refrigerants by relative shares (percentages).

Table 2: 1998-2002 Typical refrigerant distribution in RAC devices by design, average refrigerating capacity and average charge						
Design	Mobile		Split		Multi-Split	
Refr. Capacity	3 kW		6 kW		15 kW	
Charge	1.0 kg*		1.55 kg		6.2 kg	
Refrigerant	R-290**	407C	407C	410A	407C	410A
1998	27%	73%	100%	n.o.	100%	n.o.
1999	27%	73%	100%	n.o.	100%	n.o.
2000	27%	73%	90%	10%	100%	n.o.
2001	27%	73%	80%	20%	100%	n.o.
2002	27%	73%	80%	20%	90%	10%

Sources: See section 3. * The charges shown here only apply to HFC filled systems, not to systems with propane, which need half the charge in weight units. ** R-290 = Propane.
Explanation: The percentages only refer to chlorine-free refrigerants (HFC and hydrocarbons), not to all refrigerants. Until 2000, new systems with HCFC were imported.

1.C Annual HFC input through new RAC systems

The annual input (In_{bank}) of a particular refrigerant in year n is arrived at in two steps: First, multiply the number of sold units of a particular RAC design (Table 1) by the attributable average charge in kg – as per Table 2, line "charge". Further, multiply this product by the refrigerant percentage of the respective design in year n – likewise according to Table 2. This calculation gives the HFC input as shown in Table 3.

Table 3: 1998-2002 HFC input through new RAC systems, in t/y		
	HFC-407C	HFC-410A
1998	25.2	n.o.
1999	79.3	n.o.
2000	157.6	7.3
2001	139.0	36.8
2002	126.6	40.6

Sources: Number of units as per Table 1. Refrigerant shares and charges as per Table 2.
Explanation: n.o. (not occurring) means that the refrigerant (410A) was not yet in use.

Comment

After the late start of HFCs in RAC systems (1998), only the blend 407C represented HFC input for the first years. Hydrocarbons have only been used in mobile systems with a market share in this RAC category of more than 25%. Since 2001, HFC-410A has grown in weight, as it is deemed energetically superior to 407C. The technical application problems (high pressures) are considered to be under control now, so that HFC-410A is likely to rise faster in the future.

2. HFC bank in RACs

From 1998 onwards, the HFC end-of-year bank in year n (EB n) in domestically used RACs annually increases by domestic annual HFC input (In_{bank} n), as long as departures from bank do not occur in a considerable number. Systematic RAC decommissioning is not expected to take place before 2008 in the face of a ten-year-lifetime.

The average annual bank (B n) is half the sum of the previous year's end-of-year bank (EB n-1) and the current year's end-of-year bank (EB n). The equation is:

$$B\ n = \frac{EB\ n\text{-}1 + EB\ n}{2} \qquad \text{Where:} \quad EB\ n = EB\ n\text{-}1 + In_{bank}\ n$$

The average annual bank (B n) shows the following time series:

Table 4: 1998-2002 Average annual HFC bank (B n) in RAC systems, in t/y		
	HFC-407C	HFC-410A
1998	12.6	-
1999	64.9	-
2000	183.3	3.6
2001	331.6	25.6
2002	464.5	64.3

Sources: Table 3 and the above equation.

3. Collection of activity data and sources of information

Statistical data on annual sales of RACs by design, refrigerant, charge and suchlike is not available. The major suppliers, however, inform each other about their annual sales at an annual meeting held by the professional journal CCI.Print (Fachzeitung für Technische Gebäudeausrüstung), so that they know the total market in detail. Sales data and data on the refrigerants in each design category are obtained from inquiries of experts from two leading German importers of Japanese products (Hitachi, Daikin). The European market leader in the sector of mobile systems De'Longhi (Italy) was interviewed about the market share of halogen-free hydrocarbon refrigerants. The refrigeration and air-conditioning experts from the HFC producer Solvay Fluor & Derivate have appraised the overall data, too.

In the future, it should be possible to obtain the data directly from CCI.Print. The chief editor did not exclude this possibility to Öko-Recherche.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Polenz Klimageräte GmbH, Norderstedt, 01.03.99, 16.11.02; 10.10.03.
Daikin Airconditioning Germany GmbH, Unterhaching, 16.10.03.
Solvay Fluor & Derivate GmbH, Hannover: HFC RAC sold to the German market and key figures for the estimation of their lifetime, average capacities in kW and charge in kg/kW. Internal compilation, 27.03.03.
Öko-Recherche/Solvay Fluor: Conference on basic data and sales quantities of HFC in stationary refrigeration and air conditioning applications. Participants: Winfried Schwarz (ÖR), Christoph Meurer (Solvay) und Felix Flohr (Solvay), Hannover 26.03.03.
Chief editor of CCI.Print, Karlsruhe, 21.11.03.
De'Longhi S.p.A., Treviso (Italia), 21. u. 23.01.04.

4. Factor of operating emissions from bank

With 2.5%/y, operating HFC emissions from RAC systems are of the same order for all versions (mobile, split, Multi-Split), capacities and refrigerant-types.

5. Estimation of operating emission factor

Aside from the value 1.5% estimated by W. Schwarz in the trade journals KK and Ki in the year 2000, no values could be found in literature. In the context of data updating in 2003/2004, ÖR interviewed several sector experts again. The expert from the Italian manufacturer De'Longhi, who delivers both HFC and hydrocarbon filled systems, gave the highest estimation. She took 1.5% loss per annum possible at the best for systems completely assembled and sealed. In split systems with on-site laid and connected refrigerant pipes she estimated the emissions distinctly higher – in single cases at up to 30% per year. Reason: Vibrations would loosen mechanical connections, and the assemblymen were not always able to create permanently tight connections.

It is quite plausible that on-site assembled split systems are more liable to loose refrigerant than compact systems. If 1.5% loss for compact systems is deemed close to reality, operating emissions from split systems must be taken at least twice this amount, i.e. 3-4%. As in stationary air-conditioning above 20 kW refrigerating capacity, in RAC systems the emission factor is not distinguished by system design. A uniform emission factor is used. By weighting the market shares of compact systems and of split systems, the average level of the emission factor can be calculated. This exercise results in a collective value of 2.5% for all RACs.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Winfried Schwarz, HFKW-Emissionen aus Kälte- und stationären Klimaanlagen. Aus einer neuen Studie des Umweltbundesamts zu Minderungspotentialen fluorierter Treibhausgase in Deutschland, in: DIE KÄLTE & Klimatechnik 4/2000, S. 16.
Winfried Schwarz, HFKW-Emissionen aus Kälte- und Klimaanlagen bis 2010, in: KI Luft- und Kältetechnik 4/2000, 164-170.
Öko-Recherche/Solvay Fluor: Conference on basic data and sales quantities of HFC for refrigeration and air conditioning applications. Participants: Winfried Schwarz (ÖR), Christoph Meurer (Solvay) und Felix Flohr (Solvay), Hannover 26.03.03.
Daikin Air-conditioning Germany GmbH, Unterhaching, 16.10.03.
De'Longhi S.p.A., Treviso (Italia), 23.01.04.

6. Operating HFC emissions from bank

Operating emissions in a particular year n are estimated by application of the operating emission factor (EF_{op}) to the average bank of year n (B n), which for its own has been built up by preceding annual inputs (In_{bank}) – see section 2.

EF_{op} (in %) x B n

Provided an EF of 2.5%/y for HFC containing RAC systems, whichever the design is, the specific equation for operating emissions is as follows:

EF_{op} (2.5 %) x B n

Operating annual HFC emissions from the bank are reproduced in Table 5.

Table 5: 1998-2002 Average banks and operating emissions of 407C and 410A from RAC systems, in t/y				
	HFC-407C		HFC-410A	
	Average Bank	Operating Emissions	Average Bank	Operating Emissions
1998	12.6	0.32	-	-
1999	64.9	1.62	-	-
2000	183.3	4.58	3.6	0.1
2001	331.6	8.29	25.6	0.6
2002	464.5	11.61	64.3	1.6

Sources: Table 4 and equation in this section.

Comment

Operating HFC emissions from RAC systems are constantly increasing in step with the average banks. This applies to both HFC refrigerants. In the possible event of saturation of the market by 2010 with 190,000 new systems being sold annually (20,000 Multi-Split, 90,000 split, 80,000 mobiles), refrigerant bank and operating emissions would peak at 3,200 tonnes (bank) and 80 tonnes (emissions) respectively, by the year 2000. Supposing a constant relation between 407C and 410A of 80% to 20%, the then emissions would amount to 64 tonnes of 407C and 16 tonnes of 410A respectively. However, it should be reckoned with a shift towards HFC 410A.

7. Quality control and uncertainty assessment of data

Activity data. Data on annual sales figures by technical design as well as by refrigerants used are deemed robust, as the interviewed experts know the total market from their annual round-table conversations at CCI.Print. The error band is limited to rounding off to the next "full thousand", which means, it varies about ± 2%. The average charges of mobile, split, and Multi-Split systems (1.0, 1.55, and 6.2 kg) stem from other estimations, which differed between the individual judging experts (five in number) by 10% at the maximum.

To date, quality control is limited to a comparison of the different supplier indications (on the total market and its segments) with each other. Direct access to statistical data at CCI.Print up to now being only commercially available, would provide considerable improvements.

Emission factor. The average emission factor of 2.5% is based on plausibility of higher liability to leakage in split systems compared to compact systems. Leading manufacturers admit for the latter 1.5% annual emissions. In that even split systems have hermetic compressors, the emission factor of split systems is not estimated higher than 3 to 4%.

Nevertheless, data uncertainty remains relatively high, as long as actual and systematically evaluated experience values are not available. The margin of error is estimated relatively high - at 2.5% ± 1%.

8. Relation to IPCC method

IPCC manual GPG presents under "3.7.4 Stationary refrigeration sub-source category" the general equation (3.42) of operating emissions in the framework of a bottom-up-approach:

Operating Emissions = (Amount of HFC and PFC Stock in year t) * (x/100)

In this equation, x/100 is the emission factor. In Table 3.22 (best estimates), a default factor (percentage of initial charge/year) for "Residential and Commercial A/C" is proposed in the order of from 1 to 5. According to Box 3 of the "Decision Tree for Actual Emissions (Tier 2)", country-specific values should be used preferably. This study's country-specific 2.5% value is situated in the centre of the IPCC default suggestion.

The ÖR assumption of 10-year-lifetime is situated in the lower range of the IPCC estimation, which goes from 10 to 15 years.

9. Entry in CRF

The CRF Table where data on "Average annual stocks" and "Emissions from stocks" are primarily entered is Table 2(II).Fs1, rows 64-67 for 407C, rows 68-70 for 410A. The columns in question are C and I.

F-Gas-Sheet 7: Industrial Refrigeration

F-Gases	**HFC-134a, HFC-404A, HFC-407C, HFC-23, HFC-227ea, HFC-236fa, PFC-116**
Application	**Industrial Refrigeration**
Reported Years	**1995 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**

Background

Industrial refrigeration is refrigeration in industrial firms. In distinction to the bulk of commercial applications, refrigeration is used for fabricating products. Usually, the product is food, which is either cooled or frozen. Outside of food industries, refrigeration is used in several other industrial sectors in order to keep definite process temperatures. Although some commercial sectors are also producing goods (butchers, bakers, and the agriculture), the craftsman's or farmer's small-scale manner of production is different from the industrial mode of large-scale manufacturing and refrigeration.

Commercial refrigeration and industrial refrigeration have in common that the refrigerating equipment is normally not manufactured off-the-shelf, but represents an individually customised technical solution as to design, size, and refrigerant type. This fact has consequences to the achievable leak tightness of the plants.

An important difference from commercial refrigeration is the fact that in industrial applications fluorine-containing refrigerants are not at all the general norm, with natural refrigerants being the exotic exception. On the contrary, especially in food industries large refrigeration plants normally run on ammonia. This is without doubt associated with the fact that here appropriate handling of toxic refrigerants by professional personnel can be taken for granted, which is usually not the case with the person group exposed to commercial refrigeration plants.

Today, the most important HFC for stationary industrial refrigeration is the blend HFC-404A, which has ahead of the pure HFC-134a. In addition, the blend 407C plays a role and – for very low temperatures – HFC-23 and PFC-116. In the rare applications at higher temperatures, HFC-227ea and sometimes HFC-236fa are used.

I. Domestic HFC consumption and manufacturing emissions

1 Activity data I. Annual domestic HFC consumption

Foreign trade with on-site erected refrigeration plants is negligible. Therefore, annual HFC consumption for new systems equals HFC input through new systems ($C_{manu} = In_{bank}$). As with commercial refrigeration, direct data on refrigerant consumption disaggregated by user-firms is not available. The domestically represented HFC producers know their own annual sales and have a picture of their major application spheres. These estimates, however, do not suffice for a detailed breakdown of refrigerants into different industrial and non-industrial sub sectors. Although there are refrigerants that can clearly be assigned to stationary refrigeration in contrast to mobile air-conditioning (e.g. 404A), there is hardly a refrigerant that can be said to be used solely for industrial or solely for commercial refrigeration. Therefore, the refrigerant model used to determine annual consumption in industrial refrigeration is nearly as complicated as that for commercial refrigeration.

Excursus on method: The multi-step refrigerant model for industrial refrigeration

The approach which is taken here, as long as no direct statistical data on refrigerant end-use is available, does not aim at determining the annual domestic bank through annual HFC consumption or HFC inputs, but the opposite way round:

<u>Firstly</u>, by means of a detailed model the refrigerant bank is estimated for the (not yet reached) final state, in which all systems where HFCs are a possibility (natural refrigerants must be subtracted), actually run solely with HFCs, i.e. without chlorine-containing refrigerants. This final or full bank is, from a quantitative perspective, supposed to remain stable over the medium term, which seems to be close to reality.

<u>Secondly</u>, given this full bank, by means of the average systems lifetimes that refrigerant quantity will be calculated, which must annually be filled into new refrigeration systems to maintain the full level of the bank, that means to compensate for the reduction of the bank by decommissioned old systems. Given a 10-year-lifetime, the balanced input In_{bank} (or consumption C_{manu}) amounts to one tenth of the bank size.

Clearly, in this way empirical fluctuations in the market cannot be taken account of, but so to speak only their long-run means. These, in turn, are just as reliable, as the model of the bank reflects reality.

<u>Thirdly</u>, in the above-described way, annual HFC input over the 1990s will not be met exactly. It is well known that HFCs did not supersede ODS refrigerants for new systems on a certain qualifying date. From 1993 onwards, new refrigeration systems were being filled over years simultaneously with both kinds of refrigerants. This is why information is necessary on the – annually growing – shares of HFCs in the calculated input into new systems. These proportions are available for the most important refrigerants from interviews with HFC producers.

<u>Fourthly</u>, because of the – physically - premature replacement of R-12 (above all by HFC-134a), there were some years in the 1990s, when more than 100% of the balanced input was supplied to the bank. This is also taken account of in the following.

1.1 The model of the refrigerant bank in industrial refrigeration

The extension of the detailed model for industrial refrigeration is too high to be presented here. It is shown as an appendix to this F-Gas sheet. Here we start immediately with the results derived from that model.

1.2 Refrigerant bank and calculated HFC/PFC consumption in balance state

From the model presented in the appendix total values can be derived for the "full-sized bank" as well as for the calculated annual consumption, sub-divided into the HFC refrigerants 404A, 134a, 407C, 23, 227ea (with a small share of 236fa) and the PFC-116. Table 1 shows the final or target bank (balance state) by refrigerants.

Table 1: Final refrigerant bank in industrial refrigeration, in t

Refrigerant	404A	134a	407C	23/116	227/236	Total
Quantity	3,065	1,479	300	105	73	5,021

Sources: Model in the appendix to this sheet.

Table 2 gives the balanced annual HFC/PFC consumption under the assumption of a general plant lifetime of ten years. Each figure represents one tenth of the respective quantity in Table 1.

Table 2: Balanced annual consumption in industrial refrigeration by refrigerants, in t/y

Refrigerant	404A	134a	407C	23+116	227/236	Total
Consumption	306.5	147.9	30	10.5	7.3	502.1

Sources: Table 1.

1.3 Shares of HFC/PFC refrigerants for new equipment and CFC replacement

HFC/PFC have been filled in new equipment since 1993. Their shares against ODS have increased with rates different to each other, but all of them have reached the 100%-share by 2000. Being the most important substitute for CFC-12 in industrial refrigeration, especially in centrifugal chillers, HFC-134a achieved consumption levels above balance values, namely 123% and 146%, respectively, in 1997 and 1998. That means that in both years almost half the consumed refrigerant was filled into old systems. Table 3 shows the HFC/PFC shares for each chlorine-free refrigerant used.

Table 3: 1993-2002 Shares of HFC/PFC in refrigerants for new and retrofitted old systems, against balanced figures

	404A	134a	407C	23	116	227/236
1993	2%	5%	10%	32%	0%	3%
1994	3%	17%	17%	42%	0%	3%
1995	20%	34%	33%	53%	0%	45%
1996	39%	78%	33%	63%	50%	72%
1997	64%	**123%**	50%	74%	60%	86%
1998	97%	**146%**	67%	95%	70%	100%
1999	100%	100%	100%	100%	80%	100%
2000	100%	100%	100%	100%	100%	100%

Sources: Section 3. In bold type: years of CFC-12 replacement with more than 100% of the balance value.

1.4 Annual consumption of HFC/PFC refrigerants since 1993

Annual consumption of HFC and PFC refrigerants for new systems and – in the case of HFC-134a – additionally for retrofitted old systems can be calculated through multiplication of the balance values as per Table 2 by their respective percentages against ODS shown in Table 3. The consumption figures obtained this way are entered in Table 4.

Table 4: 1993-2002 Calculated annual consumption of HFC/PFC for new and retrofitted old systems in industrial refrigeration, in t/y

	404A	134a	407C	23	116	227/236*
1993	5	8	3	3	0	0.3
1994	10	25	5	4	0	0.3
1995	60	50	10	5	0	3.3
1996	120	115	10	6	0.5	5.3
1997	196	**182**	15	7	0.6	6.3
1998	296	**216**	20	9	0.7	7.3
1999	306	148	30	9.5	0.8	7.3
2000	306	148	30	9.5	1	7.3
2001	306	148	30	9.5	1	7.3
2002	306	148	30	9.5	1	7.3

Sources: Calculation via Tables 2 and 3. In bold types: years of intensified CFC-12 substitution.
* Only in crane air-conditioning (final bank: 2.5 t) HFC-236fa has a share of 10%, since 1999 (rest: 227ea). Because of its very small importance, 236fa is not considered separately.

Comment on annual consumption in industrial refrigeration

In the years 1993 and 1994, HFC-134a was the main HFC refrigerant. Its importance has been surpassed, however, since 1995 by HFC-404A (incl. 507). This was the case even in the top years of CFC-12 replacement by HFC-134a. In industrial refrigeration, the predecessor of HFC-134a, namely CFC-12, had never been the most important halogenated refrigerant. This has always been HCFC-22. Successor of HCFC-22 is HFC-404A, which additionally replaces certain parts of CFC-12 and of the ODS blend R-502.

HFC-407C plays a role chiefly in industrial liquid chillers, likewise in succession of HCFC-22. The determinative role of HCFC-22 is the reason why replacement of CFC containing refrigerants by service refrigerants is of minor importance in industry. HFC-23 is used for low temperatures and serves – like PFC-116 - as replacement for R-13, R13B1, and R 503. HFC-227ea is a successor of CFC-114 and of R-12B1 with the main application in high-temperature heat pumps.

Since 2000, all HFC refrigerants have reached the level of their balance consumption values, which are derived from the refrigerant model.

2. Emissions on the first HFC fill of old and new refrigeration systems

Manufacturing or filling emissions are generally low in case of refrigeration plants. Nevertheless, their reporting is required by the CRF from 1995 onwards.

2.1 Emission factor of filling

Generally, an emission factor (EF_{manu}) of 0.15% applies to annually filled quantities of HFC/PFC refrigerants.

This EF_{manu} is based on experience that per filling operation roughly one hose filling of 5 to 10 grams escapes to the atmosphere. Provided an average charge of 5 kg for industrial refrigeration plants, 0.15% are arrived at as centre of variations.

2.2 Manufacturing emissions from industrial refrigeration

Table 5: 1995-2002 HFC/PFC losses on filling of new and retrofitted old stationary plants in industrial refrigeration, in t/y (EF_{manu} = 0.15%)

	404A	134a	407C	23	116	227/236
1995	0.09	0.08	0.02	0.01	0.00	0.00
1996	0.18	0.17	0.02	0.01	0.00	0.01
1997	0.29	0.27	0.02	0.01	0.00	0.01
1998	0.44	0.32	0.03	0.01	0.00	0.01
1999	0.46	0.22	0.05	0.01	0.00	0.01
2000	0.46	0.22	0.05	0.01	0.00	0.01
2001	0.46	0.22	0.05	0.01	0.00	0.01
2002	0.46	0.22	0.05	0.01	0.00	0.01

Sources: Calculation via Table 4. The consumption figures there are multiplied by 0.15%.

Comment

Table 5 shows, in absolute terms, filling emissions range in magnitudes of kilograms only with exemption of the main refrigerants HFC-134a and HFC-404A. Annual filling losses of 404A have amounted to slightly half a tonne since 1999, whereas 134a is annually being lost in the order of 220 kg. According to the refrigerant model, these figures will remain constant for the near future.

3. Collection of activity data and sources of information

In the absence of direct statistical surveys on annual refrigerant consumption for industrial refrigeration, this data must be estimated indirectly through several determinants contained in a model, which is supposed to reflect the situation in the food industries as well as in other industries. Of decisive importance is the internal structure of the refrigerant bank in its final or full-size state. The point is, to ascertain for every individual application the number of systems and their application-specific refrigeration data, especially the typical refrigeration capacity.

For a large part, the model of food industries (accounting for 75% of the refrigerant bank) is based on data from the 2002 DKV status report "Energiebedarf für die technische Erzeugung von Kälte" provided by FKW-Hannover and ILK-Dresden. The subdivision of food industries, the number, and average refrigerating capacities are adopted from there.

As the refrigerating capacities have been given without refrigerants, the next step was to estimate the respective HFC share in each individual application (above all against ammonia). After that, from the refrigerating capacities the associated refrigerant charges in kg were determined. For this purpose, several application-specific indicators of "kg HFC/kW" had to be created. Finally, the refrigerant 404A was assigned to freezing and deep freezing, and 134a to "normal" refrigeration.

These three supplementary steps were carried out by Öko-Recherche together with the refrigeration experts from Solvay Fluor & Derivate, Mr Meurer and Mr Flohr, in 2003 (partially with the assistance of external experts and specialist literature).

The Solvay experts likewise helped in tapping those industrial refrigeration applications outside food industries that have not been presented in the above-mentioned DKV status report. Data on high-temperature heat pumps, on freeze-drying plants and plants in the chemical industry go back to former studies by the FKW-Hannover. From own former surveys ÖR took information on industrial centrifugal chillers, on liquid chillers in processing industries (cooling of lubricants etc.) and on crane air conditioning in heavy industries and in harbours.

A special study about substituting CFC-12 in existing systems carried out by ÖR on behalf of the German Umweltbundesamt served as source of information on the particularly high consumption levels of 134a in 1996/1997.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz der FCKW R11, R13, R503, R13B1, R113, R114 und R12B1 in bestehenden Kälte-, Klima- und Wärmepumpen-anlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, Statusbericht im Auftrag des Umweltbundesamtes, Berlin, Hannover, Mai 1998.

Öko-Recherche: R 12 replacement in existing equipment from 1996 to middle of 1998. Report on the Umweltbundesamt (in German), August 1998. http://www.oekorecherche.de/deutsch/berichte/volltext/vollR12.pdf

DKV, Energiebedarf für die technische Erzeugung von Kälte, Statusbericht des Deutschen Kälte- und Klimatechnischen Vereins Nr. 22, Juni 2002.

Öko-Recherche/Solvay Fluor: Conference on basic data and sales quantities for HFC in stationary refrigeration and air-conditioning. Participants: Winfried Schwarz (ÖR), Christoph Meurer (Solvay) and Felix Flohr (Solvay), Hannover 26.03.03.

DuPont Deutschland GmbH, Bad Homburg, pers. communication on the sales of HFC-236fa as a refrigerant at the IKK 2003, Hannover, 10.10.03.

Weisshaar GmbH & Co. KG, Bad Salzuflen. Information on refrigerants for crane air conditioning, 14.10.03.

Refrigerant producers. Direct enquiries 1999 and 2003 about sales quantities and perspectives of chlorine-free refrigerants for the use in stationary refrigeration and air conditioning:
Deutsche ICI GmbH bzw. Ineos Fluor International Ltd., Frankfurt, 16.03.99 u. 10.10.03.
Du Pont Deutschland GmbH, Bad Homburg, 17.02.99 u. 10.10.03.
Elf Atochem bzw. ATOFINA Deutschland GmbH, Düsseldorf, 12.04.99 u. 10.10.03.
Westfalen AG, Münster, 24.02.99 u. 10.10.03
Solvay Fluor und Derivate GmbH, Hannover, 16.03.99 u. 10.10.03.

ILK Dresden/FKW Hannover, Aktuelle TEWI-Betrachtung von Kälteanlagen mit HFKW- und PFKW-Kältemitteln unter Berücksichtigung der unterschiedlichen Rahmenbedingungen für verschiedene Anwendungsgebiete, im Auftrag des Forschungsrats Kältetechnik e.V., FKT 96/03, Frankfurt, November 2003.

4. Estimation and source of information of the factor of filling emissions

The emission factor EF_{manu} (0.15%) is based on estimation by Öko-Recherche.

5. Quality control and uncertainty assessment of data I

Activity data. The refrigerant bank in its final state, broken down into several applications, is starting point for all further activity data. The numbers of plant operators are statistically well founded by authorities or associations, whereas application-specific refrigeration plant configurations including refrigerating capacities and shares of HFC-filled systems in the entirety of plants are completely based on expert judgements.

The most crucial point, however, is the next step, namely the establishment of average refrigerant charges in kg per kW refrigerating capacity. For this purpose, rules of thumb had to be used, i.e. expert values based on experience. Additional steps in finishing the model are division into different refrigerants and estimation of the systems lifetime. Annual refrigerant consumption for new systems cannot be derived before this point has been reached.

The margin of error accumulated up to that point is relatively high. According to Öko-Recherche, in annual new consumption (C_{manu}) by individual refrigerants it amounts to somewhat ± 30%. In overall refrigerant consumption the margin of error is certainly not so high, but still amounts to ± 20%. The high error bands are due to the circumstance that the refrigerant model cannot consider real fluctuations in general business and investment activities.

To date, the only correction factor is the expert judgement of refrigerant producers, which in fact is of limited use, as producers know their total sales per year, but cannot distinguish between filling of new systems and refilling of existing systems to compensate for operating emissions.

Emission factor. The emission factor (EF_{manu}) of 0.15% is based on interviews with sector experts. As there are no measurements available, the proper value may be 0.10% or 0.20% with the same right. The total emissions (filling plus operating emissions) are affected by this uncertainty just marginally.

6. Relation to IPCC method I

Table 3.22 (IPCC GPG) presents default values for "Industrial Refrigeration including Food Processing and cold storage" under "best estimates for charge, lifetime, and emission factors". The charges indicated range from 10 kg to 10 tonnes. The lifetime is estimated to range between 10 and 20 years. The "initial emission" is estimated at 0.5 to 3 percent of the initial charge. The country-specific value of 0.15% by ÖR is far below that level.

7. Entry in CRF I

The CRF-Table where data on fluids "Filled in new manufactured products" and on "Emissions from manufacturing" are primarily entered is Table 2(II).Fs1. The rows for industrial refrigeration are 45-57 with the columns B and H.

II. Bank and operating emissions from bank

As remarked in the introduction to Part I, because of negligible foreign trade with HFC/PFC containing stationary refrigeration systems annual input to domestic HFC/PFC banks (In_{bank}) equals domestic HFC consumption (C_{manu}) considered in Part I. Thus, annual inputs can be taken from Part I in order to determine the size of domestic banks.

8. The HFC/PFC bank in systems of industrial refrigeration

Since the starting year 1993, the HFC/PFC end-of-year bank (EB n) in stationary refrigeration systems has increased annually by the amount of domestic inputs (In_{bank}), as to date considerable departures from the bank have not yet taken place. Systematic decommissioning of refrigeration systems is not to be expected before 2003 in view of ten years lifetime. This applies likewise to retrofitted old systems.

The average annual bank (B n) is half the sum of the last year's end-of-year bank (EB n-1) and the current year's end-of-year bank (EB n). The equation is as follows.

$$B\,n = \frac{EB\,n\text{-}1 + EB\,n}{2} \qquad \text{Where:} \qquad EB\,n = EB\,n\text{-}1 + In_{bank}\,n$$

The time series of average annual banks (B n) is shown in Table 6. The refrigerants are not distinguished by refrigeration system design, as no design-specific differences between relative operating emissions are assumed.

Table 6: 1995-2002 Average annual HFC/PFC banks (B n) in stationary systems of industrial refrigeration (including retrofitted systems), in t

	404A	134a	407C	23	116	227/236
1995	45	58	13	10	0	2
1996	135	141	23	15	0.3	6
1997	293	289	36	22	0.8	12
1998	540	488	53	30	1.5	19
1999	841	670	78	39	2.2	26
2000	1,147	818	108	48	3.1	33
2001	1,454	966	138	58	4.1	41
2002	1,760	1,114	168	67	5.1	48

Sources: Consumption figures in Table 4 recalculated according to the above equations.

9. Factor of operating emissions from bank

To estimate operating HFC/PFC emissions from stationary systems in industrial refrigeration a uniform factor of 7% per annum is applied.

10. Estimation of the operating emission factor

Unlike commercial refrigeration, there are no representative emissions measurements available for industrial refrigeration. Even expert judgements are rare.

In 1994, at an Umweltbundesamt conference emissions were estimated by representatives of the chemical industry at 7% of a 5,000 tonnes overall bank.

In its status reports on CFC replacement published in 1995-1998, the FKW-Hannover used emission factors of from 5.5 to 7% (R-12, R-502, R13, R13B1, R-11) for industrial refrigeration, but did not present a value for the main refrigerant HCFC-22.

The Solvay expert for refrigeration and air-conditioning estimated the emission rate in industrial refrigeration at 6%, in 2003.

The expert from the leading supplier of industrial refrigeration equipment, Axima Refrigeration, estimated HFC emissions from industrial refrigeration at "rather more than 7%".

Overall, 7% per annum can be taken as a mean value of these several expert estimations.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Fachgespräch zum Thema "Umrüstung von bestehenden Kälte- und Klimaanlagen" der chemischen Industrie, Umweltbundesamt Berlin, 20.09.94.

FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz von R 12 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, im Auftrag des Umweltbundesamtes, Statusbericht im Auftrag des Umweltbundesamtes, Berlin, Hannover, November 1995, S. 96.

FKW: Ersatz von R 502 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, im Auftrag des Umweltbundesamtes, Texte 29/97, Berlin, Juni 1997, S. 90.

FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz der FCKW R11, R13, R503, R13B1, R113, R114 und R12B1 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, Statusbericht im Auftrag des Umweltbundesamtes, Berlin, Hannover, Mai 1998.

Öko-Recherche/Solvay Fluor: Conference on basic data and sales quantities for HFC in stationary refrigeration and air conditioning applications. Participants: Winfried Schwarz (ÖR), Christoph Meurer (Solvay) und Felix Flohr (Solvay), Hannover 26.03.03.

Axima Refrigeration GmbH, Lindau, 21.11.03.

11. Operating HFC emissions from bank

Operating emissions in a particular year n are achieved by applying the factor of operating emissions (EF_{op}) to the average bank of year n (B n), which has been built up by several annual HFC/PFC inputs over the past time – see section 8.

$$EF_{op} \text{ (in \%)} \quad x \quad B\ n$$

With an EF of 7%/y for HFC/PFC containing new and retrofitted old stationary systems in industrial refrigeration, the specific equation of operating emissions is as follows:

$$EF_{op} \text{ (7\%)} \quad x \quad B\ n$$

Operating annual HFC/PFC emissions from banks are shown in Table 7.

Table 7: 1995-2002 Operating HFC/PFC emissions from banks in stationary systems of industrial refrigeration (inclusive of retrofitted systems), in t/y						
	404A	134a	407C	23	116	227/236
1995	3	4	1	0.7		0.1
1996	9	10	2	1.1		0.4
1997	21	20	2	1.5	0.06	0.8
1998	38	34	4	2.1	0.1	1.3
1999	58	47	5	2.7	0.2	1.8
2000	80	57	8	3	0.2	2.3
2001	102	68	10	4	0.3	2.8
2002	123	78	12	5	0.4	3

Sources: Table 6 and equation in this section.

Comment

HFC/PFC emissions from banks in stationary refrigeration systems increase constantly in step with the growth in average banks. This also applies to the two main refrigerants 404A and 134a. Although in 2002 emissions of HFC-23 amounted to just 5 tonnes, this emission is the third largest in terms of global warming due to the high specific GWP (11.700).

The total of emissions in metric tonnes amounted to 221 tonnes by 2002. Saturation can be expected at 350 tonnes per year. This is 7% of a 5,000 tonnes overall bank.

12. Quality control and uncertainty assessment of data II

Emission factor. The (activity) data on the bank have already been rated in Part I. The emission factor EF_{op} of 7%, which was introduced in Part II, is based on expert judgements. The estimates given by specialists do not differ widely from each other, ranging between 5.5 and "more than 7%". Thus, the emission factor can be considered relatively reliable. The margin of error might be in the order of ± 1%.

13. Relation to IPCC method II

IPCC manual GPG gives under "3.7.4 Stationary refrigeration sub-source category" the general equation 3.42 of operating emissions in line with a bottom-up approach:

$$\text{Operating Emissions} = (\text{Amount of HFC and PFC Stock in year t}) * (x/100)$$

In this equation, x/100 is the emission factor. A magnitude of from 7 to 25% is proposed as default emission factor in Table 3.22 where "best estimates" in percentage of initial charge/year for "Industrial Refrigeration including Food Processing and Cold Storage" are given. The 7% used by ÖR is situated on the bottom of the IPCC default value.

14. Entry in CRF II

The CRF Table where data on "Average annual stocks" and "Emissions from stocks" are primarily entered for the numerous refrigerants is Table 2(II).Fs1, rows 45 to 57, with the columns C and I.

Appendix. Refrigerant model for industrial refrigeration

	Systems	Qo kW	Qo total kW	HFC share	HFC systems	Qo HFC kW total	HFC kg/kW	HFC kg/unit	HFC all kg
Food industries									
Refrigeration (134a)									
Fruit	360	231	83,160	40%	144	33,264	1	231	33,264
Vegetables	1,200	690	828,000	50%	600	414,000	1	690	414,000
Dairy products	156	385	60,060	30%	47	18,018	1	385	18,018
Fish	72	778	56,016	30%	22	16,805	1	778	16,805
Meat	840	208	174,720	40%	336	69,888	1	208	69,888
Cakes and pastries	60	493	29,580	30%	18	8,874	1	493	8,874
Storage	1,000	200	200,000	40%	400	80,000	1	200	80,000
Subtotal/Mean	3,688	**388**	1,431,536	42%	1,166	640,849	1	388	640,849
Freezing (404A)									
Fruit	180	210	37,800	25%	45	9,450	1.5	315	14,175
Vegetables	192	4472	858,624	25%	48	214,656	1.5	6,708	321,984
Dairy products	1,017	775	788,175	30%	305	236,453	1.5	1,163	354,679
Fish	128	1584	202,752	20%	26	40,550	1.5	2,376	60,826
Meat	2,547	200	509,400	40%	1019	203,760	1.5	300	305,640
Cakes and pastries	332	722	239,704	30%	100	71,911	1.5	1,083	107,867
Storage	1,050	2500	2,625,000	20%	210	525,000	1.5	3,750	787,500
Subtotal/Mean	5,446	**966**	5,261,455	32%	1,752	1,301,780	1.5	1,449	1,952,670
Deep freezing (404A)									
Fruit	60	160	9,600	15%	9	1,440	2	320	2,880
Vegetables	1,452	690	1,001,880	25%	363	250,470	2	1,380	500,940
Dairy products	351	1108	388,908	30%	105	116,672	2	2,216	233,345
Fish	72	778	56,016	20%	14	11,203	2	1,556	22,406
Meat	672	131	88,032	40%	269	35,213	2	262	70,426
Cakes and pastries	140	1911	267,540	30%	42	80,262	2	3,822	160,524
Subtotal/Mean	2,747	660	1,811,976	29%	803	495,260	2	1,319	990,521
Breweries									
Cooling 134a	1,283	**177**	227,091	5%	64	11,355	1	177	11,355
Fruit juice manufacture									
Juice cooling 134a	450	**24.5**	11,025	50%	225	5,513	1	25	5,513
Slaughterhouses									
Refrigeration 134a	228	113.7	25,924	25%	57	6,481	1	114	6,481
Freezing 404A	228	11.5	2,622	25%	57	656	1.5	17	983
Cool down rooms 134a	228	31.2	7,114	25%	57	1,778	1.5	47	2,668
Deep freeze room 404A	228	7.2	1,642	25%	57	410	2	14	821
Processing rooms 404A	228	48.3	11,012	25%	57	2,753	1	48	2,753
Subtotal/Mean	1,140	**42**	48,313	25%	285	12,078	1.13	48	13,706
	Systems	Qo kW	Qo total kW	HFC share	HFC systems	Qo HFC kW total	HFC kg/kW	HFC kg/unit	HFC all kg
Cold storage depots									
Cold store rooms 134a	519	121	62,799	15%	78	9,420	1	121	9,420
Freezer rooms 404A	519	683	354,477	15%	78	53,172	1.5	1,025	79,757
Deep freez. plants 404A	260	510	132,600	15%	39	19,890	2	1,020	39,780
Subtotal/Mean	1,298	**424**	549,876	15%	195	82,481	1.56	662	128,957

	Systems	Qo kW	Qo total kW	HFC share	HFC systems	Qo HFC kW total	HFC kg/kW	HFC kg/unit	HFC all kg
Food industries									
Subtotal food industr.	16,052	**582**	9,341,272	30%	4,890	2,549,316	1.47	855	**3,743,570**
Other industries									
Industrial centrifugals									
Chemical Industry	500	1,500	750,000	100%	500	750,000	0.4	600	300,000
Car industry	300	1,500	450,000	100%	300	450,000	0.4	600	180,000
Nuclear power stations	30	1,500	45,000	100%	30	45,000	0.4	600	18,000
Other industries	170	1,500	255,000	100%	170	255,000	0.4	600	102,000
Subtotal (134a only)	1,000	1,500	1,500,000	100%	1,000	1,500,000	0.4	600	600,000
Crane A/C (227,236)									
Heavy indust./harbours	1,000	5	5,000	100%	1000	5,000	0.5	2.5	2,500
Processing industry									
Liquid chillers									
134a (instead of R12)									200,000
407C (instead of R 22)									300,000
Subtotal									500,000
Deep freezing plants									
Environm. simulation, Freeze-drying (R 23)	500			100%	500			10	5,000
Chemical industry									
Deep freezing 23,116 in place of 13, 503,13B1	100			100%	100			1,000	100,000
Other Applications									
High temp. HP (227) in place of R114, R12B1	100			100%	100			700	70,000
Subtotal Other Indust.									**1,277,500**
Industrial Total									**5,021,070**

Explanation. In the food industries (upper part of the Table) aside from the number of systems in each application (col. 2), col. 3 contains the installed refrigerating capacity "Qo kW" per system. Col. 4 (Qo total kW) shows the installed refrigerating capacity per application (col. 2 x col. 3). Refrigerating capacity is indicated regardless of refrigerants. In col. 5 "HFC-share" the share and in col. 6 the number of HFC systems in the total number of systems (col. 2) is estimated. The next column contains under "Qo HFC kW total" the total capacity, limited to HFC systems. Under the heading "HFC kg/kW", the specific refrigerant charge per one kW is shown. With the aid of this figure, under "HFC kg/unit" the refrigerant quantity per system is estimated. The last column to the right gives the overall refrigerant quantity per application, through multiplication of the number of systems by the system-specific charge. For space reasons division into different refrigerants is included in the first column (left). In "other industries", comparable disaggregation is not available.

F-Gas-Sheet 8: Commercial Refrigeration

F-Gases	**HFC-134a, HFC-404A, HFC-407C, HFC-23, HFC-125, HFC-152a, PFC-116, PFC-218**
Application	**Commercial Refrigeration**
Reported Years	**1995 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**

Background

Commercial refrigeration forms the largest and at the same time most heterogeneous application sector of F-Gases. There is a variety of refrigerating systems differing by design, dimensions, refrigerant type, and leak tightness. That result from the fact that mass-produced systems with exactly defined performance and refrigerant data are not as frequent as individually adjusted solutions. This is not so much the case in the sub-sector of general food trade refrigeration, which is supplied by a small number of major equipment companies intending to standardise the systems. Here, the number of operating enterprises is of manageable size; hence, direct data estimation is not impossible.

The situation is otherwise for the sub-sector of "other commercial refrigeration". Under this heading, there is the large number of stationary refrigeration plants outside industrial production processes, which typically are custom-made in design, installation, and operation. In Germany, this heterogeneous sector had not been investigated en detail before recent time (DKV 2002), and information on it still mainly depends on expert estimates. This sector is the domain of the numerous small contractors for refrigeration and air-conditioning, whose number exceeds 2,000. With help of them in-depth data collection were possible, however has not yet been tackled.

Today (2004), the most important HFC for stationary refrigeration plants is the mixture R-404A, followed by the pure HFC-134a. Of less relevance is the HFC-blend 407C. At very low temperature, some quantities of HFC-23 and of PFC-116 are used.

Some further HFCs and one PFC have just temporary relevance in service refrigerants for old systems, as long as the phase out of CFC refrigerants has not yet been completed.

I. Domestic HFC consumption and manufacturing emissions

1 Activity data I. Annual domestic HFC consumption

As foreign trade with on-site erected refrigeration plants is negligible, annual HFC consumption for new systems can be equalised to HFC input through new systems ($C_{manu} = In_{bank}$). This coincidence does not make determination of HFC consumption easy, because there is virtually no direct data available. The domestically represented refrigerant producers know their own annual sales and have ideas of their main end-uses. This may be useful for data controlling. However, these estimations do not suffice to answer the question how much new refrigerant is annually sold into the commercial refrigeration sector, in which proportions it reaches systems with low, middle or high leakage, and how much is used to replace emissions. Hence, the refrigerant model for determining annual HFC consumption is somewhat more complex than in other cases.

Excursus on the method: Multi-step refrigerant model in commercial refrigeration

In the absence of direct statistical refrigerant data, the special approach used here is not to determine the domestic refrigerant bank by means of annual inputs or consumption, but the other way round.

Firstly, the multi-segmented refrigerant bank undergoes estimation for its (not yet reached) final or full-sized state, when all existing plants do no longer contain any chlorine-containing refrigerants, but are exclusively filled with HFCs. This balance state is assumed to remain stable over the medium-term. Unlike the sharply growing mobile air-conditioning sector, stability of the bank seems to be a realistic option for stationary refrigeration.

Secondly, starting from the "full" bank, via average plant lifetimes it can be calculated how much refrigerant must be filled into new systems per year, in order to maintain the bank, which annually diminishes by retired old systems. Given a general 10-year-lifetime, balanced input (In_{bank}) amounts to one tenth of the bank size.

Clearly, in this way empirical variations in the market cannot be taken account of, but so to speak only their long-term means. The latter, in turn, are themselves just as reliable, as the model of the bank reflects the reality.

Thirdly, in the above-described way annual HFC input over the 1990s will not be met exactly. It is well known that HFCs did not supersede ODS refrigerants in new systems on a certain qualifying date. From 1993 onwards, new refrigeration systems were being filled over years simultaneously with both kinds of refrigerants. Thus, information is necessary on the – annually rising – proportions of HFCs in calculated balanced input into new systems. For the most important refrigerants such as 404A and 134a, these data are available from interviews.

In the face of the differences between the two sub-sectors of commercial refrigeration, the first sub-sector, the general food trade, will be treated separately from the second sub-sector, the other commercial refrigeration. First, the multi-step determination of the annual refrigerant input (= consumption) in general food is carried out.

1.1 Annual HFC consumption for the general food trade

1.1.1 The model of the refrigerant bank in general food trade 2001/2003

Table 1: Number of refrigerating plants in food trade by refrigeration and freezing, installed refrigerating capacity (Qo in kW), and refrigerant (HFC), by shop formats										
		Freezing		Refrigeration		Freez	Refr	Total	404A	134a
Shop format/ Systems	Number	Qo kW	HFC kg/kW	Qo kW	HFC kg/kW	HFC t	HFC t	HFC t	80%	20%
Food retailing										
Superstores										
Central systems	681	56	2.5	215	1.8	95.3	263.5	358.9	287.1	71.8
Consumer markets										
Central systems	1682	32	2.5	85	1.8	134.6	257.3	391.9	313.5	78.4
Large supermarkets										
Central systems	4615	9	2.5	35	1.8	103.8	290.7	394.6	315.7	78.9
Multi-deck cabinets	137010			0.6	0.67		54.8	54.8	43.8	11.0
Frozen food islands	13701	4	1			54.8		54.8	43.8	11.0
Small supermarkets										
Central systems	4615	3	2.5	30	1.8	34.6	249.2	283.8	227.1	56.8
Multi-deck cabinets	91340			0.6	0.67		36.5	36.5	29.2	7.3
Frozen food islands	9134	4	0.5			18.3		18.3	14.6	3.7
Grocery markets	45900									
Central systems	8779	3	2.5	13	1.8	65.8	205.4	271.3	217.0	54.3
Serve-over cases	105362			0.2	1		21.1	21.1	16.9	4.2
Multi-deck cabinets	53715			1.2	0.67		43.0	43.0	34.4	8.6
Frozen food islands	53715	0.6	0.67			21.5		21.5	17.2	4.3
Freezers	26857	0.72	0.69			13.4		13.4	10.7	2.7
Cold rooms	19180			8	0.5		76.7	76.7	61.4	15.3
Freezer rooms	19180	3	1			57.5		57.5	46.0	11.5
Discounters										
Central systems	13135	3	2.5	30	1.8	98.5	709.3	807.8	646.2	161.6
Multi-deck cabinets	183890			0.6	0.67		73.6	73.6	58.8	14.7
Frozen food islands	13135	4	0.5			26.3		26.3	21.0	5.3
Food whole sale										
Cash & Carry-markets										
Central systems	600	100	2.5	300	1.8	150.0	324.0	474.0	379.2	94.8
Small cold stores										
Central systems	750	80	2.5	60	1.8	150.0	81.0	231.0	184.8	46.2
Subtotal	806976							3710.7	2968.6	742.1
Bottom-up-Surcharge		10% on all						371.1	296.9	74.2
Central systems	768673							321.3	257.1	64.3
Condensing units	119001							49.7	39.8	9.9
Total	887674							4081.8	3265.4	816.4

Explanation: For each shop format in column 1 the assigned systems are listed, the domestic number of which is shown in the second column. Under the headings "Freezing" and "Refrigeration", the installed refrigerating capacity (Qo) in kW is entered left-hand, and the specific refrigerant (HFC) filling in "kg per kW installed" is shown right-hand. The product of "number" x "Qo (kW)" x "kg/kW" is the refrigerant quantity in t, firstly for freezing ("Freez") and secondly for refrigeration ("Refr"). The third column from right ("Total") sums both figures up to the total HFC quantity contained in all the systems of a particular line. Finally, this sum per line is sub-divided according to a fixed key of 80 to 20 into "404A" and "134a" shown in the two columns right.

1.1.2 Refrigerant bank and calculated HFC consumption in balance state

From the model in Table 1 total quantitative figures are derived for 404A and 134a in the final state of the banks (Table 2, last line to the right). In order to determine emissions, one needs to know whether the refrigerants come into centralised systems with highly complex piping and numerous connectors, emissions from which are relatively high, or in less emissive condensing units with a shorter stretch of on-site laid pipes, as it is typical of refrigerated counters, frozen food islands or multi-shelf cabinets, etc.

Table 2 shows the final HFC bank (balance state) by refrigerants and by plant's design.

Table 2: Final HFC bank of 404A and 134a by plant design in general food trade, in t

	404A	134a	Refrigerant total
Centralised systems	2827.7	706.9	3534.6
Condensing units	437.8	109.4	547.2
Total	3265.4	816.4	4081.8

Sources: Table 1.

Table 3 contains the calculated annual HFC consumption, given a general plant lifetime of 10 years (each figure represents one tenth of the respective quantity in Table 2).

Table 3: Calculated annual consumption of 404A and 134a by plant design in general food trade, in t/y

	404A	134a	Refrigerant total
Centralised systems	282.8	70.7	353.5
Condensing units	43.8	10.9	54.7
Total	326.6	81.6	408.2

Sources: Table 2.

1.1.3 Shares of HFC refrigerants for new equipment, 1993-1998

From 1993 onwards HFCs have been filled into new systems. The shares against ODS were constantly growing and reached 100% in case of 134a by 1997, in case of 404A by 1998.

Table 4: 1993-1998 Shares of HFCs vs. ODS in refrigerants for new systems

	1993	1994	1995	1996	1997	1998
HFC-134a	7%	25%	50%	75%	100%	100%
HFC 404A	1%	10%	33%	66%	85%	100%

Sources: see section 3.

1.1.4 Annual consumption of HFC refrigerants since 1993

The annual consumption of HFC-134a and 404A for centralised systems and condensing units in the general food trade can directly be taken from Table 3 regarding the years from 1998 onwards. For the time from 1993 to 1997, the balance values in Table 3 have to be weighted with the respective percentages shown in Table 4. The consumption figures arrived at this way have been entered in Table 5.

Table 5: 1993-2002 Calculated annual consumption of HFC-134a and 404A for new refrigeration systems in general food trade by plant design, in t/y										
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
HFC-134a										
Central. systems	4.9	17.7	35.3	53.0	70.7	70.7	70.7	70.7	70.7	70.7
Condensing units	0.8	2.7	5.5	8.2	10.9	10.9	10.9	10.9	10.9	10.9
HFC 404A										
Central. systems	2.8	28.3	93.3	186.6	240.4	282.8	282.8	282.8	282.8	282.8
Condensing units	0.4	4.4	14.4	28.9	37.2	43.8	43.8	43.8	43.8	43.8

1.2 Annual HFC consumption in other commercial refrigeration

1.2.1 The model of the refrigerant bank in other commercial refrigeration

The detailed model of the other commercial applications is too extensive for a presentation within the regular text. It is shown as an appendix to this F-Gas sheet. Here we start immediately with the results from that model.

1.2.2 Refrigerant bank and calculated HFC/PFC consumption in balance state

From the model presented in the appendix total values can be derived for the "final bank" as well as for the calculated annual consumption, sub-divided into the HFC refrigerants 404A, 134a, 407C, 23, and the PFC refrigerant 116 (the latter being a component of the low temperature blend 508B, together with HFC-23). In order to determine emissions it is relevant whether the refrigerants reach plug-in systems (refrigerators, freezers) or site assembled equipment.

Table 6 shows the final bank (balance state) by refrigerants and by system design.

Table 6: Refrigerant final bank in other commercial refrigeration by system design, in t					
	404A	134a	407C	23	116
Plug-in systems	241	473	n. e.	144*	n. e.
Site-assembled	3207	1692	494	n. e.	35
Total	3448	2165	494	144	35

Sources: Table in the appendix to this sheet. n. e. = not estimated.
* A considerable proportion of R-23 is filled together with R-116 in site-assembled systems.

Table 7 shows calculated annual HFC/PFC consumption, given a general plant lifetime of 10 years (each value represents one tenth of the respective quantity in Table 6).

Table 7: Calculated consumption of HFC/PFC in other commercial refrigeration by plant design, in t/y (balanced)					
	404A	134a	407C	23	116
Plug-in systems	24.1	47.3	n. e.	14.4*	n. e.
Site-assembled	320.7	169.2	49.4	n. e.	3.5
Total	344.8	216.5	49.4	14.4	3.5

Sources: Table 6; n. e. = not estimated.

1.2.3 Shares of HFC/PFC refrigerants for new equipment, 1993-2002

HFC/PFC has been filled into new equipment since 1993. Their share against ODS increased with growth rates different to each other. The 100% were reached in 134a by 1997 and in 404A by 1998. HFC-23 (in use since 1993) and PFC-116 (in use since 1996) reached the 100%-share by 1999. The HFC-blend 407C, in considerable use since 1997, needed the time until 2003 to reach the full 100%.

Table 8a: 1993-1999 Shares of HFC/PFC in refrigerants for new systems							
	1993	1994	1995	1996	1997	1998	1999
HFC-134a	7%	25%	50%	75%	100%	100%	100%
HFC 404A	1%	10%	33%	66%	85%	100%	100%
HFC-23	7%	7%	7%	14%	14%	21%	100%
PFC-116			0%	29%	57%	57%	100%

Sources: See section 3. The first two lines (134a, 404A) are identical to Table 4.

Table 8b: 1997-2003 Shares of HFC-407C in refrigerants for new systems							
	1997	1998	1999	2000	2001	2002	2003
HFC-407C	6%	14%	30%	51%	69%	89%	100%

Sources: See section 3.

1.2.4 Annual HFC/PFC consumption in other commercial refrigeration since 1993

Annual consumption of HFC and PFC refrigerants over the 1993-2002 period for new plug-in systems and new on-site assembled systems in the field of other commercial refrigeration is arrived at by weighting the balanced HFC/PFC values of Table 7 with their respective shares against ODS according to Tables 8a/8b. The resulting consumption figures are presented in Table 9.

Table 9: 1993-2002 Calculated annual consumption of HFC/PFC for new refrigeration systems in other commercial refrigeration by plant design, in t/y							
Refrigerant	134a		404A		407C	23	116
Design	Plug-in systems	Site-assembled	Plug-in systems	Site-assembled	Site-assembled	Plug-in systems	Site-assembled
1993	3	12	0,2	3		1	
1994	12	42	2,4	32		1	
1995	24	85	8	106		1	
1996	35	127	16	212		2	1
1997	47	169	21	273	3	2	2
1998	47	169	24	321	7	3	2
1999	47	169	24	321	15	14.4	3.5
2000	47	169	24	321	25	14.4	3.5
2001	47	169	24	321	34	14.4	3.5
2002	47	169	24	321	44	14.4	3.5

Sources: Calculated from Table 7 and Tables 8a/8b.

1.3 HFC/PFC consumption for old systems in commercial refrigeration 1993-2002

Following the CFC-Halon Ban Ordinance, from 1995 onwards (partially even since 1993) in a number of existing systems the refrigerants CFC-12 or R-502 (HCFC-22/CFC-115) were replaced by HFC and PFC containing service refrigerants. CFC-12 was exchanged mainly for HFC-134a, either pure or as a component in drop-in refrigerants such as 413A. HFC-125, which is a component in the blends 402 A/B, 417A (Isceon 59) and Isceon 89, was important in replacing R-502. HFC-152a, contained 13% in the mixture 401A, is worth mentioning, too. R-401A was widely used to replace CFC-12 in old equipment. Finally, there is also a PFC of relevance, namely PFC-218, which is an ingredient of some drop-in refrigerants: 403 A/B (Isceon 69), 413 A (Isceon 49), and Isceon 89.

Annual sales figures of these service refrigerants are well known from interviews with producers and from special investigative studies. The five main HFCs/PFCs used are listed in the following Table 10 with their annual domestic consumption. Please note that a distinction between general food trade and other commercial refrigeration is not made.

Table 10: 1993-2002 Consumption of new HFCs and PFCs as replacements for CFC-12 and R-502 in the entire commercial refrigeration, in t/y

HFC/PFC	HFC-134a	HFC-404A	HFC-125	HFC-152a	PFC-218
1993			6		1
1994			54		3
1995	60	10	84	6.5	8
1996	140	20	84	13	12
1997	200	40	84	39	14
1998	200	30	69	26	19
1999	100	20	31	13	8
2000			6	5	5
2001			0.9		5
2002			0.9		3

Sources: See section 3.

1.4 Total consumption for old and new systems in commercial refrigeration

Table 11 summarises total HFC/PFC consumption for stationary refrigeration plants over the 1993 to 2002 period, which is the sum of the total consumption for new-installed plants during that time (Table 5, 9) and of the total consumption of new HFC/PFC for CFC-replacement in old systems (Table 10).

Table 11: 1993-2002 Total HFC/PFC consumption for old and new stationary systems in the entire commercial refrigeration in t/y

HFC/PFC	134a	404A	407C	23	116	125	152a	218
1993	21	7		1		6		1
1994	75	67		1		54		3
1995	**209**	**232**		1		84	6.5	8
1996	**364**	**463**		2	1	84	13	12
1997	**498**	**611**	3	2	2	84	39	14
1998	**498**	**701**	7	3	2	69	26	19
1999	**398**	**691**	15	14.4	3,5	31	13	8
2000	298	671	25	14.4	3,5	6	5	5
2001	298	671	34	14.4	3,5	0.9		5
2002	298	671	44	14.4	3,5	0.9		3

Sources: Calculation via Tables 5, 9, 10. Bold: consumption for old as well as for new plants.

Comment on annual consumption in the entire commercial refrigeration

In the years 1993 and 1994, HFC-134a was the main refrigerant. Its importance has been surpassed, however, by HFC-404A (incl. 507) since 1995. This happened against the background that the traditional division into three refrigerants, namely one (R-12) for normal refrigeration (chilling), another for freezing (R-22) and a third (R-502) for still lower temperatures did not last any longer. In many cases, the users wanted 404A to be the only refrigerant for the whole temperature range, even in normal refrigeration, for which HFC-134a was originally designated. The consumption of HFC-125 is rather high between 1994 and 1999. In the first line, this goes back to the extensive R-502 substitution in old systems. The respective new systems run on 404A.

Data on HFCs for new systems is derived from the two underlying models for commercial refrigeration and is just as robust as the models themselves. The model data can be controlled only to a limited extension by sales data of producers. The drop of HFC-134a and the stagnation of 404A as of 1999 do not inevitably result in dropping sales figures. This is because sales include not only consumption for new systems, but also the – increasing – quantities used to compensate emissions.

2. Emissions on the first HFC/PFC fill of old and new refrigeration systems

Manufacturing or filling emissions are in principle rather low in refrigeration plants. Nevertheless, their reporting from 1995 onwards is required by CRF.

2.1 Emission factor of filling

Generally, an emission factor (EF_{manu}) of 0.2% is applied to annual first-fill quantities of HFC/PFC refrigerants.

Plausibility check: This EF_{manu} is based on experience that per filling operation more or less than one hose filling of 5 to 10 grams (length of the hose: 1 metre) escapes to the atmosphere. Roughly estimated, about 3 million operating plants can be assumed with 10,000 tonnes refrigerant content. Thus, the average charge amounts to 3.3 kg, and 5 to 10 grams per 3,300 grams are equal to 0.15 to 0.3%.

2.2 Manufacturing emissions from entire commercial refrigeration

Table 12: 1995-2002 HFC/PFC emissions from filling of new and retrofitted old stationary systems in commercial refrigeration, in t/y (EF_{manu} = 0.2%)

Refrigerant	134a	404A	407C	23	116	125	152a	218
1995	0.418	0.464		0.002		0.168	0.013	0.016
1996	0.728	0.926		0.004	0.002	0.168	0.026	0.024
1997	0.996	1.222	0.006	0.004	0.004	0.168	0.078	0.028
1998	0.996	1.402	0.014	0.006	0.004	0.138	0.052	0.038
1999	0.796	1.382	0.030	0.029	0.007	0.062	0.026	0.016
2000	0.056	1.343	0.050	0.029	0.007	0.012	0.010	0.004
2001	0.056	1.343	0.068	0.029	0.007	0.002		0.004
2002	0.056	1.343	0.088	0.029	0.007	0.002		0.006

Sources: Calculation from Table 11. The consumption figures have been multiplied by 0.2%.

Comment

Table 12 shows, in absolute terms, first-fill emissions are just in the range of some kilograms with exemption for the main refrigerants HFC-134a and HFC 404A. Manufacturing emissions of 404A are higher than 1 t/y since 1997, emissions of 134a figured in 1997/98 near to 1 t/y and amount to somewhat above 0.5 t/y ever since.

3. Collection of activity data and sources of information

In the absence of direct statistical surveys on annual refrigerant consumption in commercial refrigeration, this quantity must be estimated indirectly through several determinants contained in two models, which are supposed to reflect the situation in food trade as well as in other commercial refrigeration. Of decisive importance is the internal structure of the two refrigerant banks in their final state. The point is to ascertain for every individual application the number and design of systems and their application-specific refrigeration data, especially the typical refrigeration capacities.

For a large part the model of general food trade ("supermarkets") and the model of other commercial refrigeration are based on data from the 2002 DKV status report "Energiebedarf für die technische Erzeugung von Kälte" provided by FKW-Hannover (supermarkets) and ILK-Dresden (other refrigeration). Subdivision of the two sectors, number of systems, and average refrigerating capacities are adopted from there.

As the application-specific refrigerating capacities have been given without refrigerant charges, the next step was to estimate these associated charges in kg, which required stating several application-specific indicators of "kg HFC/kW". This was done by Öko-Recherche together with the refrigeration experts from Solvay Fluor & Derivate, Mr Meurer and Mr Flohr, in 2003 (partially with the assistance of external experts and specialist literature).

In addition, the refrigerants were sub-divided into several types with the aid of internal sales data of the producer Solvay. In the course of this exercise the basic data of the above-mentioned FKW/ILK study were checked up, in some cases changed, and supplemented with missing applications, which were known from former studies made by Öko-Recherche as well as by FKW. The most important supplemented positions are food wholesale, milk and fruit cooling in agriculture and the bottom-up surcharge as substitute for further applications that have not yet been found.

With that, some older models presented by Öko-Recherche have been updated, as well as many data from several status reports carried out by FKW on behalf of the Umweltbundesamt in the 1990s.

The data on consumption of service refrigerants in the 1990s and the HFC shares against ODS from 1993 to 2002 for new systems have been estimated by means of direct interviews with each HFC producer who is represented in Germany. Apart from this, HFC producers helped control and correct the two models in commercial refrigeration with respect to annual HFC consumption that was derived from them.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Fachgespräch zum Thema "Umrüstung von bestehenden Kälte- und Klimaanlagen in Gewerbe und Industrie" mit dem Kältehandwerk (BIV und VDKF) und der Transfrigoroute, Umweltbundesamt Berlin, 08.05.95.
FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz von R 12 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, im Auftrag des Umweltbundesamtes, Statusbericht im Auftrag des Umweltbundesamtes, Berlin, Hannover, November 1995.
FKW: Ersatz von R 502 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, im Auftrag des Umweltbundesamtes, Texte 29/97, Berlin, Juni 1997.
Linde: Linde Refrigeration Engineering Phasing out CFCs and HCFCs in the food trade; Linde AG, 1997.
Steinborn, Dieter, Deutsche Kältebranche – vielfältige Einsatzgebiete bringen einen Umsatz von 17 Mrd. DM, in: Ki Luft und Kältetechnik 2/1998, 59-62.
FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz der FCKW R11, R13, R503, R13B1, R113, R114 und R12B1 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, Statusbericht im Auftrag des Umweltbundesamtes, Berlin, Hannover, Mai 1998.
Öko-Recherche: R 12 replacement in existing equipment from 1996 to middle of 1998. Report on the Umweltbundesamt (in German), August 1998.
http://www.oekorecherche.de/deutsch/berichte/volltext/vollR12.pdf
Winfried Schwarz, HFKW-Emissionen aus Kälte- und stationären Klimaanlagen. Aus einer neuen Studie des Umweltbundesamts zu Minderungspotentialen fluorierter Treibhausgase in Deutschland, in: DIE KÄLTE & Klimatechnik 4/2000, S. 16.
DKV, Energiebedarf für die technische Erzeugung von Kälte, Statusbericht des Deutschen Kälte- und Klimatechnischen Vereins Nr. 22, Juni 2002.
EHI, Handel aktuell 2001 – Struktur, Kennzahlen und Profile aus dem deutschen und internationalen Handel, Euro-Handelsinstitut, Köln, 2002.
BKT Bonnet Kältetechnik GmbH, Mannheim, Fachgespräch über Kühlanlagen des allgemeinen Lebensmittelhandels, Weinheim, 08.08.02.
DuPont Deutschland GmbH, Bad Homburg, Fachgespräch mit Katja Schwaab (Umweltbundesamt) und Winfried Schwarz (Öko-Recherche), Bad Homburg, 04.11. 02.
Öko-Recherche/Solvay Fluor: Conference on basic data and sales quantities for HFC in stationary refrigeration and air-conditioning applications. Participants: Winfried Schwarz (ÖR), Christoph Meurer (Solvay) und Felix Flohr (Solvay), Hannover 26.03.03.
Haaf, Siegfried u. Pauls, Gerlef, Linde AG, Geschäftsbereich Linde Kältetechnik, Köln, Fachgespräch im Umweltbundesamt, Berlin, 25.06.03.
Refrigerant-Producers. Direct survey 1999 and 2003 on sales figures and perspectives for chlorine-free refrigerants for use in stationary refrigeration and air-conditioning:
Rhodia Limited, Bristol, UK 18.02. 99 u. 10.10.03.
Deutsche ICI GmbH bzw. Ineos Fluor International Ltd., Frankfurt, 16.03.99 u. 10.10.03.
Du Pont Deutschland GmbH, Bad Homburg, 17.02.99 u. 10.10.03
Elf Atochem bzw. ATOFINA Deutschland GmbH, Düsseldorf, 12.04.99 u. 10.10.03
Westfalen AG, Münster, 24.02.99 u. 10.10.03
Solvay Fluor und Derivate GmbH, Hannover, 16.03.99 u. 10.10.03.
ILK Dresden/FKW Hannover, Aktuelle TEWI-Betrachtung von Kälteanlagen mit HFKW- und PFKW-Kältemitteln unter Berücksichtigung der unterschiedlichen Rahmenbedingungen für verschiedene Anwendungsgebiete, im Auftrag des Forschungsrats Kältetechnik e.V., FKT 96/03, Frankfurt, November 2003.

4. Estimation and source of information of the filling emission factor

The emission factor EF_{manu} (0.2%) is based on estimations by Öko-Recherche.

5. Quality control and uncertainty assessment of data I

Activity data. The refrigerant bank in its final state, broken down into numerous applications and system designs, is the starting point for all further activity data. The number of system operators is based on official and other statistics from 2002/2003. Experts, who additionally carried out direct interviews with equipment suppliers as well as with system operators, estimated the typical refrigerating characteristics of these systems. The most crucial point was the next step, namely estimation of the average refrigerant charge in kg per kW capacity. Here frequently rules of thumb had to be made use of. Further steps to finish the models were subdivision into refrigerant types and estimation of the average systems lifetimes. It is only this point, from which the modelled annual refrigerant consumption for new systems can be derived.

The error risk that has accumulated up to then is relatively large. In annual consumption (C_{manu}) of different refrigerants, it figures at least ± 30%, in the undivided overall refrigerant consumption the error risk still amounts to ± 20%. So far, the only correction factor is the market estimation by refrigerant producers, which is in fact an instrument of limited use, as producers know the total sales, but cannot distinguish between sales for charging new systems and sales for offsetting emissions. It is only the sector of service refrigerants where the data estimation is reasonably reliable (± 10%).

Emission factor. The emission factor (EF_{manu}) 0.2% is based on enquiries of numerous practical experts. Since there are no measurements available, the effective value may be 0.15% or 0.3%. Total emissions from commercial refrigeration (manufacturing plus operating emissions) are just marginally affected by this uncertainty.

6. Relation to IPCC method I

In Table 3.22 (IPCC GPG), "best estimates for charge, lifetime, and emission factors" are presented for "Stand-alone Commercial Application" as well as for "Medium & Large Commercial Refrigeration". The charges range from 0.2 to 6 kg and from 50 to 2000 kg respectively. The lifetime is estimated at between 7 and 10 years.

According to IPCC-GPG, "initial emission" ranges from 0.5 to 3 percent of the initial charge. With 0.2 percent, the country-specific factor by ÖR is far below that suggestion.

7. Entry in CRF I

The CRF-Table where data on fluids "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered is Table 2(II).Fs1. Entries in the columns B and H extend from row 14 to row 27 for the numerous refrigerants in commercial refrigeration.

II. Bank and operating emissions from bank

As remarked in the introduction to Part I, on account of negligible foreign trade with HFC/PFC containing stationary refrigeration systems annual input to domestic HFC/PFC bank (In_{bank}) basically equals domestic HFC consumption (C_{manu}) considered in Part I. Thus, annual input can be taken from Part I in order to determine the size of domestic banks.

8. HFC/PFC bank in systems of commercial refrigeration

Since the starting year 1993, the HFC/PFC end-of-year bank (EB n) in stationary refrigeration systems has annually increased by the amount of annual domestic input (In_{bank}), as to date considerable departures from the bank have not yet taken place. Systematic decommissioning of refrigeration systems is not to be expected before 2003 in view of a ten-year-lifetime. That likewise applies to converted old systems.

The average annual bank (B n) is half the sum of the last year's end-of-year bank (EB n-1) and the current year's end-of-year bank (EB n). The equation is as follows.

$$B\,n = \frac{EB\,n\text{-}1 + EB\,n}{2} \qquad \text{Where:} \quad EB\,n = EB\,n\text{-}1 + In_{bank}\,n$$

The time series of the average annual banks (B n) is shown in Table 13. The refrigerants are distinguished by different system designs, as their emission tightness differs from each other.

Table 13: 1995-2002 Average annual HFC/PFC banks (B n) in stationary commercial refrigeration systems (incl. converted systems), in t

KM	System design	1995	1996	1997	1998	1999	2000	2001	2002
134a	Central/site-assembly	137	287	497	736	976	1216	1456	1696
	Condensing units	6	13	23	34	45	55	66	77
	Plug-in units	27	56	98	145	192	240	287	334
	Old systems	30	130	300	500	650	700	700	700
	Subtotal 134a	***200***	***486***	***918***	***1415***	***1863***	***2211***	***2509***	***2807***
404A	Central/site-assembly	166	465	920	1479	2082	2685	3289	3892
	Condensing units	12	34	67	107	151	195	239	282
	Plug-in units	7	19	37	59	83	107	132	156
	Old systems	5	20	50	85	110	120	120	120
	Subtotal 404A	***190***	***538***	***1074***	***1730***	***2426***	***3107***	***3780***	***4450***
407C	Site-assembled	0	0	2	7	18	38	67	106
23	Plug-in units	3	4	6	9	17	32	46	60
116	Site-assembled	0	1	2	4	6	9	13	16
125	Old systems	102	186	270	347	396	415	418	419
152a	Old systems	3	13	39	72	91	100	103	99
218	Old systems	8	18	31	48	61	67	72	76
	Total	**505**	**1244**	**2340**	**3630**	**4879**	**5980**	**7007**	**8038**

Sources: Consumption data from Tables 5, 9, 10, recalculated according to the equation above.

9. Factors of operating emissions from bank

Operating HFC/PFC emissions from stationary refrigeration plants in commercial applications strongly differ from each other according to plant design.

The following factors for annual use-phase emissions are applied:

1. Centralised systems in general food trade 10%,
2. On-site assembled systems in other commercial use 10%,
3. Condensing units in general food trade 5%,
4. Plug-in systems in other commercial applications 1.5%,
5. Old equipment in the total commercial refrigeration 15%.

10. Estimation of operating emission factors

The emission factors of centralised systems in food markets are estimated at some 10% by most experts on condition that gradual regular refrigerant release and sudden irregular loss caused by breakdowns are taken together, and that the refrigeration plant has been designed to run with HFCs. This value has representatively been confirmed by a study on "leak tightness of refrigeration plants" conducted on behalf of the German Forschungsrat Kältetechnik by ILK Dresden on the basis of 62 centralised and distributed plants in supermarkets in Hesse and Saxony. This value is used here for centralised systems and other on-site assembled plants.

In contrast, for single plug-in systems, which do not need on-site-laid refrigerant pipes and run with hermetic compressors, an emission factor of only 1.5% (including cases of total loss) is used.

The value of 5% is used for distributed condensing units, which are assembled on site, however with relatively short pipes and just few joints. It is based on plausibility, that emissions there are lower than from widely ramified systems, but higher than from plug-in systems. Measurements are not available.

Old systems stem from the era of chlorine-containing refrigerants and with that from the time before increased attention for leak tightness. The 15% were common knowledge amongst the experts in the first half of the 1990s (see literature of FKW 1995, 1997).

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz von R 12 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, im Auftrag des Umweltbundesamtes, Status report on behalf of the Umweltbundesamt, Berlin, Hannover, November 1995, S. 96.
FKW: Ersatz von R 502 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, im Auftrag des Umweltbundesamtes, Texte 29/97, Berlin, Juni 1997, S. 90.
Winfried Schwarz, HFKW-Emissionen aus Kälte- und stationären Klimaanlagen. Aus einer neuen Studie des Umweltbundesamts zu Minderungspotentialen fluorierter Treibhausgase in Deutschland, in: DIE KÄLTE & Klimatechnik 4/2000, S. 16.
ILK Dresden, Projektleitung Ralf Birndt, Dichtheit von Kälteanlagen, im Auftrag des Forschungsrats Kältetechnik, Frankfurt am Main 1999.

BKT Bonnet Kältetechnik GmbH, Mannheim, Fachgespräch über Kühlanlagen des allgemeinen Lebensmittelhandels, Weinheim, 08.08.2002.
Öko-Recherche/Solvay Fluor: Conference on basic data and sales quantities for HFC in stationary refrigeration and air-conditioning applications. Participants: Winfried Schwarz (ÖR), Christoph Meurer (Solvay) und Felix Flohr (Solvay), Hannover 26.03.03.
ILK Dresden, Verbesserung der Dichtheit kältetechnischer Erzeugnisse, im Auftrag des Forschungsrats Kältetechnik e.V., FKT 86/01, Frankfurt, Januar 2003.

11. Operating HFC emissions from bank

Operating emissions in a particular year n are arrived at by applying the factor of operating emissions (EF_{op}) to the average bank of year n (B n), which has been built up by several annual HFC/PFC inputs over the past time – see section 8.

$$EF_{op} \text{ (in \%)} \quad x \quad B\,n$$

With EF of 1.5%, 5%, 10% and 15% for HFC/PFC containing new and old systems in commercial refrigeration the specific equation of operating emissions is as follows:

$$EF_{op} \text{ (1.5\%, 5\%, 10\%,15\%)} \quad x \quad B\,n$$

Operating annual HFC/PFC emissions from bank are shown in Table 14.

Table 14: 1995-2002 Operating HFC/PFC emissions from banks in stationary commercial refrigeration systems (incl. converted systems), in t/y

RF	System design	1995	1996	1997	1998	1999	2000	2001	2002
134a	Central/site-assembly	14	29	50	74	98	122	146	170
	Condensing units	0	1	1	2	2	3	3	4
	Plug-in units	0	1	1	2	3	4	4	5
	Old systems	5	20	45	75	98	105	105	105
	Subtotal 134a	***19***	***51***	***97***	***153***	***201***	***234***	***258***	***284***
404A	Central/site-assembly	17	46	92	148	208	269	329	389
	Condensing units	1	2	3	5	8	10	12	14
	Plug-in units	0,1	0,3	1	1	1	2	2	2
	Old systems	1	3	8	13	17	18	18	18
	Subtotal 404A	***19,1***	***51,3***	***104***	***167***	***234***	***299***	***361***	***423***
407C	Site-assembled			0,2	1	2	4	7	11
23	Plug-in units	0,1	0,2	0,3	0,4	0,9	2	2	3
116	Site-assembled	0,0	0,1	0,2	0,4	0,6	1	1	2
125	Old systems	15	28	41	52	59	62	63	63
152a	Old systems	0,5	2	6	11	14	15	15	15
218	Old systems	1,2	3	5	7	9	10	11	11
	Total	**54**	**134**	**252**	**391**	**519**	**624**	**718**	**812**

Sources: Table 13 and equation in this section.

Comment

HFC/PFC emissions from banks in commercial refrigeration systems are increasing constantly with the growth in average banks. In relation to the total bank (Table 13, last line), total emissions (Table 14, last line) make up integrated emission rates between 10.8 and 10.1%. From Table 14 emerges that HFC/PFC emissions from highly emissive converted old systems are of decisive importance for overall emissions. Still in 2002, they accounted for 26% of total emissions. As soon as from 2003 onwards old systems are being retired from banks, "total emissions rate" will consequently drop. At the same time, absolute emissions will drop then from their 2006 peak at roughly 1,000 t/y (all refrigerants together), and will level out on constant 925 t/y from ca. 2010 onwards. The final state of approx. 10,300 t will be reached then with an emission rate of about 9%.

Due to the emissions rate of 10%, centralised systems and other on-site-assembled plants will show determining influence on total emissions over the near future. Therefore, the highest emission reduction is achievable in this application sector. That can be expected to take place in the course of implementation of legal measures to mitigate F-gas emissions from stationary refrigeration.

12. Quality control and uncertainty assessment of data II

Emission factor. The (activity) data on the bank have already been discussed in Part I. The emission factors, which were introduced in Part II can be considered highly reliable compared with other emission factors, as the 10% value for centralised and other likewise on-site-assembled systems has been confirmed by a representative field study in Germany, recently. At the same time, this 10% value serves as benchmark for the emission factors 5% and 15% respectively. The 1.5% for single plug-in systems can be taken for safe, too. According to Öko-Recherche, the deviations in case of the factors 5%, 10%, and 15% may be in the order of ± 2% (absolute).

13. Relation to IPCC method II

IPCC manual GPG gives under "3.7.4 Stationary refrigeration sub-source category" the general equation 3.42 of operating emissions in line with a bottom-up approach:

Operating Emissions = (Amount of HFC and PFC Stock in year t) * (x/100)

In the equation, x/100 is the emission factor. As default emission factor in percentage of initial charge/year (best estimates) for "Stand-alone Commercial Applications" (identical to condensing units as described in this study), a magnitude of from 1 to 10 is proposed in Table 3.22. ÖR uses 5%. For "Medium & Large Commercial Refrigeration", which is the common heading for centralised and on-site assembled systems as described in this study, a value between 10 and 30% is suggested. The 10 to 15% used by ÖR are localised in the lower region of the IPCC default values.

14. Entry in CRF II

The CRF Table where data on "Average annual stocks" and "Emissions from stocks" are primarily entered for the numerous refrigerants is Table 2(II).Fs1, rows 14 to 27, with the columns C and I.

Appendix – Model of Other Commercial Refrigeration

Other comm. Refrigeration I	Number	System-design	Qo kW	HFC kg/kW	HFC kg/syst.	HFC in kg	404A	134a	23 116	407C
Butcher's shops										
Enterprises	19402	freezer room	5	2.5	12.5	242525	242.5			
(thereof branches)	11401	cold room	5.5	2	11	213422	160.1	53.4		
		processing room	4.2	1	4.2	81488	40.7	40.7		
		refrigerated cabinet	3.6	1	3.6	69847		69.8		
			18.3		**31.3**	**607283**				
Bakeries	18468	fermentation interupt.	2.69	2.5	6.725	124197	124.2			
		cold cells (cases)	3.38	1	3.38	62422		62.4		
		freezer cells (cases)	0.62	1.5	0.93	17175	17.2			
			6.69		**11.035**	**203.794**				
Inns	49548	counter	0.67	1	0.67	33197		33.2		
		cold cells (cases)	1.28	1	1.28	63421		63.4		
		freezer cells (cases)	1.26	1.5	1.89	93646	93.6			
		small refriger. units	0.67	1	0.67	33197		33.2		
			3.88		**4.51**	**223461**				
Ice cream parlours	6785	ice-cream show case	1.13	2	2.26	15334	15.3			
		refrigerated counter	1.05	1	1.05	7124	7.1			
		chest freezer	1.13	1	1.13	7667	7.7			
		freezer	1.01	1	1.01	6853	6.9			
		ice cream machine	2	2	4	27140	27.1			
		pasteuriser	3.2	1	3.2	21712	21.7			
		whipped cream mach.	0.1	1	0.1	679	0.7			
		soft ice machine	3	1.8	5.4	36639	36.6			
			12.62		**18.15**	**123148**				
Snack bars	24408	refrigerated counter	1.05	0.5	0.525	8477		8.5		
without domestic refrigeration only	16147	bottle refrigerator	0.53	1	0.53	8558		8.6		
		comm. refrigerator	0.49	1	0.49	7912		7.9		
		commercial freezer	0.91	1.5	1.365	22041	22.0			
		cold storage cell	2.86	1	2.86	46180		46.2		
			2.98		**5.77**	**93168**				
Canteens/caterers	8210	cold storage cell	2.2	1	2.2	18062		18.1		
		freezer cell	3.2	1.5	4.8	39408	39.4			
		small refrigeration	2.3	0.5	1.15	9442		9.4		
					8.15	**66912**				
Restaurants	92642	cold storage cell	2.2	1	2.2	203812		203.8		
		freezer cell	3.2	1.5	4.8	444682	444.7			
		small refrigeration	2.3	0.5	1.15	106538		106.5		
					8.15	**755032**				
Canteen kitchens	30000	cold storage cell	2.2	1	2.2	66000		66.0		
		freezer cell	3.2	1.5	4.8	144000	144			
		small refrigeration	2.3	0.5	1.15	34500		34.5		
					8.15	**244500**				
Small flower shops	11000	cold storage cell	**4.73**	1	**4.73**	**52030**		52		
Large flower shops	5415	cold storage cell	**16**	1	**16**	**86640**		86.6		
Cemeteries	4500	cold storage cell	**4.73**	1	**4.73**	**21285**		21.3		
Plants/nurseries	20000	cold storage cell	**3.315**	1	**3.315**	**66300**		66.3		
Retail beverages	9820	bottle refrigerator	0.47	0.5	0.235	2308		2.3		
		chest freezer	0.15	0.7	0.105	1031		1.0		
			0.62		**0.34**	**3339**				
Pharmacies	21590	refrigerator for drugs	**0.39**	0.5	**0.195**	**4210**		4.2		
Vending machines	200000	refrigerator			0.25	**50000**		50.0		

Other comm. refrigeration II	Number	system design	Qo kW	HFC kg/kW	HFC kg/sys.	HFC in kg	404A	134a	23 116	407C
Filling stations	16617	multi-deck cabinet	0.47	1	0.47	7810		7.8		
		freezer	0.63	0.7	0.441	7328	7.3			
		frozen food island	1.1	0.7	0.77	12795	12.8			
		cold storage cell	1.8	1	1.8	29911		29.9		
			4.00		**3.48**	**57844**				
Laboratories	6600	commercial fridge	0.45	0.5	0.225	1485		1.5		
	3300	commercial freezer	0.39	0.7	0.273	901	0.9			
	3300	cold storage cell	3.3	1	3.3	10890		10.9		
			4.14		**3.798**	**13276**				
Dairy cattle	25000	immersion cooling	**3**	0.5	**1.5**	37500	37.5			
	50000	cooling tanks	**6**	1	**6**	300000	225			75
	50000	cooling tanks	**10**	1	**10**	500000	250			250
						837500				
Fruit & vegetable	52000	cold room	13	1	**13**	**676000**	169	338		169
Flower whole sale	600	cold room	**30**	1	**30**	**18000**		18		
Military										
- stationary		kitchen refrigeration	8000	1		8000		8		
		kitchen freezing	1000	1.5		1500	1.5			
		hospitals	4500	1		4500		4.5		
		chilled devices	41500	1		41500	41.5			
		other refrigeration	10000	1		10000		10		
- **mobile**		single devices	42000	1		42000		42		
		marine	40000	1		40000	40.0			
		provisions marine	500	1		500		0.5		
						148000				
Hotel/guesthouse	19968	refrigeration	2.2	1	2.2	43930		43.9		
with beds		freezing	3.2	1.5	4.8	95846	95.8			
					7	**139776**				
Boarding houses	10707	refrigeration	1	0.5	0.5	53535		5.4		
with beds		freezing	1	0.7	0.7	74949	7.5			
					1.2	**12848**				
Hospitals	2242	cold storage cell	2.2	1	2.2	4932		4.9		
(without air condit.)		freezer cell	3.2	1.5	4.8	10762	10.8			
	208	pathology	1	1	1	208		0.2		
					8	**15902**				
Rehabil. centres	1393	cold storage cell	2.2	1	2.2	3065		3.1		
		freezer cell	3.2	1.5	4.8	6686	6.7			
					7	**9751**				
Blood bottles	400	quick-freezing	6.25	1.5	9.375	3750			3.75	
Blood donation		interim storage	1.4	2	2.8	1120	1.1			
		frozen blood stor.	10	2	20	8000	8			
		storage decentral.	1.2	2	2.4	960	1			
					34.575	**13830**				
Funeral parlour	3000	chilling corpses	1	1	1	3000		3		
(with pathology)		freezing corpses	2	2	4	12000	12			
					5	**15000**				
Lab apparatus	30000	instead of 13B1			5	**150000**			150	
Low temp. labs	100000	instead R13. R503			0.25	**25000**			25	
Ice sports halls	136	25% with HFC	1311	2	2622	**89148**	89.1			
Outd. ice rinks	39	10% with HFC	1573	2	3146	**12269**	12.3			
Subtotal						**4835247**	**2481**	**1681**	**179**	**494**
Bottom-up-surch.	30% on subtotal (67% 404A – 33% 134a)					1450574	967	484		
Total						**6285820**	**3448**	**2165**	**179**	**494**

F-Gas-Sheet 9: Passenger Car Air Conditioning

F-Gas	**HFC-134a**
Application	**Mobile Air Conditioning of Passenger Cars**
Reported Years	**1995 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**
Emission Type 5	**Disposal Emissions**

Background

Equipment of new-registered passenger cars with air-conditioning (A/C) has been greatly rising since 1994. The A/C penetration (A/C ratio) increased from 19% to 87% over the 1994-2002 periods.

From 1994 (model year) onwards, new A/C systems for passenger cars have entered the domestic market exclusively with HFC-134a instead of CFC-12. The transition began in April 1991 with the S-class vehicles of Mercedes-Benz. In 1992, the other German manufacturers started introducing HFC-134a systems. At the end of 1993, the switchover was completed. In imported vehicles, refrigerant HFC-134a was not represented to a considerable extent before 1993. The process of changing to 134a, however, was completed at the beginning of 1994. In the following years, especially from 1996 to 1998, in a number of old A/C systems CFC-12 was exchanged for HFC-134a.

In the near future, new passenger cars without A/C will be exemptions. At the same time, as opposite tendency to rising HFC consumption, a reduction in the specific refrigerant charges takes place, which, however, cannot approximately compensate the growth in new registered cars equipped with A/C systems, and with that the growth in HFCs banked on the road.

Because of high operation emissions in conjunction with high number of units, A/C systems of passenger cars are by far the largest single source of emissions of fluorinated greenhouse gases in Germany.

I. Bank und operating emissions from bank

1 Activity data I. Annual domestic HFC input

1.A Annual new registrations of passenger cars with A/C

Direct inquiries of all the suppliers of passenger cars with more than 8,000 vehicles sold annually into the domestic market form the basis of the following presentation. For the 1993-2002 period, for each car model of German make and for 83% to 97% of the models of foreign make, the specific A/C ratio as well as the refrigerant charge have been determined and summarised to average annual figures. Information gaps in case of some imported models were closed by means of extrapolation based on KBA statistics. From that, the time series in Table 1 is derived.

Table 1: 1993-2002 New registrations of passenger cars (million units), their average A/C ratio (in %) and HFC refrigerant charge (in kg)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
New registered	3.429	3.930	3.194	3.209	3.314	3.496	3.528	3.736	3.802	3.378	3.342	3.253
A/C Ratio %	0.4*	1.5*	9.4*	18.5	25.0	37.9	51.8	62.3	73.5	79.6	84.1	86.6
Charge kg	1.20	1.03	0.94	0.88	0.88	0.88	0.83	0.82	0.76	0.76	0.73	0.70

Sources: Direct enquiries of manufacturers with relevant domestic sales (see section 3).
* Only HFC-134a, without R-12 systems. The year 1994 is the first year of comprehensive HFC-134a charging of new A/C systems.

Ex 1991, the first year of filling HFC-134a in new vehicle A/Cs, annual registrations of new passenger cars vary between 3.2 and 3.9 million units. Over the same time the A/C ratio has been raised from 10% (including R-12 systems) to 87% (only 134a systems). Simultaneously, the specific refrigerant charge has dropped from 1.20 to 0.70 kg, above all because more and more small vehicles are being equipped with A/C systems.

1.B Annual HFC input through new domestic passenger car A/Cs

Domestic HFC input to the bank (In_{bank}) through new (ex-works) A/C systems in year n is arrived at by means of Table 1 in two steps: Firstly, by weighting the new registrations of year n (line 1) with the A/C ratio of that year n (line 2). Secondly, through multiplication of the A/C-ratio-weighted number of units by that HFC charge (in kg) that is specific to the same year (line 3). The resulting annual HFC input through new domestic car A/Cs is entered in Table 2.

Table 2: 1993-2002 Annual HFC input through new domestic car A/Cs in t/y

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
134a in t	17	63	282	524	726	1,165	1,521	1,902	2,138	2,037	2,050	1,962

Sources: Data from Table 1.

1.C Additional HFC input due to re-fitting and R-12 replacement

By far the most part of A/C systems is installed and charged already in the car factory. As of 1994, however, a considerable number of A/C systems have been installed ex post. The estimated HFC quantity in after-market systems, which is not included in the figures above, is shown in Table 3 (line 1). Moreover, since 1995 a number of R-12 systems, which were no longer allowed by German law to be refilled, were converted to run with HFC-134a. The HFC quantities used for that are neither included in Table 2, but are shown separately (Table 3, line 2). The total annual HFC-134a first fill into A/C systems of domestically registered passenger cars is presented in Table 3, line 4, as the sum of charging new cars (taken from Table 2 into Table 3, line 3) and old cars. Charging old cars means to fill HFC refrigerants in after-market systems (no A/C existing beforehand) and in converted systems (running on R-12 beforehand). (Please note: "First filling" with 134a also includes old systems originally filled with CFC-12).

Table 3: 1994-2002 Annual filling of new HFCs in after-market and converted A/C systems, and corrected overall HFC input in domestic A/C systems, in t/y

	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. After-market in t	27	32	32	30	29	19	16	11	11
2. Conversions t	0	7	53	70	72	46	12	7	0
3. Charging new A/Cs	524	726	1,165	1,521	1,902	2,138	2,037	2,050	1,962
4. Corr. new charge t	551	765	1,249	1,621	2,003	2,204	2,065	2,061	1,973

Sources: Table 3 (New systems). Section 3 (After-market and converted R-12 systems).

Annual domestic input (In_{bank}) consists of three fractions: HFC input through A/Cs in new cars (In_{new}), input through after-market A/Cs (In_{after}), and input through old A/Cs which are converted to run with 134a (In_{conv}). The equation for year n is:

Equation 1:	$In_{bank}\ n = (In_{new} + In_{after} + In_{conv})\ n$

The necessity to treat after-market units and conversions separately results from the fact that residual lifetime of ex post installed and of converted A/C systems is shorter (8 and 7 years respectively), so that such systems are decommissioned earlier than ex-works A/C systems (12-year-lifetime) of the same filling year. Systematic decommissioning of after-market or converted systems commenced in 2002 (filling years 1994 and 1995). As of 2003, first ex-works A/C systems are retired systematically from the fleet, beginning with the still poor HFC filling year 1991.

That means that from 2002 onwards the removal of 134a-A/Cs must be taken account of when estimating operation emissions from banked HFCs. Thus, in 2002 disposal of some 27 t from after-market systems (charged in 1994) and of some 7 t from converted R-12-systems (HFC charged in 1995) must be considered.

2. HFC bank in passenger car air conditioners

The HFC end-of-year bank of the previous year (EB n-1) in car A/Cs increases over the current year n by domestic input of year n (In_{bank} n) to end-of-year bank of the current year n (EB n). According to equation 1, In_{bank} n is the sum of In_{new} + In_{after} + In_{conv}. This equation (2) sufficed until 2001, when the end-of-year bank of a particular year included only inputs and not yet any departures (outputs):

Equation 2:	$EB\ n = EB\ n\text{-}1 + In_{bank}\ n$

By departures must be understood the HFC quantity in retired systems due for disposal. This quantity is called De_{bank}. Therefore, equation 2 for determining the end-of-year bank must be developed further to equation 2 a:

Equation 2 a:	$EB\ n = EB\ n\text{-}1 + In_{bank}\ n - De_{bank}\ n$

In principle, the HFC quantity due for disposal in year n (De_{bank} n) equals the input of that year which dates back just as long as the (residual) lifetime (LT) of the A/C system lasts. The general equation (3) for determining this quantity is:

Equation 3:	$De_{bank}\ n = In_{bank}\ (n - LT)$

Since the lifetime (LT) is different for new, after-market, and converted A/C systems, the HFC quantity for disposal in year n (De_{bank} n) consists on its own part of three fractions, namely:

- Input through new systems 12 years ago (In_{new} n-12),
- Input through after-market systems 8 years ago (In_{after} n-8),
- Input through conversions of old systems 7 years ago (In_{conv} n-7).

Therefore, the specific equation (4) for HFC end-of-year bank in year n (EB n) is: End-of-year bank one year ago (EB n-1) plus input over year n ($In_{new} + In_{after} + In_{conv}$) minus quantity for disposal in year n (In_{new} n-12 + In_{after} n-8 + In_{conv} n-7).

Equation 4:
$EB\ n = EB\ n\text{-}1 + (In_{new} + In_{after} + In_{conv})\ n - (In_{new}\ n\text{-}12 + In_{after}\ n\text{-}8 + In_{conv}\ n\text{-}7)$

Reference quantities for emissions estimating are not end-of-year banks, but annual average banks, which result from two consecutive end-of-year banks. The average bank in year n (B n) is half the sum of the previous year's end-of-year bank (EB n-1) and of the current year's end-of-year bank (EB n) - see equation 5.

Equation 5:		
$B\ n = \frac{EB\ n\text{-}1 + EB\ n}{2}$	Where:	EB n follows equation 4

After integration of the data from Table 1-3 into equation 5 the following time series for the average HFC bank in domestic car A/C systems emerges, as of 1995:

Table 4: 1995-2002 Average HFC bank in domestic passenger car A/C systems, in t

	1995	1996	1997	1998	1999	2000	2001	2002
HFC-134a in t	1,295	2,302	3,737	5,549	7,652	9,786	11,849	13,849

Sources: Calculation based on data of section 1, following equation 5. The average banks of the years 1991 to 1994 are not relevant for estimating operation emissions as of 1995.

Comment on time series of activity data I

Both new registrations of passenger cars with air conditioner and average annual HFC banks show a steep rising tendency, expressing the rapidly growing equipment of new cars with A/C systems. Since 1998, a decrease in new after-market units is visible (Table 3), which is an outcome of the fact that the bulk of domestically sold passenger cars is already fitted ex-works with an A/C system. In 2000, the first time a drop in HFC input through new car A/Cs took place. Decreasing A/C penetration of new cars, however, did not cause this drop. Neither can it be sufficiently explained by decreasing numbers of after-market and converted units. Main reason, apart from a temporary reduction in new registrations, was the ongoing trend to reduce average refrigerant charges. The latter kept on being reduced between 1999 and 2002 from 0.76 kg to 0.70 kg (Table 1).

Saturation of A/C ratio may be anticipated at 95% of annual new registrations, while the reduction in specific refrigerant charge is assumed to continue. Taking both tendencies together, the growth of 134a in new domestic registrations (input) could peak in 2006 at some 2,532 t (calculated). The HFC bank, however, is assumed to grow longer, probably until 2015/16 to almost 30,000 t.

3. Collection of activity data and sources of information

Data as of 1995: The data on A/C ratios and charges has been determined by ÖR by means of direct inquiries of those carmakers who sell into the German market.
Objective was to ascertain for every reported year since 1995:
1) Number of domestically sold A/C systems from German car manufacturers,
2) Number of domestically sold A/C systems from foreign car manufacturers, and
3) Average specific refrigerant charge of A/C systems, separately for German and foreign car-makes.

The make-specific average A/C system charge depends on the sales composition of the individual car models, in that the models themselves have different and variable A/C system charges. These figures are not ready available at the auto companies. Consequently, data gathering consists for a large part in enquiries about the annual A/C ratio and AC charges of some 100 domestic and some 300 foreign models, of which only the total sales figures (regardless of the A/C ratio) are being published by official KBA statistics.

Transition 1991-1994: For the first time the complex period before 1994 was investigated by ÖR in the scope of a special study for the Umweltbundesamt on R-12-replacement in old systems, in the year 1998. A second investigation (only for German makes) was conducted in the framework of a study on emissions from mobile air conditioners for the Umweltbundesamt in 2001. The VDIK (Association of Motor Vehicle Importers) gave useful information on imported passenger cars.

After-market systems: Indications on after-market A/Cs stem from the market leader Waeco International, who has been contacted continuously over the past years.

Sources of information for activity data (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

1. A/C ratios and refrigerant charges by models of individual carmakers as of 1995
Adam Opel AG, Rüsselsheim, 22.05.96, 17.02.99, 12.06.01, 25.10.02, 05.09.03.
AUDI AG, Ingolstadt, 19.06.96, 24.02.99, 17.08.01, 21.10.02, 02.09.03.
BMW AG, München, 12.06.96, 11.03.99, 22.05.01, 21.10.02, 29.08.03.
Citroen Deutschland AG, Köln, 30.05.96, 03.03.99, 30.10.02, 12.09.03.
Daihatsu Deutschland GmbH, Tönisvorst, 15.03.99, 31.10.02, 26.09.03.
DaimlerChrysler AG (formerly Mercedes-Benz AG), Stuttgart, 07.06.96, 23.03.99, 26.07.01, 14.10.02, 01.10.03.
Deutsche Renault AG, Brühl, 11.06.96, 26.03.99, 21.10.02, 23.10.03.
Dr. Ing. h.c. F. Porsche AG, Zuffenhausen, 22.06.96, 23.02.99, 18.10.02, 29.08.03.
Fiat-Automobil AG, Heilbronn, ab 1997 Frankfurt (Fiat Group with makes Fiat, Alfa-Romeo, Lancia). 30.05.96, 02.03.99, 20.10.02, 28.08.03.
Ford Werke AG, Köln, 22.07.96, 29.03.99, 18.05.01, 14.10.02, 22.09.03.
Honda Deutschland GmbH, Offenbach, 17.06.96, 03.03.99. As of 2002: Honda Motor Europe (North) GmbH, same address. 19.11.02, 26.09.03.
Hyundai Motor Deutschland GmbH, Neckarsulm, 29.05.96, 15.03.99, 13.11.02, 18.09.03.
Kia Motors GmbH, Bremen, 01.09.03.

Mazda Motors Deutschland, Leverkusen, 30.05.96, 26.03.99, 08.10.02, 25.09.03.
Mitsubishi Motors Deutschland GmbH (Mitsubishi Auto Deutschland GmbH), Trebur, 07.06.96, 16.03.99, 29.10.02, 02.09.03.
Nissan Motors Deutschland GmbH, Neuss, 04.06.96, 02.03.99. As of 1998: Renault Nissan Deutschland AG, Brühl, 01.09.03.
Peugeot Deutschland GmbH, Saarbrücken, 05.06.96, 01.03.99, 23.10.02, 26.08.03.
Rover Deutschland GmbH, Neuss, 17.07.96, 01.03.99, 11.10.02. Ex 2003 no longer included in the survey. Make MINI now sub bei BMW.
Saab Deutschland, Bad Homburg, 03.06.96, 01.09.99, 10.10.02, 29.08.03.
SEAT Deutschland GmbH, Mörfelden, 04.06.96, 12.03.99, 09.10.02, 29.08.03.
Skoda Deutschland, Weiterstadt, 31.05.96, 11.03.99, 09.10.02, 29.08.03.
Smart GmbH, Böblingen, 21.11.02, 29.08.03.
Subaru Deutschland, Friedberg, 09.03.99, 17.10.02, 05.09.03.
Suzuki Auto GmbH, Oberschleißheim, 12.06.96, 02.03.99, 28.10.02, 10.09.03.
Toyota Deutschland, Köln, 31.05.96, 12.03.99, 21.10.02, 01.09.03.
Volkswagen AG, Wolfsburg, 29.05.96, 17.02.99, 20.03.01, 15.10.02, 08.09.03.
Volvo Car Germany GmbH (formerly Volvo Deutschland), Köln, 11.06.96, 22.02.99, 22.10.02. Terminated in 2002, as all cars have AC-systems.

<u>Additionally on refrigerant charges:</u>
Autodata 2003, Air Conditioning. Table of filling charges ex 1997, Essen.

<u>2. Transition period 1991-1994 (selection)</u>
VDIK (Verband der Importeure von Kraftwagen e.V.), Bad Homburg, Scheiben vom 03.07.96.
Öko-Recherche: R 12 replacement in existing equipment from 1996 to 1998. Report on the Umweltbundesamt (in German), August 1998 (Unpublished correspondence in Öko-Recherche archives).
Öko-Recherche: R-12-Ersatz bei Altanlagen von 1996 bis Mitte 1998. Im Auftrag des Umweltbundesamtes, Berlin, August 1998. (Unveröffentl. Korrespondenz im ÖR-Archiv).
Öko-Recherche (Winfried Schwarz): Emission of Refrigerant R-134a from Mobile Air-Conditioning Systems. Annual Rate of Emission from Passenger-Car Air-Conditioning Systems up to Seven Years Old, Report on the Umweltbundesamt Berlin, Frankfurt 2001. http://www.oekorecherche.de/english/berichte/volltext/MAC-LOSS-2001.pdf

<u>3. After-market systems</u>
Waeco International GmbH (former Waeco Wähning & Co. GmbH), Emsdetten, Communications as of 1996.

4. Factor of operating emissions

The factor of operating emissions, which consist of "regular" and "irregular" emissions, figures 10%/y of the initial charge of an A/C system. It is understood as constant relation to the initial charge and with that to the accumulated HFC bank. Since 1991, emission reduction per A/C system chiefly occurs through charge reductions. The average charge has decreased by some 20% from 1995 to 2002 – from 0,876 kg to 0,697 kg.

Sources of information on operating emission factor

Estimations of R-134a emissions from mobile air conditioners that are ex-works designed to run with HFCs range from below 5% to over 20%. They are mostly based on expert judgements and, less frequently, on laboratory measurements (amongst others see Clodic 1997, AFCE 1998; Baker 1999; IPCC 1999; Preisegger 1999, Fischer 1997, with reservations Siegl et al. 2002).

Up to now (2003), the only two studies on refrigerant losses of vehicles being used in real road traffic stem from 2001 and 2003 (Öko-Recherche 2001 and Öko-Recherche/Ecofys 2003). These studies estimate an operating leakage rate of 10%. These 10% break down into 7% regular refrigerant loss and 3% irregular loss (accidents, mechanic damages by stones, etc.). This figure excludes emissions upon servicing (opening and evacuation of the refrigerant circuit). Estimates of service emissions range from "a few grams" to some 10% of the full charge, per one procedure. For lack of reliability, service emissions are not considered further here.

Written sources on emission factor

AFCE (Alliance Froid Climatisation Environment), Projection à 15 ans des émissions de HFC, Rapport d`etude par L. Palandre, D. Clodic, A.M. Pougin, mai 1998.

Baker, James A. (Delphi Automotive Systems, Inc): Mobile Air Conditioning: HFC-134a Emissions and Emission Reduction Strategies, in: Joint IPCC/TEAP Expert Meeting on Options for the Limitation of Emissions of HFCs and PFCs, Petten, 26-28 May 1999.

Clodic, D., Ben Yahia, M. (Centre d'Energétique, Ecole des Mines de Paris): New Test Bench for Measuring Leak Flow Rate of Mobile Air Conditioning Hoses and Fittings. Earth Technology Conference, Baltimore, 1997.

Fischer, Marcus: Klimawirksame Emissionen durch Pkw-Klimaanlagen. Diplomarbeit an der TU Berlin, FB 10, ISS-Fahrzeugtechnik, 1997.

IPCC 1999 = IPCC/OECD/IEA Programme for National Greenhouse Gas Inventories, Good Practice in Inventory Preparation for Industrial Processes and the New Gases, Draft Meeting Report Washington DC, United States, 26-28 January 1999.

Öko-Recherche (Winfried Schwarz): Emission of Refrigerant R-134a from Mobile Air Conditioning Systems. Annual Rate of Emission from Passenger-Car Air Conditioning Systems up to Seven Years Old, Report on the Umweltbundesamt Berlin, Frankfurt 2001. http://www.oekorecherche.de/english/berichte/volltext/MAC-LOSS-2001.pdf

Öko-Recherche (Winfried Schwarz)/ Ecofys (Jochen Harnisch): Establishing the Leakage Rates of Mobile Air Conditioners. Report on the EU Commission (DG Environment). B4-3040/2002/337136/MAR/C1. Frankfurt/Nürnberg 2003. http://www.oekorecherche.de/english/berichte/volltext/leakage_rates.pdf

Preisegger, Ewald (Solvay Fluor und Derivate GmbH): Automotive Air Conditioning Impact of Refrigerant on Global Warming, in: Joint IPCC/TEAP Expert Meeting on Options for the Limitation of Emissions of HFCs and PFCs, Petten, 26-28 May 1999.

Siegl, W.O. and T.J. Wallington et al., R-134a Emissions from Vehicles, ENVIRON. SCI & TECHNOL., VOL. 36, 561-566 (2002).

5. Operating emissions as of 1995

Operating emissions in a particular year can be estimated by relating the emission factor (EF_{op}) to the average bank (B n) of that year. The bank itself has been built up over the past years by annual HFC inputs (cf. section 2):

$$EF_{op} \text{ (in \%)} \quad \times \quad B\ n$$

Because of the EF of 10% for passenger car A/C systems, the specific equation of operating emissions is as shown hereafter:

$$\text{Emissions } n \;=\; EF_{op} \text{ (10 \%)} \quad \times \quad B\ n$$

Operating annual HFC emissions from bank are shown in Table 5, in t/y.

Table 5: 1995-2002 Operating emissions from average HFC bank in all passenger car A/C systems, in t/y								
	1995	1996	1997	1998	1999	2000	2001	2002
Average Bank	1,295	2,302	3,737	5,549	7,652	9,786	11,849	13,849
Operating Ems.	129	230	375	555	765	979	1,185	1,385

Sources: Calculation based on the previous sections in conjunction with the above equation.

Comment

Since 1995, emissions have constantly risen in pace with the growth in HFC bank in air-conditioning systems. Under business-as-usual conditions, the bank goes on growing until 2015/17. Then, emissions will peak at some 2,900 t/y.

6. Quality control and uncertainty assessment of data I

Activity data. The reliability of the reported data on numbers and charges of domestically sold MAC systems by vehicle models is very high for the reported years 1995 to 2002. The data are based on sales-records from the individual auto companies themselves, and with that, they are as reliable as the KBA statistics on new registrations. The quality of data on after-market systems can be considered equally high. Its source is the market leader whose sales were projected to 100% from his (known) percentage market share. Although reconstruction of the transition from R-12 to R-134a in old systems, which is necessary for determining the total HFC bank, was rather complicated, it might also be considered reliable, because both German and foreign carmakers (importers) were inquired by Öko-Recherche about that in the framework of two studies for the Umweltbundesamt in 1998 and 2001.

Regarding bank size, there is one source of uncertainty with growing importance in the future, namely the number of exported A/C equipped vehicles leaving the car fleet before the end of their technical lifetime. Over the medium term, empirically based examinations would be very useful to elucidate the situation as well as the practice of decommissioning old systems in general.

Emission factor. Compared to other emission factors applied in refrigeration and air-conditioning sectors the factor of operation emissions from passenger cars is robust, as it has been recently established with 10% for systems of the model years 1995 to 2001. At a confidence interval of 95%, statistical deviation is less than ± 1% (identical to ± 2 x Standard Error).

7. Relation to IPCC method I

Emissions from car air conditioning systems are addressed in IPCC GPG under "3.7.5 Mobile air-conditioning sub-source category". ÖR follows the requirements set out in Box 3 of the Decision Tree for Actual Emissions, "Calculate emissions by vehicle class and age, using country-specific bottom-up emission factors."

In Equation 3.49 determination of Operating Emissions is shown as follows:

Operating Emissions = (Amount of HFC-134a Stock in year t) * (x/100).

In this equation, x/100 is the emission factor. In place of the default emission rate of 10-20% (Table 3.23), a factor of 10% is used by ÖR, which is based on real measurements and situated at the lower bound of the default value. The IPCC default average lifetime is 12 years. This value is used by ÖR, too. As in IPCC GPG proposed for determination of activity data, the stock of HFC-134a in operating vehicles is arrived at by estimation of number of A/C systems and their average charges within the domestic car fleet. The accuracy achieved by ÖR is still higher, in that no default charge is used but an empirically established figure.

8. Entry in CRF I

The CRF-Table where stock and operating emissions of 134a from passenger car A/C systems are primarily entered is Table 2(II).Fs1, row 84, columns C und I.

II. Domestic HFC consumption and manufacturing emissions

9. Activity data II

CRF requires estimation of domestic HFC consumption for manufacturing and of HFC emissions arising on manufacture. Annual domestic consumption (C_{manu}) is no function of annual domestic new registrations of cars with A/C system but of domestically manufactured cars with A/C system.

The German Automobile Industry Association (VDA) annually publishes for the previous year data on domestic production of passenger cars by single models. However, the number of air-conditioned cars is not surveyed. Alternatively, ÖR applies the A/C quotas of domestic new registrations of these models (see section 3) to their domestic new production. The refrigerant charges by individual models, being the same for new registration and for new manufacture, are likewise known and can be taken to assess the refrigerant quantity applied per car model. In this way with the help of external spread sheet, domestic consumption quantity (C_{manu}) of HFC-134a is calculated, which is used for filling A/C systems of all the 55 different car models being manufactured in Germany (see Table 6). (Charging of old and aftermarket systems is disregarded here because of the insignificance of the associated emissions).

Table 6: 1995-2002 Number of domestically assembled passenger car A/C systems, in million of units, and HFC consumption for charging in car factories

	1995	1996	1997	1998	1999	2000	2001	2002
Mn of units A/C	1.553	2.283	2.935	3.991	4.562	4.667	4.982	4.875
Consumption in t	1,446	2,076	2,544	3,345	3,789	3,486	3,607	3,474
Avg. charge in kg	0.91	0.91	0.87	0.84	0.83	0.75	0.72	0.71

Sources: VDA - German Automobile Industry Association, Facts and Figures from the Motor Traffic Industry, issues from 1994 to 2003, Frankfort on Maine. Direct inquiries by ÖR: A/C quotas and charges by models. The calculation is based on external spreadsheet analysis.

Comment

Since 1995, the number of passenger car A/C systems assembled in domestic car factories has more than tripled, from 1.5 to 4.9 million units. Somewhat slower in growth is HFC-134a consumption due to dropping average charges (shown in the bottom line of Table 6).

10. Emissions per charge: 2 grams

On filling of passenger car A/C systems in the auto factory a refrigerant release of 2 grams per one charge is assumed (EF_{manu} = 2-grams/MAC).

11. Sources of information on emissions during charging (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

The leading European manufacturer of suchlike filling machines, the Danish company AGramkow, indicated the value of 2 grams loss on charging one passenger car A/C system in the assembly line by means of automatic filling machines ("filling guns"). According to Mr Bjarne Lund (Manager Auto Projects), that value is based on measurements. Likewise, the Sales Manager Refrigerants of the German DuPont branch referred to 2 grams. This expert made calculations of "fugitive" losses on the way from refrigerant distributor to charged A/C systems in several car factories.

Personal communications
AGRAMKOW Fluid Systems A/S, Sonderborg (Denmark), pers. comm. at VDA-Wintermeeting in Saalfelden 2003, 14.02.03.
DuPont Deutschland GmbH, Bad Homburg, pers. comm. at IKK 2002 in Nürnberg, 16.11.02.

12. Filling emissions

Given 2 grams emissions per charging, manufacturing emissions in t/y (as shown in Table 7) can be derived as well as the implied emission factor as a percentage of HFC consumption (C_{manu}). Both are based on the number of units and on annual HFC consumption as presented in Table 6.

Table 7: 1995-2002 Passenger car air conditioners: Loss per charging, filling emissions and implied emission factor

	1995	1996	1997	1998	1999	2000	2001	2002
Loss in g/A/C	2	2	2	2	2	2	2	2
Filling emiss. in t	3.170	4.557	5.868	7.982	9.125	9.332	9.964	9.751
EF (% of Cons.)	0.22	0.22	0.23	0.24	0.25	0.26	0.28	0.28

Sources: Calculations based on Table 6 and EF_{manu} of 2-g/charge.

13. Emission factor of domestic consumption

By relating filling emissions, which arise due to 2 grams loss per charged A/C system, to annual refrigerant consumption (Table 6, line 2), implied emission factors can be calculated as presented in Table 7, bottom line. They start in 1995 with 0.22% and go on rising to 0.28% in 2002. This rise expresses decreasing charges of A/C systems. It should be noted that filling emissions are considered constant quantities of 2 grams per A/C system.

14. Quality control and uncertainty assessment of data II

Activity data. Safety of activity data relevant to the filling process in principle depends on safety of activity data that underlies operating emissions. Its safety is deemed high. When estimating annual HFC consumption required to charge new passenger car A/C systems, uncertainty arises to some degree because A/C quotas per model are not directly surveyed, but are "proxy" data, estimated by applying the A/C quotas in new domestic registration to domestic production.

Excursus: Testing the method of application

Because of the outstanding importance of filling emissions from passenger car A/C systems compared with any other domestic refrigerant filling emissions (75% of ca. 13 t in 2002), ÖR found this data quality worth being control-checked and attempted to crosscheck the thus calculated HFC consumption by actual HFC consumption. The latter was available as a total figure. German carmakers annually call refrigerant producers for tenders to meet their refrigerant demands, so that refrigerant producers know the envisaged purchase quantities of each individual domestic carmaker. ÖR asked the refrigerant producers to communicate the 2002 quantities – with two or three different buyers aggregated for confidentiality. Two out of four refrigerant producers handed over to ÖR such data, from which the quantities destined for trucks and buses were deducted. Table 8 shows both actual purchase quantities and calculated consumption.

Table 8: Comparison between calculated consumption and actually purchased quantities of HFC-134a of the seven domestic makers of passenger cars, 2002

Carmakers	1 + 2	3 + 4	5 + 6 + 7	Total
1. Actually purchased t	1,160	1,080	1,200	3,440
2. Calc. consumption t	1,173	1,073	1,227	3,473
Deviation 2. from 1. (t)	+ 13	- 7	+ 27	+ 23

Sources for purchase quantities: Communications from refrigerant producers made anonymous.

The comparison between calculated and actual quantities does not show substantial deviations from each other. In total the difference amounts to only 23 tonnes or less than 1%. That proves that the method of application of market to production data used by ÖR makes sense, although strictly speaking only for 2002. However, it seems to be true that at least in recent years the A/C quotas of domestic new registrations are not far away from the A/C quotas of domestic car production, on a model-by-model comparison.

Emission factor: Emissions of 2 grams per charged new A/C system can be considered a robust value, particularly since Europe's leading supplier of filling machines guarantees this value.

15. Relation to IPCC method II

In Table 3.23 about default emission parameters for a bottom-up approach a First Fill emission rate of 0.5% (updated after originally 4-5%) is mentioned. The country-specific value of ÖR is 2 grams per system, which after recalculation to percentage comes to 0.22 to 0.28%, in other words to half the IPCC default value.

16. Entry in CRF II

The CRF Table where the data "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered is Table 2(II).Fs1. The data for HFC-134a is entered into row 84, into columns B and H.

III. Disposal emissions

17. Activity data III

First time in 2002, certain HFC quantities were systematically due for disposal. These were 27 t HFC-134a in after-market systems, charged in 1994, and 7 t in converted old systems charged with HFCs in 1995.

These figures can be read off Table 3 in Part I (lines 1 and 2), where they are entered as domestic input (In_{bank}). According to equation 4 (section 2 in Part I), they become HFCs for disposal after 8 or 7 years ($De_{bank}\ n = In_{bank}\ (n - 8)/(n - 7)$).

With respect to data safety, there is nothing new against the considerations in Part I.

18. Emission factor on disposal

EF_{disp} on decommissioning amounts to 30% of the initially charged quantity.

19. Emissions on disposal

On decommissioning, emissions of 10.1 t (30%) arose from the above-mentioned 34 t HFCs.

20. Quality control and uncertainty assessment of data III

The EF_{disp} of 30% may seem to be too high, particularly as it cannot be assumed that A/C systems are still full when being scrapped. This, however, is not supposed to be the case. Eventually, a loss of 50% from a half-full system comes roughly to the same. Admittedly, there is not yet much knowledge of the real practice of disposal of refrigerants from A/C systems, because in 2002 a regular system of decommissioning old A/C systems was still in its infancy.

Given even best recovery infrastructure, there will always be limits preventing oil-solved refrigerants from being extracted by means of recovery devices down to less than some 50 grams. The only value recently found in literature on "losses on decommissioning vintage-by-vintage" stems from ÖR, who estimates today's disposal emissions on scrapping at 25% for the time being. However, this figure is meanwhile thought to be too low.

Öko-Recherche (Winfried Schwarz): Emission of Refrigerant R-134a from Mobile Air Conditioning Systems. Annual Rate of Emission from Passenger-Car Air Conditioning Systems up to Seven Years Old, Report on the Umweltbundesamt Berlin, Frankfurt 2001.

21. Relation to IPCC method III

Disposal emissions from car air conditioners are dealt with in IPCC GPG under "3.7.5 Mobile air-conditioning sub-source category" in the framework of a bottom-up approach. Equation 3.50 is as follows:

$$\text{Disposal Emissions} = (\text{HFC-134a Charged in year } t - n) \times (y/100) \times (1 - z/100).$$

In this equation, y is the percentage of the initial charge that still exists inside the A/C system when being decommissioned. The variable z expresses the recovery efficiency on disposal. If recovery of refrigerant takes place, the percentage z (fraction recovered) must be subtracted from the old refrigerant. By that, disposal emissions are reduced.

The "updated default values" in Table 3.23 take 40% of the full A/C unit for the "typical remaining charge (y)". The "fraction recovered (z)" is set to 0%, if in the country in question a "recovery and recycling program" does not exist.

If these default values were applied, disposal emissions of 40% would arise. In Germany, a Regulation on End-of-Live Vehicles (ELV) has entered into force in July 2002. Thus, a recovery efficiency of 0% is no longer applicable here.

Compared to the IPCC assumption of 40% emissions in countries without recovery (total emission of the remaining refrigerant), 30% disposal emissions in Germany 2002 as assumed by ÖR can be taken as recovery of 25% from 40% remainder [(40%-30%)/40%]. This order of magnitude is not seen to be unrealistic.

22. Entry in CRF III

The CRF Table where data on "Amount of fluid remained in products at decommissioning" and "Emissions from disposal" are primarily entered is Table 2(II).Fs1, row 84, columns D and J. The fluid is HFC-134a.

F-Gas sheet 10: Truck Air Conditioning

F-Gas	**HFC-134a**
Application	**Truck Air Conditioning**
Reported Years	**1995 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**

Background

Since 1994, new truck A/C systems have entered the domestic market only with HFC-134a instead of CFC-12. At the end of 1993, half the new air-conditioned trucks ran with HFC refrigerant.

From 1994 through 2002, the A/C quota of annually new registered commercial road vehicles of all weight categories has increased from 5% to 32%. This quota generally keeps rising, it is, however, especially high in driver cabins of heavy trucks. Specific refrigerant charges have been decreasing (from 1.06 to 1.03 kg), but by far not as sharply as in case of passenger cars.

The high physical strain on A/C systems due to long running times and stressing driving style leads to refrigerant losses higher than from passenger cars.

I. Bank and operating emissions from bank

1 Activity data I. Annual domestic HFC input

1.A Annual new registrations of trucks by weight categories

The German Federal Office for Motor Vehicles (KBA) annually publishes for the previous year the number of new domestic registrations of trucks and, additionally, tractors, broken down into ten net weight categories. Table 1 reproduces these numbers with the 10 categories being combined into just three of importance for air-conditioning. Tractors are generally included in the net weight class > 7.5 tonnes.

Table 1: 1993-2002 New registrations of trucks by net weight classes, in units

Weight class	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. < 1.5 t	140,682	153,466	148,865	144,057	156,016	169,007	180,197	173,315	165,340	154,419
2. 1.5 t – 7.5 t	45,786	42,838	41,335	36,737	38,087	46,469	51,930	47,989	42,846	37,200
3. > 7.5 t	34,917	31,801	37,903	36,127	38,195	46,680	54,545	53,388	47,004	39,920
Total	221,385	228,105	228,103	216,921	232,298	262,156	286,672	274,692	255,190	231,539

Sources: KBA, Statistische Mitteilungen, Reihe 3, Kraftfahrzeuge, div. Jahresbände.

Since 1993, the first year of applying the refrigerant HFC-134a, annual registrations of new trucks have oscillated between 217 and 286 thousand units. Quantitatively, trucks with net weight below 1.5 tonnes are the largest single group.

1.B The refrigerant model for trucks

Apart from the number of new registrations as per Table 1, annual domestic input of refrigerants through new truck A/C systems in each of the three weight classes depends on two factors. Firstly, the A/C quota and secondly, the specific refrigerant charge. Table 2 contains this information. Please note that the charge (bottom line) is presented only for the weight category < 1.5 tonnes. This is because changes took place only there, which is to say a reduction from 1.0 to 0.85 kg. In the middle and upper net-weight classes, HFC charges remained constant with 1.0 kg and 1.2 kg, respectively.

Table 2: 1993-2002 A/C quotas by weight categories, and refrigerant charges in kilograms in the class < 1.5 t,

Weight class	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. < 1.5 t	1%*	3%	4%	6%	9%	12%	12%	13%	16%	20%
2. 1.5 t – 7.5 t	2%	4%	7.5%	8.5%	10%	11%	18%	20%	21%	24%
3. > 7.5 t	5%*	20%	36%	41%	53%	63%	69%	74%	82%	83%
Charge [<1.5t]	1.00 kg	0.90 kg	0.90 kg	0.90 kg	0.88 kg	0.87 kg	0.86 kg	0.86 kg	0.86 kg	0.85 kg

Sources: See section 2.

* In 1993, in the upper and the lower net-weight class only 50% of new A/C systems were charged with 134a, the remainder still with R-12. This is the reason for the low A/C quotas, which in fact are HFC specific A/C quotas.

Notice: The charges in the two weight classes >1.5 t are constantly 1.0 and 1.2 kg, respectively.

1.C Annual domestic HFC input through new truck A/C systems

The input (In_{bank}) of the refrigerant 134a in year n is arrived at in two steps: firstly, through multiplication of the number of new trucks in one of the three weight classes in year n (Table 1) by the A/C quota of the same weight class in the same year n – according to Table 2. Secondly, through multiplication of the A/C-quota-weighted number of units by the respective refrigerant charge in kg (in the class < 1.5 t according to Table 2, last line, in the middle class by 1.0 kg, and in the upper class by 1.2 kg). From that, annual HFC input according to Table 3 can be derived.

Table 3: 1993-2002 Annual HFC input through truck A/C systems, in t/y

Weight class	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. < 1.5 t	1.4	4.1	5.1	7.5	11.9	18.1	19.5	19.5	23.6	27.3
2. 1.5 t – 7.5 t	0.9	1.5	3.1	3.1	3.8	4.9	9.5	9.5	9.0	8.8
3. > 7.5 t	2.2	7.5	16.6	17.9	24.2	35.2	45.0	47.4	46.3	39.9

Sources: Tables 1 and 2.

2. HFC bank in truck A/C systems

Over the current year n, the HFC end-of-year bank n-1 (EB n-1) in truck A/C systems increases by domestic input (In_{bank} n) and grows EB n. EB n is the sum of all inputs (In_{bank}) that have taken place until the end of year n, minus domestic output of HFCs for disposal with old systems. In view of a 12-year-lifetime, a decrease in the bank because of decommissioning will not occur before 2005.

The average domestic bank B n is half the sum of the previous end-of-year bank (n-1) and the current end-of-year bank n. This is the equation:

$$B\,n = \frac{EB\,n\text{-}1 + EB\,n}{2} \qquad \text{Where:} \quad EB\,n = EB\,n\text{-}1 + In_{bank}\,n$$

In the following, the average annual bank (B n) will be broken down into just two instead of three weight categories. This is because the emission behaviour is the same in the two upper weight categories, so that both classes can be united into one class in order to compare it with the lightweight class < 1.5 tonnes. From 1995 onwards, a time series emerges as shown in Table 4.

Table 4: 1995-2002 Average HFC bank in truck A/C systems by weight classes, in t/y

Weight class	1995	1996	1997	1998	1999	2000	2001	2002
< 1.5 t	8.1	14.4	24.1	39.1	57.9	77.4	98.9	124.4
1.5 t – > 7.5 t	22.0	42.3	66.8	100.8	148.1	203.7	259.8	311.8
Total	30.1	56.7	90.9	140.0	206.0	281.1	358.7	436.2

Sources: Calculation based on data of section 1.

Comment on time series of activity data I

While new registrations of trucks keep constant, their A/C ratio, and consequently HFC bank exhibit a marked trend upwards, expressing the steady growth of air-conditioning in the truck sector. Although in 2002 for the first time a distinctly reduced HFC input through A/C systems of new-registered trucks could be assessed, the reason for that was no dropping A/C quota (which in fact went on growing), but a reduction in the number of new-registered trucks in each weight category.

From 1995 to 2002, average charge in the light class was decreasing from 0.90 to 0.85 kg, while it remained constant in the upper weight categories.

Intensified HFC-134a input in the years from 1996 to 1998 due to R-12 replacement in old systems did not occur in the truck sector as it did in passenger cars and buses. According to the sector expert Mr Schuster of Webasto Fahrzeugtechnik based in Stockdorf (personal comm. 20.07.98), old truck A/C systems were virtually not converted.

Possible future saturation of air conditioning in new trucks must be seen with differentiation. Heavy trucks (net weight class > 7.5 t) have a high A/C quota of 83% already today (2002). At 90%, saturation may be possible, which can be reached by 2004. In the middleweight category (net weight 1.5 – 7.5 t), the 2002 A/C quota figured 24%, and in the lightweight category (< 1.5 t) 22%. In case of the middle class saturation at 50% could be reached by 2010. Forecasting is difficult in the lightweight sector. Here, saturation is assumed at the 45% level that will be reached by 2013 on condition the slow but steady growth continues.

At any rate, average HFC bank will increase until 2024 in all weight categories even considering departures of old systems at end-of-life after 12 years use phase. Then the bank will amount to 1,670 t. In heavy trucks, a maximum of 648 t could already be reached by 2015, thanks to earlier saturation on high level.

3. Collection and sources of information on activity data

The above-presented data were estimated by ÖR not the same way as for passenger cars (direct inquiries of each relevant carmaker supplying the German market about the A/C quota of any model sold). Firstly, facing 37 different relevant truck-makers partly selling a wide model range, the expenditure would have been rather high. Secondly, unlike with passenger cars, in the truck sector no official (KBA) statistics of new registrations by individual models are available. Therefore, comparable inquiries would be much more complicated.

Activity data were determined by a combination of official statistics, specific interviews of manufacturers, and projections. The projections are based on KBA statistics on "Annual registrations of new-manufactured trucks by weight categories and of tractors". From a methodological point of view, the decisive step was to find for each of the three weight categories a few "typical" truck models, for which number of registrations, A/C quota, and refrigerant charge could be assessed by means of direct inquiries of truck-makers.

These typical or representative trucks are in the

Weight category > 7.5 t:	Model Actros from DaimlerChrysler with a market share of between 40% and 52% in this segment, which comprises 35,000 to 55,000 new vehicles annually.
Weight category 1.5-7.5 t:	Model Artego from DaimlerChrysler with a market share of between 22% and 35% in this segment, which comprises 37,000 to 52,000 new vehicles annually.
Weight category < 1.5 t:	Mercedes models Sprinter and Vito, the VW models Transporter, LT and Caddy, and the Renault models Master and Kangoo with summarised market shares of between 40% and 73% in this segment, which comprises 140,000 to 180,000 new vehicles annually.

The A/C quotas and refrigerant charges being annually inquired for those weight-class-typical vehicles are directly applied to the total number of new registrations per year in the three weight categories according to the KBA statistics (extrapolation).

<u>Remark on the lightweight class</u>: *From a practical standpoint, the number of directly inquired truck-makers should be kept small. This is because the five German and two French models used in the estimation are vehicles that can be registered both as passenger cars and as trucks (utility vehicles). In difference from some other countries, where these vehicle types are clearly classified as Light Commercial Vehicles, in Germany the definition is not made by technical terms, but by legal terms concerning taxation. At least DaimlerChrysler, Volkswagen and Renault are able to report separately the respective numbers of A/C equipped vehicles.*

Sources of information on activity data (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Models Actros and Artego:
DaimlerChrysler AG (Werk Wörth), 09.03.99, 07.11.02, 01.10.03.
Models Vito and Sprinter:
DaimlerChrysler AG, Stuttgart, 18. und 19.11.02, 19.09.03.
Models Transporter/Caravelle, LT, Caddy:
Volkswagen AG, Werk Hannover, 12.03.01, 13.11.02, 01.09.03.
Models Master and Kangoo:
Deutsche Renault AG, Brühl, 21.10.02, 23.10.03.

4. The factors of operating emissions

The factor of operating emissions, consisting of "regular" and "irregular" use phase emissions, amounts for light trucks (net weight class < 1.5 t) to 10% per year. This figure is derived from the value for passenger cars, because there is very likely no much difference in design as well as in driving conditions between the two road vehicle types concerning the A/C system.

In the two upper truck weight categories an emission factor of 15%/y of the initial charge is used. This is because these vehicles and their A/C systems are exposed to higher mechanical stress, and the A/C systems do run much longer during their use-phase. In addition, tilting cabins, introduced to make engines more accessible, require fairly long refrigerant lines (6-10 metres), with some 6% flexible hoses to connect compressors with chassis-mounted condensers and cabin-integrated evaporators.

As the share of the two upper weight categories changes from year to year against the share of the light class in the total of new registrations, there is no constant emission factor for the whole source category of truck A/C systems. However, since 1995 the common calculated factor of operating emissions just slightly oscillates around an average value of 13.6% or 13.7% annually.

Sources of information on emission factors

Based on evaluation of professional literature, the 1995 status report on R-12 replacement suggests an emission factor of 16.6% for air-conditioning of trucks, following an Öko-Recherche study for Greenpeace published the same year (15%). Two studies made later on about refrigerant losses from air-conditioners of real road-going vehicles stem from 2001 and 2003 (Öko-Recherche 2001 and Öko-Recherche/Ecofys 2003). In these studies an operating annual leakage rate of 10% was established, which consists of 7% regular refrigerant loss and some 3% irregular loss caused by accidents, mechanical damages by stone impacts and that like.

Although these two studies concentrate on passenger cars, they also contain data on vehicles that could be registered as light trucks too, such as VW-Transporters.

Specific studies on emissions from truck air conditioners were not available by 2003, apart from emission measurements at 28 mostly big vehicles that were parked for two days in a closed room (Siegl 2002). Unfortunately, neither the measured and then projected value of 30 grams/y (mean) was related to any refrigerant charges nor was operating states other than parking considered. The 15% used here for trucks in the middle and upper weight class are based on plausibility that higher stress on A/C systems in heavy trucks leads to leakage by some 5% higher than in passenger cars and light utility vehicles.

Written sources

FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz von R 12 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, im Auftrag des Umweltbundesamtes, Statusbericht im Auftrag des Umweltbundesamtes, Berlin, Hannover, November 1995. S. 96.

Öko-Recherche, No "all-clear" for ozone and climate. 1995 German consumption forecast for CFCs, HCFCs and HFCs (in German), Study for Greenpeace e.V. Hamburg 1995, S.14. http://www.oekorecherche.de/english/berichte/volltext/keine-entwarnung.pdf

Öko-Recherche (Winfried Schwarz): Emission of Refrigerant R-134a from Mobile Air-Conditioning Systems. Annual Rate of Emission from Passenger-Car Air-Conditioning Systems up to Seven Years Old, Report on the Umweltbundesamt Berlin, Frankfurt 2001. http://www.oekorecherche.de/english/berichte/volltext/MAC-LOSS-2001.pdf

Siegl, W.O. and T.J. Wallington et al., R-134a Emissions from Vehicles, ENVIRON. SCI & TECHNOL., VOL. 36, 561-566 (2002).

Öko-Recherche (Winfried Schwarz)/ Ecofys (Jochen Harnisch): Establishing the Leakage Rates of Mobile Air Conditioners. Report on the EU Commission (DG Environment). B4-3040/2002/337136/MAR/C1. Frankfurt/Nürnberg 2003. http://www.oekorecherche.de/english/berichte/volltext/leakage_rates.pdf

5. Operation HFC emissions from the bank

Operating emissions in a particular year n are arrived at by applying the factor of operating emissions (EF_{op}) to the average bank of that year n (B n), which has been built up by several annual HFC inputs over the past years – see section 2.

$$EF_{op} \text{ (in \%)} \quad x \quad B\ n$$

Because of EF_{op} of 10% and 15%, respectively, for truck A/C systems the specific equation of operating emissions is:

$$EF_{op} \text{ (10\%, 15\%)} \quad x \quad B\ n$$

Operating annual HFC emissions from bank are shown in Table 5, in t/y.

Table 5: 1995-2002 Operating emissions from average HFC bank in truck A/C systems, in t/y by weight categories								
Weight category	1995	1996	1997	1998	1999	2000	2001	2002
< 1.5 t	0.8	1.4	2.4	3.9	5.8	7.7	9.9	12.4
1.5 t – > 7.5 t	3.3	6.4	10.0	15.1	22.2	30.6	39.0	46.8
Total	4.1	7.8	12.4	19.0	28.0	38.3	48.9	59.2

Sources: Calculation from data in Table 4 with EF_{op} of 10% (<1.5 t) and 15% (>1.5 t).

Comment

Since 1995, emissions have grown constantly pursuant to the growth of the bank in A/C systems. Under business-as-usual conditions, the bank will go on increasing until 2020 (to 1,670 t). The then emissions will amount to calculated 212 t.

6. Quality control and uncertainty assessment of data I

Activity data. The accuracy of KBA statistics on new registrations by weight categories is out of doubt. Likewise very high is the reliability of the data reported by the truck-makers DaimlerChrysler, VW, and Renault on their total number of domestically sold trucks (1) by models, (2) by models with A/C system, and (3) by model-specific refrigerant charge.

Unlike passenger car A/C systems, in case of trucks, only partial quantities (subsets) of the annually new-registered vehicles with A/C system are directly inquired of manufacturers. These subsets represent a number of between 22% (at the minimum) and 62% (at the maximum) of the overall population of new truck registrations, depending on weight category and year of reference.

It must be admitted that it is only a more or less plausible assumption that the A/C data inquired directly of DaimlerChrysler, VW, and Renault actually match the respective data of all trucks inclusive of the projected trucks, which have not been directly inquired about A/C quota and refrigerant charge. This assumption on representativity is made by ÖR in accordance with the above ("sources of information on activity data") mentioned experts from the two leading truck-makers. A deviation of direct inquired A/C quotas from the A/C quotas of the other models is considered by these experts to range about ± 10%. (German models are thought to feature somewhat higher A/C quotas than foreign make models.)

Emission factors. Because of the resemblance in design, the factor of 10% for operating emissions from light truck A/C systems can be seen as robust as the 10% value, which recently has been established for passenger car systems empirically and statistically (standard error of ± 1% at a confidence interval of 95%).

There are no investigations known about refrigerant loss from A/C systems of trucks in the true sense of the word, i.e. of vehicles for net weights over 1.5 t. The surcharge of 5% on the 10% operating emissions from usual car air conditioners is based on plausibility that higher physical strain on a vehicle and its A/C system in combination with the longer stretch of flexible piping causes higher emissions.

7. Relation to IPCC method I

Emissions from vehicle air conditioners in general are addressed in IPCC GPG under "3.7.5 Mobile air-conditioning sub-source category". There are, however, no special comments on Mobile Air Conditioners of trucks. ÖR generally follows the requirements laid down in Box 3 of the Decision Tree for Actual Emissions, "Calculate emissions by vehicle class and age, using country-specific bottom-up emission factors."

In Equation 3.49, the estimation of Operating Emissions is proposed as follows:

Operating Emissions = (Amount of HFC-134a Stock in year t) * (x/100).

In this equation, x/100 is the emission factor. As (updated) default emission factor 10% to 20% are suggested. The mean value of 13.6% - 13.7%, which is used by ÖR, is localised within this region. Average vehicle lifetime in IPPC GPG is 12 years. This value is used by ÖR, too.

8. Entry in CRF I

The CRF Table to enter data on operating emissions of HFC-134a from truck A/C systems is Table 2(II).Fs1, row 85, columns C and I.

II. Domestic HFC consumption and manufacturing emissions

9. Activity data II

CRF requires estimation of domestic HFC consumption for manufacturing and of HFC emissions arising on manufacture. Domestic consumption (C_{manu}) is no function of domestic new registrations of vehicles with A/C system but of domestically manufactured vehicles with A/C system.

The German Automobile Industry Association (VDA) annually publishes for the previous year data on domestic production of trucks and tractors. The vehicles are subdivided into gross weight categories, not into net weight classes. Within certain limits the light net weight corresponds to gross weight below 6 t, the middle net weight equals gross weight of from 6 to 16 t. Heavy net weight is compatible with gross weight over 16 t. Table 6 shows the domestic production numbers.

Table 6: 1995-2002 Domestic production of trucks and tractors by gross weight categories, in units

Gross weight	1995	1996	1997	1998	1999	2000	2001	2002
< 6 t GW	173,778	189,942	211,965	224,769	223,651	238,593	246,416	212,358
6-16 t GW	41,371	35,711	40,813	44,903	44,761	35,724	30,255	26,810
> 16 t GW	82,190	67,320	80,559	96,016	97,931	106,862	101,878	97,158
Total	297,339	298,075	337,427	365,688	366,343	381,179	378,549	336,326

Sources: VDA - German Automobile Industry Association, Facts and Figures from the Motor Traffic Industry, issues from 1994 to 2003, Frankfort on Maine.

In the absence of specific data on air-conditioning of domestic production, alternatively A/C quotas and refrigerant charges of domestic new-registrations are applied. Linking these data from Table 2 with those in Table 6, we arrive at "proxy" data that can be taken with reservations as appropriate data on number of units, average refrigerant charge, and total HFC consumption for domestically fitted A/C systems.

The data are entered in Table 7 together with manufacturing emissions in kg that occur under the assumption of a 2-gram-loss per charging one new A/C system.

10. Emissions on manufacturing

A loss of two grams, which occurs on charging a passenger car A/C system, is used as default value for all A/C systems of road vehicles of similar size.

Table 7: 1995-2002 Domestically fitted truck A/C systems by number of units, average charge, HFC consumption (in t), loss per charge (in g) and charging emissions (in kg)

	1995	1996	1997	1998	1999	2000	2001	2002
Number of truck AC	39,615	41,781	64,940	92,631	106,444	119,989	134,318	133,761
Average charge	1.14 kg	1.12 kg	1.10 kg	1.09 kg	1.09 kg	1.09 kg	1.08 kg	1.07 kg
Dom. HFC cons. t	45.0	46.7	71.7	101.1	115.8	131.2	145.2	143.8
Loss per A/C g	2	2	2	2	2	2	2	2
Manuf. ems. in kg	79	84	130	185	213	240	269	268

Sources: Calculations based on data given above.

11. Emission factor of domestic manufacturing

Charging emissions are in the range of a few hundreds of kilograms. By relating this manufacturing loss to domestically charged HFCs (domestic consumption), an implied emission factor can be calculated. This factor was 0.175% in 1995 and 0.186% in 2002. The slight rise is a result of the growing number of smaller A/C systems.

12. Quality control and uncertainty assessment of data II

Safety of activity data that is of importance for the filling process in principle depends on the safety of activity data that underlies operating emissions. On the one hand, the reported number of annually manufactured trucks is highly reliable, on the other hand, uncertainties arise because A/C quotas and refrigerant charges are not surveyed directly but are estimated by application of market conditions to manufacturing conditions. Up to now, a control check of the thus calculated HFC consumption by real HFC quantities purchased by domestic truck-makers (DaimlerChrysler, MAN, VW, and Ford) has not been conducted.

The emission factor (EF_{manu}) 2-g/new system is a reliable value for passenger cars. Because charging truck A/C systems is not substantially different from charging passenger car A/C systems, the same data quality can be assumed for both cases.

13. Relation to IPCC method II

Like any other default emission parameters, the First-Fill emission rate of MACs is completely oriented towards passenger cars in IPCC GPG. Its current version does not provide special guidance for other mobile A/C systems.

14. Entry in CRF II

The CRF Table where the data "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered is Table 2(II).Fs1. The data for HFC-134a are entered into row 85, columns B and H.

F-Gas Sheet 11: Bus Air Conditioning

F-Gas	**HFC-134a**
Application	**Air Conditioning of Buses**
Reported Years	**1995 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**

Background

Since 1994, the German omnibus fleet comprises almost constantly about 85,000 units; annual new-registrations oscillate around 6,000 units. Air-conditioning of new buses has steadily risen to 70% in 2002, starting from a high level, namely 36% in 1993. Looking closer, a more differentiated picture of the three bus types emerges. New city buses were placed into service in 2002 with an A/C quota of only 38%, new overland buses with 70%. Coaches, however, have been equipped with air-condition 100% since 1999.

The refrigerant charges of bus A/C systems are large, ranging from eight to 15 kg HFC-134a with an average of 12 kg. This is caused by design. As a rule, the complete refrigeration set is fitted to the rear end and to the rooftop; in case of large vehicles, an additional box is assembled to the front. From there, refrigerant pipes of 20 metres and longer run through the whole vehicle in order to provide every passenger seat and the driver's place with conditioned air by means of a number of evaporators. These refrigerant pipes with numerous connections increase the risk of refrigerant loss in buses, compared with passenger cars.

Since 2001, both German market leaders, DaimlerChrysler's EvoBus and NEOMAN (MAN-Neoplan), have offered water-cooling A/C systems for coaches, where HFC only runs through the primary refrigeration circuit. With that, the necessary refrigerant charge could be reduced to 7 kg. Some 25% of all the new-registered coaches are delivered with such an air-conditioning design.

I. Bank and operating emissions from bank

1 Activity data I. Annual domestic HFC input

1.A Annual new registrations of buses by types

The German Federal Office for Motor Vehicles (KBA) annually publish for the previous year the number of new domestic bus registrations. This number is not broken down into different bus categories that are of relevance for the degree of air-conditioning. With the assistance of experts, this subdivision could be made. According to the experts' estimation, since several years the domestic market is constantly split into 40% city buses, 20% overland buses, and 40% coaches. In addition to the total number of annual new-registrations (last line), Table 1 shows for every year since 1993 the number of units in the three different bus categories according to that 40/20/40 break.

Table 1: 1993-2002 New registrations of buses by categories, in units

Category	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. City Bus	3,072	2,474	2,141	2,350	2,206	2,321	2,528	2,537	2,448	2,295
2. Overland Bus	1,536	1,237	1,070	1,175	1,103	1,160	1,264	1,269	1,224	1,147
3. Coach	3,072	2,474	2,141	2,350	2,206	2,321	2,528	2,537	2,448	2,295
Total	7,679	6,184	5,352	5,876	5,514	5,802	6,321	6,343	6,121	5,737

Sources: KBA, Statistische Mitteilungen, Reihe 3, Kraftfahrzeuge, div. Jahresbände (for the total number); Estimation of experts from EvoBus and NEOMAN (for the breakdown).

Since 1993, the first year of general use of refrigerant HFC-134a, annual new registrations oscillate between 7.7 and 5.5 thousand.

1.B The refrigerant model for bus A/C systems

Apart from the number of new registrations as per Table 1, the annual quantity of new refrigerant increasing the existing bank depends in each of the three bus categories on two factors: 1) the specific A/C quota and 2) the average refrigerant charge. Table 2 contains this additional information: in lines 1-3 the A/C quotas for each bus category, in line 4 the weighted A/C quota for all three classes. The bottom line shows the average refrigerant charge, which was generally 12 kg before 2001. The change in charge from 2001 onwards is explained below Table 2.

Table 2: 1993-2002 A/C quotas and refrigerant charges by bus category

A/C Quota	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. City Bus	5%	9%	14%	18%	23%	27%	30%	33%	35%	42%
2. Overland Bus	10%	18%	26%	34%	42%	50%	55%	60%	65%	70%
3. Coach	80%	90%	95%	96%	97%	98%	100%	100%	100%	100%
4. All Buses	36%	43%	49%	52%	56%	60%	63%	65%	67%	71%
Charge	12 kg	12 kg	12 kg	12 kg	12 kg	12 kg	12 kg	12 kg	11.2 kg*	11.2 kg*

Sources: See section 2.
* As of 2001, the two market leaders EvoBus and NEOMAN offer in coaches water-cooling A/C systems where the HFC runs only through the primary refrigeration cycle. That has reduced the charge to less than 7 kg. Roughly, 25% of new coaches are equipped with such systems. By that, average A/C charge has dropped to 10.6 kg in new coaches, and to 11.2 kg in all buses.

1.C Annual domestic HFC input through new bus A/C systems

Annual input (In_{bank}) of refrigerant HFC-134a in year n is arrived at in two steps: Firstly, through multiplying the number of buses in a particular category in year n (Table 1) by the A/C quota in the same bus category of year n (as per Table 2, lines 1-3). Secondly, by multiplying this A/C-quota-weighted number of units by the respective charge in kg (as per Table 2, line 4). The latter generally amounts to 12 kg; only in coaches from 2001 onwards, average charge is reduced to 10.6 kg. This way HFC input (In_{bank}) according to Table 3 is derived.

Table 3: 1993-2002 Annual HFC input through domestic bus A/C systems, in t/y

Category	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. City Bus	1.8	2.8	3.5	5.1	6.0	7.5	9.1	10.0	10.3	11.6
2. Overland Bus	1.8	2.7	3.3	4.8	5.6	7.0	8.3	9.1	9.5	9.6
3. Coach	29.5	26.7	24.4	27.1	25.7	27.3	30.3	30.4	26.0	24.4
All Buses	33.2	32.2	31.3	37.0*	37.2**	41.8	47.8	49.6	45.8	45.6

Sources: Tables 1 and 2. * After correction (1.D): 48.0 t. ** after correction (1.D): 48.2 t.

1.D Additional input by R-12 replacement 1996 and 1997 (Correction of Table 3)

In 1996 and 1997, HFC input through domestic bus A/C systems was higher than shown in Table 3. Over the two years, additional 22 tonnes of HFC-134a were applied to substitute R-12 in some 1,800 old systems. This was done in spite of high costs of up to 10,000 DM. A split into different bus categories is not available. Anyway, it is not required for the following estimation of bank and bank emissions. The first 11 of the total 22 tonnes of HFCs in old systems were charged in 1995, and they will leave the bank again in 2003 for being disposed of.

In the bottom line of Table 3, for the year 1996 the HFC sum must be raised from 37.0 to 48.0 t and for 1997 from 37.2 to 48.2 tonnes (see text below Table 3).

2. HFC bank in bus A/C systems

The end-of-year bank (EB) of HFCs in year n in bus A/C systems increases annually by the domestic input ($In_{bank}\ n$). The end-of-year bank of year n (EB n) is the sum of all the inputs that have taken place until the end of year n, minus domestic output of HFCs for disposal with old systems. In view of a 12-year-lifetime, systematic decrease in the bank because of decommissioning did not occur before 2003.

The <u>average domestic bank B n</u> is half the sum of the previous end-of-year bank (n-1) and the current end-of-year bank n. This is the equation:

$$B\ n = \frac{EB\ n\text{-}1 + EB\ n}{2} \qquad \text{Where:} \qquad EB\ n = EB\ n\text{-}1 + In_{bank}\ n$$

In the following, the average annual bank (B n) is no longer distinguished by different bus categories, as all categories behave the same way in respect to leakage. Table 4 shows the time series of the average bank since 1995.

Table 4: 1995-2002 Average HFC-134a bank in all bus A/C systems, in t*								
	1995	1996	1997	1998	1999	2000	2001	2002
All buses	81.0	120.6	168.8	213.7	258.5	307.2	355.0	400.7

Sources: Calculation based on the data in section 1.
* Including 22 t replacements for R-12 in old systems.

Comment on time series

While A/C quotas (Table 2) and average HFC banks (Table 4) show a clear up-trend, the HFC input through new registrations (Table 3) does not develop uniformly at all. Main reason for the high input in 1996 and 1997 was R-12 replacement in old systems. From 1998 to 2000, HFC input through new bus A/C systems was quite normal. In 2001 and 2002 the input dropped. For the first time the refrigerant reduction in water-cooling A/C systems of coaches showed an effect. It widely depends on the future share of this system design in the number of new A/C units whether HFC-134a in new registrations keeps on dropping or increases beyond 50 t/y.

The time of possible saturation in air-conditioning of new buses is probably different for the three bus types of city buses, overland buses, and coaches. In new coaches, 100% saturation has already taken place in 1999 (Table 2). In overland buses, a remainder of 5% without A/C systems is supposed to be left. The 95% A/C quota might be reached by 2007. In case of city buses, experts assume saturation at two thirds of all new vehicles. This proportion might be met by 2010.

The average HFC bank is supposed to go on growing, assuming unchanged share of water-cooling systems in air-conditioning of coaches. Thus, the bank might peak in 2022, at some 692 tonnes, with emissions then in the range of 100 t/y.

3. Collection and sources of information of activity data

Annual new registrations are taken from official KBA statistics. The refrigerant model (Table 2) which is of decisive importance for estimating air-conditioning of buses, stems from the two leading German bus-makers, DaimlerChrysler's subsidiary EvoBus and NEOMAN Bus GmbH, which unites the formerly separated activities of MAN and Neoplan. The two companies did not only provide data on themselves, but made also estimations on the total domestic market. This concerns the split of new buses into three categories, the annual A/C quotas in these three categories, and the average refrigerant charges. While the data on A/C quotas and charges was controlled every other year, the split into three bus categories has not been checked again since 2001. The split, however, was presented to the experts (see below) to undergo plausibility control.

The market share of the two groups DaimlerChrysler and NEOMAN in the domestically new-registered buses figured some 87% in 2002 (KBA statistics). Thus, their estimations of the total market conditions enjoy a broad basis.

Sources of information on activity data (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Personal Communications
EvoBus GmbH (former EvoBus Setra GmbH), Ulm, 22.07.98, 12.03.99, 28.10.02, 24.09.03.

NEOPLAN Bus GmbH (former NEOPLAN Gottlob Auwärter GmbH & Co.), Stuttgart, 05.03.99, 23.09.03.

Written sources

Jörg Peter Kirsamer, Busklimaanlagen – heute und in Zukunft, Vortrag an der FH Karlsruhe, März 1998.

Revolution im Reisebus. Mit der Serienfertigung des Neoplan Euroliner startet eine Klimatechnik, die wartungsärmer und kostengünstiger als bisherige Systeme sein soll, in: Bus Aktuell, Nr. 12/1999, S. 6.

Mayer, Helmut; Technischer Stand der Busklimatisierung, in: Ki Luft- und Kältetechnik 4/1998, 190 ff.

Particular information on R-12 replacement of buses

EvoBus GmbH Setra Omnibusse GmbH, Ulm, Schreiben 22.07.98.

MAN Nutzfahrzeuge AG, München, Schreiben 14.07. 98.

Konvekta AG, Schwalmstadt, 22.6.1998.

Sütrak Transportkälte GmbH, Renningen, 17.07. 98.

Webasto Fahrzeugtechnik AG, Stockdorf, 13.07. u. 20.07. 98.

Öko-Recherche: R-12 replacement in existing equipment from 1996 to 1998, Report on the Umweltbundesamt (in German), Berlin, August 1998. http://www.oekorecherche.de/deutsch/berichte/volltext/vollR12.pdf

4. Factor of operating emissions

For operating emissions, which consist of "regular" and "irregular" losses, a general factor of 15%/y is applied to all bus categories. Based on the finding that A/C systems of passenger cars exhibit operating emission of 10% annually, additional 5% take into account that for air-conditioning of buses a 5-50 metres long piping system is necessary (hoses, copper tubes with connections and valves). This is the main reason why professional experts estimate emissions "higher than from passenger cars" (MAN 1999, Webasto 1999, Sonnekalb 2003). Apart from that they made the much longer annual running times of buses compared with passenger cars responsible for higher leakage.

The fact that water-cooling systems do not need so long refrigerant pipes and not so numerous connections should contribute to a reduction in regular emissions. In the absence of specific information, a reducing effect has not yet been considered when estimating 2001 and 2002 emissions. So far, the emission factor remained at 15%. This also applies to retrofitted old A/C-systems whose emissions are likely to be significantly higher than 15% per year.

Sources of information on emission factor (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Special studies on emissions from bus air-conditioning systems are not available. The used 15% are based on expert statements as well as on the established 10% for passenger cars plus a 5% surcharge for higher emission risks due to design and longer running times of bus systems.

In 1995, a value of 14% for old systems was presented in the status report on R-12 replacement. This value followed an estimation made by Öko-Recherche the same year. Here, these old values are judged not to be reliable enough or high enough to meet the leakage of old systems.

Personal Communications
Webasto AG, Stockdorf, 12.03.99.
MAN Nutzfahrzeuge AG, München, 10.03.99.
Thermal-Werke – Wärme-, Kälte-, Klimatechnik GmbH, Hockenheim, 09.07.98.
Konvekta AG, Schwalmstadt, pers. comm. at the DKV meeting 2003 in Bonn, 21.11.03.

Written sources
FKW (Forschungszentrum für Kältetechnik und Wärmepumpen): Ersatz von R 12 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen in der Bundesrepublik Deutschland durch Kältemittel mit geringerem Ozonabbaupotential, Statusbericht im Auftrag des Umweltbundesamtes, Berlin, Hannover, November 1995. S. 97.
Öko-Recherche, No "all-clear" for ozone and climate. 1995 German consumption forecast for CFCs, HCFCs and HFCs (in German), Study for Greenpeace e.V. Hamburg 1995, S.24. http://www.oekorecherche.de/english/berichte/volltext/keine-entwarnung.pdf
Öko-Recherche (Winfried Schwarz): Emission of Refrigerant R-134a from Mobile Air-Conditioning Systems. Annual Rate of Emission from Passenger-Car Air-Conditioning Systems up to Seven Years Old, Report on the Umweltbundesamt Berlin, Frankfurt 2001. http://www.oekorecherche.de/english/berichte/volltext/MAC-LOSS-2001.pdf
Öko-Recherche (Winfried Schwarz)/ Ecofys (Jochen Harnisch): Establishing the Leakage Rates of Mobile Air Conditioners. Report on the EU Commission (DG Environment). B4-3040/2002/337136/MAR/C1. Frankfurt/Nürnberg 2003. http://www.oekorecherche.de/english/berichte/volltext/leakage_rates.pdf

5. Operating HFC emissions from bank

Operation emissions in a particular year n are arrived at by applying the factor of operating emissions (EF_{op}) to the average bank of year n (B n), which has been built up by annual HFC inputs (including R-12 replacements) over the past time – see section 2. This is the basic equation:

$$EF_{op} \text{ (in \%)} \quad x \quad B\ n$$

Because of EF_{op} of 15% for bus A/C systems, the specific equation for operating emissions from buses is:

$$EF_{op} \text{ (15 \%)} \quad x \quad B\ n$$

Annual operating HFC emissions from bank are presented in Table 5 in t/y.

Table 5: 1995-2002 Operating emissions from average HFC bank in all bus A/C systems, in t/y

	1995	1996	1997	1998	1999	2000	2001	2002
Average bank	81.0	120.6	168.8	213.7	258.5	307.2	355.0	400.7
Operating emiss.	12.1	18.1	25.3	32.1	38.8	46.1	53.2	60.1

Sources: Calculation based on data from previous sections.

Comment

Operating emissions have been rising constantly since 1995, in step with the growing annual average HFC bank in A/C systems. Under business-as-usual conditions this bank is supposed to go on increasing until 2021 (to 692 t), so that emissions are to peak then at calculated 121 t.

6. Quality control and uncertainty assessment of data I

Activity data. Safety of activity data is classified high. This does not only apply to officially surveyed new registrations, but also to the refrigerant model (split into three categories, different A/C quotas in these three categories, average refrigerant charges). The latter is the case because both experts from the directly inquired bus companies can make use of well-kept internal statistics. Additionally, the combined market share of the two companies is high with 86%, so that projections from the conditions of these companies may not fail the situation of the total market to a significant extent.

Emission factor. The emission factor 15% is sufficiently reliable for the first two thirds of its level, namely 10% for mobile A/C systems without refrigerant piping through the passenger cabin and at relatively short running times of the system. This factor was measured at passenger cars (statistical deviation of less than ± 1% at a 95% confidence interval). Admittedly, there are no measurements forming the basis of the surcharge of 5% for bus-specific higher emission risks due to that piping system, and due to significantly longer running times. Nevertheless, in the eyes of ÖR this order of magnitude seems to be adequate and robust enough, conceding possible up- and down deviations of 2% at the maximum (15% ± 2%).

7. Relation to IPCC method I

In IPCC GPG, emissions from mobile air-conditioning are generally dealt with under "3.7.5 Mobile air-conditioning sub-source category". There are no special comments on Mobile Air Conditioners of buses. ÖR generally follows the requirements stated in Box 3 of the Decision Tree for Actual Emissions, "Calculate emissions by vehicle class and age, using country-specific bottom-up emission factors."

In Equation 3.49, the estimation of Operating Emissions is proposed as follows:

$$\text{Operating Emissions} = (\text{Amount of HFC-134a Stock in year t}) * (x/100).$$

In the equation, x/100 is the emission factor. As (updated) default emission rate 10 to 20% are suggested. In this range the value of 15%, which is used by ÖR, is localised. In IPPC GPG, default average vehicle lifetime is 12 years. The same value is used by ÖR.

8. Entry in CRF I

The CRF Table to enter data on operating emissions of HFC-134a from bus A/C systems is Table 2(II).Fs1, row 86, columns C and I.

II. Domestic HFC consumption and manufacturing emissions

9. Activity data II

CRF requires estimation of domestic HFC consumption for manufacturing and of HFC emissions arising on manufacture. Annual domestic consumption (C_{manu}) is no function of annual domestic new registrations of vehicles with A/C system but of domestically manufactured vehicles with A/C system.

The Association of the Automotive Industry (VDA) annually publish for the previous year data on domestic production of buses. For lack of specific data on air-conditioning of domestic production, alternatively A/C quotas and refrigerant charges of domestic new-registrations are applied in order to estimate HFC consumption and number of domestically assembled and charged new bus A/C systems. In Table 6, this way gained basic data are presented which enable to estimate domestic HFC consumption as well as manufacturing emissions. (Charging of old systems is disregarded here because of the insignificance of associated emissions). Buses are not split into different categories.

Table 6: 1995-2002 Domestic production of omnibuses, their A/C quotas and average refrigerant charges

	1995	1996	1997	1998	1999	2000	2001	2002
Number of buses	9,888	10,353	11,569	12,985	11,825	13,518	11,940	9,745
A/C Quota	49%	52%	56%	60%	63%	65%	67%	71%
Av. Charge in kg	12	12	12	12	12	12	11.2*	11.2*

Sources: VDA – Tatsachen und Zahlen, 59. – 67. Folge, Frankfurt am Main (Production). Table 2 for A/C quotas and average charges before 2000.
* The reduction in charge results from fitting water-cooling A/C systems to coaches.

By means of the data in Table 6 annual HFC consumption for domestic charging of new bus A/C systems can be determined (HFC consumption = Number of Buses x A/C Quota x Average Charge). The resulting figures are entered in Table 7, line 1.

In the same way the overall number of domestically assembled and charged new bus A/C systems can be calculated (Number of A/C systems = Number of Buses x A/C Quota). This figure is also entered in Table 7 (line 2).

10. Emissions on manufacturing

Although the passenger car value of 2 grams loss per one charge provides guidance for A/C systems of any road vehicles, this value is deemed too low for buses, whose systems are charged with the ten-fold quantity used for trucks. Therefore, emissions of 5 grams per one charge are assumed in Table 7, line 3.

Table 7: 1995-2002 Domestically assembled bus A/C systems by HFC consumption (in t), number of units, loss per charge (in grams), and manufacturing emissions (in kg)

	1995	1996	1997	1998	1999	2000	2001	2002
Dom. Consumption	57.8	65.2	78.1	93.5	89.4	105.8	89.4	77.4
Number of A/Cs	4,817	5,433	6,506	7,791	7,450	8,814	8,000	6,899
Loss in g/AC	5	5	5	5	5	5	5	5
Manuf. emiss. in kg	24.1	27.2	32.5	39.0	37.2	44.1	40.0	34.5

Sources: Calculations based on previously presented data.

11. Emission factor of domestic manufacturing

As per Table 7, manufacturing emissions (Em_{manu}) range between 20 and 40 kg/y. When relating this manufacturing loss to the domestically charged HFCs (C_{manu}), an implied emission factor can be calculated. This factor is 0.04% from 1995 to 2000 and 0.05% from 2001 onwards. The slight rise is a result of the decrease in average refrigerant charge from 12 to 11.2 kg.

12. Quality control and uncertainty assessment of data II

Safety of activity data that is of importance for the filling process in principle depends on the safety of activity data that underlies operating emissions. On the one hand, the reported number of annually manufactured buses is highly reliable, on the other hand, small uncertainties arise because A/C quotas and refrigerant charges are not surveyed directly but are estimated by application of market conditions to the conditions of domestic manufacture of buses.

The emission factor (EF_{manu}) 5-g/new system is an estimation made by ÖR based on plausibility and comparison with charging processes of similar-sized systems.

13. Relation to IPCC method II

Like any other default emission parameters, the First-Fill emission rate of MACs is completely oriented towards passenger cars in IPCC GPG. Its current version does not provide special guidance for other mobile A/C systems.

14. Entry in CRF II

The CRF Table where the data "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered is Table 2(II).Fs1. The data on HFC-134a are entered into row 86, columns B and H.

F-Gas-Sheet 12: Air Conditioning of Agricultural Machines

F-Gas	**HFC-134a**
Application	**Air Conditioning of Agricultural Machines**
Reported Years	**1995 – 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**

Background

Since 1990, automobile machines in agriculture have increasingly been equipped with air-conditioning. Above all, tractors are numerically relevant, of which 25,000 units are new-registered annually. Their A/C quota has risen between 1994 and 2002 from 20% to 70%, with large tractors being delivered with an A/C quota of almost 100% as of 1999. The refrigerant charges with a mean of 1.44 kg are large.

In addition to tractors, also seasonally usable farm machines are equipped with air-conditioning systems. Firstly, about 2,500 to 3,000 combines annually, whose A/C-quota (domestic sales) has increased between 1994 and 2002 from 75% to 95%. Secondly, about 400 crop choppers annually, whose air-conditioning has raised the same rate. The refrigerant charges of both machine types are of the same size (1.6 kg).

Particularly combines are machines that are used only during summer months (July - September) and are out of use over the most part of the year. Long resting times lead to brittle seals and hoses and promote leakage no less than the full working load during the short time of employment does.

I. Bank and operating emissions from bank

1. Activity data I. Annual domestic HFC input

1.A Annual number of new farm machines in domestic agriculture

Since 1994, air-conditioning systems of tractors, combines, and crop choppers are filled with HFC-134a. Tractors have to be registered, so that the KBA can survey and publish their number. Experts have estimated the number of new combines and crop choppers for domestic agriculture. The three time series of numbers are shown in Table 1.

Table 1: 1994-2002 Annual number of new farm machines in agriculture, units

Farm Machines	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. Tractors	25,000	24,000	24,955	23,854	25,544	25,630	23,815	24,795	25,649
2. Combines	3,000	3,000	3,000	3,304	3,421	2,465	2,489	2,500	2,500
3. Crop Choppers	400	400	400	400	400	400	400	400	400

Sources: Section 3.

1.B Refrigerant model for agricultural machine A/C systems

The generally used HFC-type is 134a. The three categories of farm machines vary in A/C quotas and refrigerant charges. The figures given by sector experts are entered in the refrigerant model (Table 2). The A/C quotas change from year to year; the average system charges remain constant.

Table 2: 1994-2002 Model of refrigerant charges and A/C quotas of farm machine A/C-systems

	Refr.	Ratio of air-conditioning (A/C quota) in %								
Farm Machines	Charge	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. Tractors	1.44 kg	20%	26%	33%	39%	45%	51%	58%	64%	70%
2. Combines	1.6 kg	75%	78%	80%	83%	85%	88%	90%	93%	95%
3. Crop Choppers	1.6 kg	75%	78%	80%	83%	85%	88%	90%	93%	95%

Sources: Experts mentioned in section 3.
Notice: In each category, the charges have remained unchanged over the 1994-2002 periods.

1.C HFC input through new agricultural machine A/C systems

Annual input (In_{bank}) of the refrigerant HFC-134a in year n can be arrived at by combination of Table 1 and 2. This means to weight the number of new farm machines in one of the three categories as per Table 1 with the respective A/C quota as per Table 2 <u>and</u> the charge typical of this category (1.44 or 1.6 kg) as per Table 2, too. In this way, HFC input according to Table 3 can be calculated.

Table 3: 1994-2002 Domestic HFC input through new farm machine A/C systems, in t/y

Farm Machines	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. Tractors	7.2	9.1	11.7	13.3	16.6	18.9	19.7	22.8	25.9
2. Combines	3.6	3.7	3.8	4.4	4.7	3.5	3.6	3.7	3.8
3. Crop Choppers	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
4. Total	11.3	13.3	16.0	18.2	21.7	22.9	23.9	27.1	30.3

Sources: Tables 1 and 2.

2. HFC bank in A/C systems of agricultural machines

The end-of-year bank of HFCs in year n in A/C systems (EB n) annually increases by domestic input (In_{bank} n). The end-of-year bank of year n is the sum of all the inputs that have taken place until the end of year n, minus domestic output of HFCs for disposal with old systems. In view of a 10-year-lifetime, systematic decrease in bank because of decommissioning will not occur before 2004 (De_{bank} = 0).

The average domestic bank B n is half the sum of the previous end-of-year bank (n-1) and the current end-of-year bank n. This is the equation:

$$B\,n = \frac{EB\,n\text{-}1 + EB\,n}{2} \qquad \text{Where:} \qquad EB\,n = EB\,n\text{-}1 + In_{bank}\,n$$

In the following, the average annual bank (B n) is not distinguished by three machine categories, but only by tractors on the one hand and combines/crop choppers on the other hand. This is because combines and crop choppers behave uniformly with respect to relative emissions, but differently to tractors. From Table 3 average HFC banks in Table 4 can be derived, using the equation above.

Table 4: 1995-2002 Average HFC bank in A/C systems of farm machines, in t

Farm Machines	1995	1996	1997	1998	1999	2000	2001	2002
1. Tractors	11.7	22.1	34.6	49.5	67.3	86.6	107.8	132.1
2. Combines/Crop Ch.	6.2	10.5	15.1	20.1	24.7	28.8	33.1	37.4
3. Total	17.9	32.6	49.7	69.7	92.0	115.4	140.9	169.5

Sources: Calculation based on data presented in section 1.

Comment on time series

The three farm machines show each a uniform up-trend in annual average HFC banks. Tractors represent 80% of the banked HFC quantities. These are also of decisive importance for the up-trend in annual input (In_{bank}). The tractors' A/C quota has risen within just eight years from a relatively low initial level (20%) to considerable 70%. New tractors in the upper performance classes (over 70 kW) show A/C quotas of almost 100%, as of 2000. The numerically less important combines and crop choppers started in the first HFC-year (1994) from a high A/C quota of 75%, so that achieving a quota of 95% (2002) does not represent such a high growth rate.

Between 1996 and 1998, HFC input was within the trend of the other years. In other words, old R-12 systems have scarcely been converted.

In tractors, whose lifetime is estimated at 10 years, saturation might be conceivable at 95% A/C quota of the bank. Under business-as-usual conditions, this would be in 2016 at then 350 tonnes banked. In combines and crop choppers saturation (95%) of the bank seems to be possible earlier, i.e. by 2008 at then 38 tonnes and 6 tonnes, respectively. Total bank in 2016 could amount to 395 tonnes.

3. Collection of activity data and sources of information I

The KBA does not publish data on all automobile farm machines, but only on tractors. Data on air-conditioning (annual A/C quotas, average refrigerant charges) are not officially surveyed, but have been inquired of the three market leaders, who, incidentally, are the three only domestic manufacturers of tractors: AGCO (formerly Fendt), John Deere and SAME Deutz-Fahr. Their 2002 market shares amongst the 30 suppliers of tractors amounted to 23%, 21%, and 11% (KBA), so that the experts from the three companies inquired can be expected to have a good overview of the overall domestic market.

Domestic sales of combines and crop choppers are not officially published, as the buyers are not obliged to register such machines. Estimations on the domestic market of combines were made amongst others by the market leader Claas, who had in 2002 a market share of 47%, according to his account, followed by John Deere and Deutz-Fahr with between 10 and 20% market share, each. Concerning crop choppers, the situation is similar: no official data, but statements from the two market leaders. These are the companies Claas and John Deere, enjoying market shares of over 50% and some 20% respectively. The data on overall sales of farm machines are annually submitted to the Specialised Section Agricultural Technology with the VDMA (German Engineering Federation). In some cases, several Internet web sites helped control the company-data.

In tractors, combines, and crop choppers, no projections from data of individual companies to the total market were carried out. It seemed to be the better way directly to apply estimations made by the market leaders to the overall market, the more as the estimations agreed with each other to a high extent.

Sources of information on activity data (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Personal Communications
CLAAS KGaA mbH, Harsewinkel, Combines and crop choppers: 23./24.09.03.
John Deere, Werke Mannheim, Tractors, combines, crop choppers: 24.09.03.
AGCO GmbH & Co. OHG, Marktoberdorf, Tractors: 23.09.03.
SAME Deutz-Fahr Deutschland GmbH, Lauingen, Tractors and combines: 06.11.03.
VDMA, Specialised Section Agricultural Technology (Fachverband Landtechnik), Frankfurt, 06.11.03.

Written Sources
CLAAS KGaA mbH, Geschäftsbericht 2002, auf www.claas.com/gb02/de/index.html
To the market of combines: Franz Hensen: http://home.t-online.de/home/hensen/#markt
VDMA, Fachverband Landtechnik, Frankfurt. Wirtschaftsbericht 2003. http://www.vdma.org/vdma_root/www_lav_vdma_de/

4. Factor of operating emissions

The factor of operation emissions for tractor A/C systems is in the range of the emission factor for trucks, namely 15%. In case of combines and crop choppers, 25% are applied.

5. Sources of information on factor of operating emissions (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

There are no studies available on emissions from A/C systems of farm machines. The annual 15% (tractors) and 25% (seasonal farm machines) are mainly based on estimations of experts from the four domestic market leaders. The experts for combines and crop choppers admitted that annual operating emissions from these vehicles ranged due to their short but full load utilisation "significantly higher" than from tractors. 25% were considered "possible" or were at least not denied. It should be noted that this value was considered by an (external) expert to be a minimum.

Personal Communications
CLAAS KGaA mbH, Harsewinkel, combines and crop choppers: 23./24.09.03.
John Deere, Werke Mannheim, tractors, combines, crop choppers: 24.09.03.
AGCO GmbH & Co. OHG, Marktoberdorf, tractors: 23.09.03
SAME Deutz-Fahr Deutschland GmbH, Lauingen, tractors and combines: 06.11.03.
Bundesfachschule Kälte-Klima-Technik, Niedersachswerfen, nsw@bfs-kaelte-klima.com, pers. comm. at the IKK Nürnberg, 16.11.02.

6. Operating HFC emissions from bank

Operating emissions in a particular year n are arrived at by applying the factor of operating emissions (EF_{op}) to the average bank of year n (B n), which has been built up by several annual HFC inputs through domestic new systems over the past years – see section 2.

$$EF_{op} \text{ (in \%)} \quad x \quad B\ n$$

Because of EF of 15% and 25% for farm machine A/C systems, the specific equation for operating emissions is as follows:

$$EF_{op} \text{ (15\%, 25\%)} \quad x \quad B\ n$$

Table 5 shows annual emissions of HFC-134a from average annual banks.

Table 5: 1995-2002 Operating emissions from HFC banks in farm machines, in t/y

	1995	1996	1997	1998	1999	2000	2001	2002
1. Tractors	1.8	3.3	5.2	7.4	10.1	13.0	16.2	19.8
2. Combines/Crop Chopp	1.0	2.6	3.8	5.0	6.2	7.2	8.3	9.4
3. Total	2.8	5.9	9.0	12.5	16.3	20.2	24.4	29.2

Sources: Calculation from data in Table 4, applying EF of 15% and 25%, respectively.

Comment

Operating emissions have been rising constantly from 1995 onwards, pursuant to the growth in the average HFC-134a banks of all the three farm machine categories. The integrated EF of overall operating emissions of 29.2 tonnes (2002) was 17.3% (related to total bank). Since under business-as-usual conditions the latter is supposed to rise until 2016 (peaking at 395 t), the then emissions would come up to calculated 64 t (16.2%).

7. Quality control and uncertainty assessment of data I

Activity data. Safety of activity data on air-conditioning of farm machines (A/C quotas of domestic sales for all machine categories, average charges) can be classified sufficiently high. The experts from directly inquired companies possess not only well kept own records, but also good overviews of the three market sub-segments that, incidentally, are not large. It should be noted that the combined market shares of the companies the experts are employed by, range from 55% (tractors) to 70% (crop choppers) and even 80% (combines). Thus, a considerable degree of professional competence can be taken for granted.

Concerning data on domestic sales of the three farm machines, only for tractors official surveys of new registrations are available. However, with the help of experts inside and outside the inquired companies reliable sales data even on combines and crop choppers could be estimated.

Emission factor. All the inquired experts from the companies AGCO, John Deere, and Deutz-Fahr agreed on the 15% as a rule of thumb for tractors. Four experts were interviewed about combines and crop choppers. Two were in favour of "more than 20%", one argued for "likely at 25%" and another for "at least 25%". The order of magnitude between 20 and 30% is considered here certain enough.

8. Relation to IPCC method I

In IPCC GPG, emissions from mobile air-conditioning are generally dealt with under "3.7.5 Mobile air-conditioning sub-source category". There are, however, no special comments on systems of farm machines. ÖR generally follows the requirements stated in Box 3 of the Decision Tree for Actual Emissions, "Calculate emissions by vehicle class and age, using country-specific bottom-up emission factors."

In Equation 3.49, estimation of Operating Emissions is proposed as follows:

$$\text{Operating Emissions} = (\text{Amount of HFC-134a Stock in year t}) * (x/100).$$

In the equation, x/100 is the emission factor. As default emission rate, 10 to 20% are suggested. In this range is the value of 15%, which is used by ÖR for tractors. For combines and crop choppers the ÖR values are higher. The average vehicle lifetime in IPPC GPG has a default value of 12 years. This value is not used by ÖR for the agriculture, as all the interviewed experts considered even 10 years very high.

9. Entry in CRF I

The CRF-Table where data on operating emissions from farm machine A/C systems are primarily entered is Table 2(II).Fs1, row 87, columns C u. I.

II. Domestic HFC consumption and manufacturing emissions

10. Activity data II

CRF requires estimation of domestic HFC consumption for manufacturing and of HFC emissions arising on manufacture. Annual domestic consumption (C_{manu}) is no function of the annual number of new A/C equipped machines supplied to domestic agriculture but of domestic manufacture of machines.

The number of domestically manufactured tractors is annually surveyed by the VDMA (Specialised Section Agricultural Technology). Concerning production numbers of combines and crop choppers, expert estimations are available. These follow the rule: "Production of combines is the same size as domestic market", and "production of crop choppers is two times the domestic market". Subsequently, for combines the unaltered figure of Table 1 was inserted in Table 6, while for crop choppers the figure from Table 1 was doubled. The values for tractors are actually surveyed numbers.

Table 6: 1995-2002 Domestic production of tractors, combines and crop choppers

Farm machines	1995	1996	1997	1998	1999	2000	2001	2002
1. Tractors	50,616	53,910	45,758	45,287	43,663	44,975	46,366	53,811
2. Combines	3,000	3,000	3,304	3,421	2,465	2,489	2,500	2,500
3. Crop Choppers	800	800	800	800	800	800	800	800

Sources: VDMA, FV Landtechnik, Frankfurt, Gerd Wiesendorfer (Tractors). For Combines and Crop choppers see section 3 (Part I).

In the absence of data on air-conditioning of domestically manufactured farm machines, alternatively A/C quotas and refrigerant charges of new machines supplied to domestic agriculture (Table 2) were applied. Linking these data to the production figures in Table 6, "proxy" data can be calculated on both the number of domestically fitted A/C units and the HFC quantity charged to them.

The resulting figures are entered in Table 7 together with manufacturing emissions, which arise under the assumption of 5 grams loss per one new A/C system.

11. Emissions on manufacturing

For farm machine A/C systems 5 grams loss on charging is assumed, regardless of the system's real capacity. This is a value appraised by ÖR. A loss of only 2 grams as usual on automatic charging of passenger car systems is not supposed to be possible facing the usually small numbers of manufactured units.

Table 7: 1995-2002 Domestically assembled farm machine A/C systems by HFC consumption (in tonnes), number of units, loss on charging (in grams), and manufacturing emissions (in kg and %)

	1995	1996	1997	1998	1999	2000	2001	2002
Dom. consump. t	23.8	30.1	31.0	35.1	36.8	42.0	47.4	59.3
A/C units	16,232	20,561	21,117	23,967	25,234	28,821	32,611	40,803
Loss per unit g	5	5	5	5	5	5	5	5
Manuf. emiss. in kg	81.2	102.8	105.6	119.8	126.2	144.1	163.1	204.0
Manuf. emiss. in %	0.34%	0.34%	0.34%	0.34%	0.34%	0.34%	0.34%	0.34%

Sources: Calculations based on above presented data.

12. Emission factor of domestic manufacturing

Due to the growth in air-conditioning of new-manufactured farm machines, manufacturing emissions (Em_{manu}) have increased from some 80 kg to more than 200 kg by 2002. Relating them to domestic consumption for charging, which has likewise risen (to 59.3 t), a value of 0.34%/y emerges as implied emission factor.

13. Quality control and uncertainty assessment of data II

Safety of activity data, which is of importance for the filling process, in principle relies on safety of activity data that underlies operating emissions. This particularly applies to the number of annually manufactured combines and crop choppers. Additional uncertainties for estimating domestic HFC consumption and number of assembled A/C systems arise from the fact that refrigerant charges and A/C quotas have not directly been surveyed, but are indirectly estimated by applying market conditions to manufacturing conditions. An expert of one of the three domestic tractor manufacturers denied the A/C quotas of the domestic market to be a fully appropriate measure for domestic production, explaining that in Germany mainly tractors of higher performance were manufactured, which exhibited an A/C quota higher than on average. Therefore, it might be the case that A/C quotas of manufactured farm machines are higher in reality than shown above. The same applies to domestic HFC consumption.

The emission factor of 5-g/new system has been estimated by ÖR and is rather uncertain. The value is the same size as the standard emission factor used in stationary refrigeration.

14. Relation to IPCC method II

Like any other default emission parameters, the First-Fill emission rate of MACs is completely oriented towards passenger cars in IPCC GPG (Table 3.23). Its current version does not provide special guidance for other mobile A/C systems.

15. Entry in CRF II

The CRF Table where the data "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered is Table 2(II).Fs1. The data on HFC-134a are entered into row 87, into columns B and H.

F-Gas-Sheet: 13 Ship Air Conditioning

F-Gas	**HFC-134a**
Application	**Ship Air Conditioning**
Reported Years	**1997 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**

Background and methodological remarks

Ships have been air-conditioned for a long time, however with HFCs not before 1996. 1998 was the first year when HFCs became the prevailing refrigerant type. In 1996 just 10%, in 1997 some 25% of new ship air conditioners used HFCs. Even in 1998, the HCFC-22 was frequently applied. After some trials with HFC-407C, the HFC-134a established itself as the standard refrigerant.

In 2002, all the still 550 ocean-going vessels with registered tonnage (RT) over 100, sailing under German flag, were air-conditioned, be it cargo or passenger ships. Additionally some 50 naval ships have on board A/C systems. Concerning inland waterway ships, the 1,300 motorised cargo ships and tank ships usually are not air-conditioned, while passenger ships (943 units) are A/C equipped, amongst them all the 87 new ships that have been built since 1997.

Fishing vessels (ocean-going and inshore fishery) have refrigeration equipment on board. The twelve fish trawlers, however, use either ammonia or HCFC-22 as refrigerant. Cutter fishers use chipped ice, which is produced onshore by means of ammonia systems. (Fischverwertung Heiligenhafen-Neustadt, 19.07.02).

There are two remarks to make on the method. First, ocean going vessels as well as inland ships of German shipping companies sail partly under German and partly under foreign flag. Emissions are estimated only for ships under German flag. This has also a practical background, as data on ships under foreign flag are scarcely available. Second, though HFC emissions from ocean-going ships under German flag do not occur for the most part on German territory (harbours, inshore), but in international waters, they are considered national emissions, in the following.

I. Bank and operating emissions from bank

1 Activity data I. HFC input through new air-conditioned ships under German flag

1.A Annual number of new ships adding the German fleet

All the new-built ships adding to the German ocean-going fleet since 1997 were equipped with A/C: cargo and naval ships in favour of the crew, passenger ships additionally in favour of the passengers. Concerning inland navigation, cargo ships are not equipped with A/C in contrast to passenger ships. The latter are split into excursion boats on the one hand and cabin boats on the other hand. The new-built ships that have added to the overall German fleet from 1997 and 1998 onwards are entered in Table 1.

Table 1: 1997-2002 Annual number of new ships adding the German ocean-going and inland fleet, by categories

Ship category	1997	1998	1999	2000	2001	2002
1. Ocean-going cargo	-	22	23	22	21	21
2. Ocean-going passenger	-	1	1	1	1	1
3. Cruise liner	0	1	0	0	0	0
4. Naval ship	0	0	0	0	0	1
5. Inland excursion boat	15	13	17	10	11	7
6. Inland cabin boat	0	1	1	3	7	4

Sources: Section 3. The indication "-" in 1997 means that HFC had not not yet been used.

Comment

1. Ocean-going cargo ships: In the 1998-2002 period, 109 new cargo ships added to the fleet, namely 37 general cargo vessels, 66 container ships, and 6 tankers.

2. Ocean-going passenger ships incl. cruise liners

From 1998 to 2002, six ships increased the fleet: one big cruise liner (1998), three more passenger ships, and two ferryboats.

3. Naval ships

Since 1998 seven new ships have been being built (three frigates and four submarines), which will not be placed into service before 2004. Only one frigate (class 124) was provisionally finished by August 2001 to undergo further testing on sea.

4. Inland passenger ships

The number of new excursion boats increasing the inland fleet is 73 as of 1997 (inventory: 851 in 1996). Cabin boats, the inventory of which had amounted to just 18 units by 1997, have increased by 16 newbuildings over the 1998-2002 period.

1.B Refrigerant model for ship A/C systems

The individual ship categories differ in refrigerant charges of their A/C systems. Standard refrigerant is HFC-134a (refrigerants for food refrigeration, usually running with HFC-404A, are disregarded here, as we concentrate on mobile air-conditioning). Interviews with experts from the two leading companies in Germany (York and Noske-Kaeser) which supply A/C equipment for ships, led to the refrigerant model presented in Table 2. Notice that all new-built ships listed below are air-conditioned, so that the A/C quotes generally are 100%. This is not mentioned explicitly there.

Table 2: Refrigerant model for A/C systems of new-built ships for the German ocean-going and inland fleet		
Ship category	Standard refrigerant	Average charge in kg
1. Ocean-going cargo ships	134a	100
2. Ocean-going passenger ships	134a	250
3. Cruise liner*	134a	1000
4. Naval ships	134a	500
5. Inland excursion boats	134a	100
6. Inland cabin boats	134a	250

Sources: Sector experts from York and Noske-Kaeser, mentioned in section 3.
* "MS-Deutschland" of the shipping company Deilmann with 23,000 RT: 1,000 kg in centrifugal chillers.

1.C HFC input through new ship A/C systems (ships under German flag)

Annual input (In_{bank}) of the refrigerant 134a in year n can be calculated by combination of Table 1 with Table 2: by weighting the annual number of newbuildings in one of the six ship categories as per Table 1 with the respective average charge in kg as per Table 2. In this way, HFC input according to Table 3 is derived.

Table 3: 1997-2002 HFC input through A/C systems in new-built ships for the German ocean-going and inland fleet by categories, in t/y						
Ship category	1997	1998	1999	2000	2001	2002
1. Ocean-going cargo ships	-	2.20	2.30	2.20	2.10	2.10
2. Ocean-going passenger ships	-	0.25	0.25	0.25	0.25	0.25
3. Cruise liner*	-	1.00	0	0	0	0
4. Naval ships	-	0	0	0	0	0.50
5. Inland excursion boats	1.50	1.30	1.70	1.00	1.10	0.70
6. Inland cabin boats	0	0.25	0.25	0.75	1.75	1.00
Total in tonnes	1.50	5.00	4.50	4.20	5.20	4.55

Sources: Table 1 und Table 2.

2. HFC bank in ship A/C systems

The HFC end-of-year bank in year n (EB n) in ship A/C systems annually increases by domestic HFC input (In_{bank}), as long as departures from bank do not occur in considerable numbers. Systematic decommissioning is not expected to take place before 2020 in the face of a 25-year-lifetime.

The <u>average domestic bank B n</u> is half the sum of the previous end-of-year bank (n-1) and the current end-of-year bank n. This is the equation:

$$B\,n = \frac{EB\,n\text{-}1 + EB\,n}{2} \qquad \text{Where:} \quad EB\,n = EB\,n\text{-}1 + In_{bank}\,n$$

Subsequently, the average annual bank (B n) is no longer broken down into different ship categories, as all ship A/C systems show the same emission behaviour. Table 4 contains the time series of the average bank as of 1995 (1997).

Table 4: 1995-2002 Average HFC bank in all ship A/C systems, in t								
	1995	1996	1997	1998	1999	2000	2001	2002
All ships	-	-	0.75	4.00	8.75	13.10	17.80	22.68

Sources: Calculation based on the data in section 1.

Comment on time series

HFCs in newbuildings and in annual banks did not occur before 1997 due to the late substitution of HCFC-22 by HFC-134a. A/C systems of ocean-going cargo ships representing about half the annual refrigerant input, are predominantly built abroad (Far East). The annual quantity of new HFCs in A/C systems of ships adding to the German ocean-going and inland fleet fluctuates around 5 tonnes from 1998 onwards. Since then the bank has steadily increased. Due to 25-year-lifetime, under business-as-usual conditions (5 tonnes annual input) the growth is expected to go on until 2020 and later, peaking at more than 110 tonnes.

3. Collection of activity data

Since 1998, data on ocean-going ships coming under German flag are provided by Verband deutscher Reeder (Association of German Shipping Companies), Hamburg. Information on new naval ships can be found at the website of the German Bundeswehr-Marine (navy). New-built excursion and cabin boats for the inland fleet are annually surveyed by the authority Wasser- und Schifffahrts-Direktion Südwest, Mainz.

The two domestic market leaders in ship A/C equipment gave information on air-conditioning systems and A/C quotas by ship categories: Noske-Kaeser and York Marine, both situated in Hamburg.

Sources of information on activity data (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Data on inland fleet:
Wasser- und Schifffahrts-Direktion (WSD) Südwest, Mainz, 18.11.03.
http://www.elwis.de/Verkehrswirtschaft/schiffbestand/entw_biflo/fahrgastkabinenschiffe.pdf,
http://www.elwis.de/Verkehrswirtschaft/schiffbestand/entw_biflo/fahrgasttagesschiffe.pdf
Statistisches Bundesamt, Wiesbaden, binnenschiffahrt@destatis.de, 22.10.02, 07.10.03.
New-built passenger boats for inland navigation are additionally published in Statistisches Jahrbuch der Bundesrepublik Deutschland (Kap. 13.11), since 2001.

Data on ocean-going fleet
Verband Deutscher Reeder e.V. (VDR), Hamburg www.reederverband.de, 06.10.03.
Additionally: Reederei Peter Deilmann, Neustadt in Holstein www.deilmann-kreuzfahrten.de, 07.10.03.

Data on navy
http://www.deutschemarine.de/80256B100061BA9B/vwContentFrame/N256DM2T116MMISDE
http://www.blohmvoss.com/d/prod/frigate_f124.html

Air-conditioning of ships:
Noske-Kaeser GmbH, Hamburg, 01.07.99, 23.10.02; 23.09.03.
York Industriekälte GmbH & Co. KG, Marine, Hamburg, 23.10.02, 29.09.03.

4. Factor of operating emissions

The factor of operating emissions (EF_{op}) from ship A/C systems is 5%/y.

Conversions of existing R-12, R-11- or R-22 systems are not known, so that the systems in use are thoroughly new, i.e. they have initially been designed for running with HFC-134a. The A/C systems are usually water-chilling units, which mean that water, not refrigerant, runs through the long and ramified piping system. In addition, the soft operating conditions of waterway vehicles should be taken account of, favouring significantly lower leakage than in road vehicles.

5. Sources of information on emission factor (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Special studies on emissions from ship A/C systems were not available. The 5% used by ÖR base on expert estimations from the two domestic market leaders Noske-Kaeser and York Marine.

Noske-Kaeser GmbH, Hamburg, 23.09.03.
York Marine, Hamburg, 29.09.03.

6. Operating HFC emissions from bank

Operating emissions in a particular year n are arrived at by applying the factor of operating emissions (EF_{op}) to the average bank of year n (B n), which has been built up by several annual HFC inputs over the past time – see section 2.

$$EF_{op} \text{ (in \%)} \quad \times \quad B\ n$$

Because of EF_{op} of 5% for HFC-containing A/C systems of ships under German flag the specific equation for operating emissions is as follows:

$$EF_{op} \text{ (5 \%)} \quad \times \quad B\ n$$

Annual operating HFC emissions from bank are shown in Table 5.

Table 5: 1995-2002 Operating emissions from average HFC bank in all ship A/C systems, in t/y

	1995	1996	1997	1998	1999	2000	2001	2002
Average Bank	-	-	0.75	4.00	8.75	13.10	17.80	22.68
Operating Emiss.	-	-	0.04	0.20	0.44	0.66	0.89	1.13

Sources: Calculation based on data from previous sections and on the above equation.

Comment

Operating emissions take up from a relatively low level in 1997 and grow proportionally to the rise in average annual HFC bank in all ship A/C systems. Overall, emissions are not high compared with those from other mobile A/C systems. After 2020 (2023) the overall annual average HFC bank is expected to peak at some 125 t. The then operating emissions will amount to some 6 tonnes annually.

7. Quality control and uncertainty assessment of data I

Activity data. Concerning the number of A/C systems in new ships coming under German flag from 1997 onwards, safety of data is high as their sources are statistics from either authorities or associations. Although the refrigerant charges of the individual ship types are merely average figures (100 kg in cargo ships, 250 kg in passenger ships, 1000 kg in big custom-made ships), the indications are based on experience of well adept experts. It should be noted that both market leaders estimated the charges equally high, independently from each other.

Emission factor. The same high reliability as with refrigerant charges applies to the emission factor since both leading equipment suppliers carry out A/C maintenance so that they are capable of judging re-fillings.

Nevertheless, the true mean may range between 4% and 6% with the same right as the used 5%. Absolute emissions would hardly be affected by a difference of this small measure.

8. Relation to IPCC method I

In IPCC GPG, emissions from mobile air-conditioning are generally dealt with under "3.7.5 Mobile air-conditioning sub-source category". There are, however, no special comments on systems of ships. ÖR generally follows the requirements stated in Box 3 of the Decision Tree for Actual Emissions, "Calculate emissions by vehicle class and age, using country-specific bottom-up emission factors."

In Equation 3.49, estimation of Operating Emissions is proposed as follows:

Operating Emissions = (Amount of HFC-134a Stock in year t) * (x/100).

In the equation, x/100 is the emission factor. As default emission rate 10 to 20% are suggested being completely oriented towards passenger cars. The ÖR values for ships are far below that level. The average lifetime is 25 years and by that much longer than in case of passenger cars.

9. Entry in CRF I

The CRF-Table where data on operating emissions from ship A/C systems are primarily entered is Table 2(II).Fs1, row 89, columns C u. I.

II. Domestic HFC consumption and manufacturing emissions

10. Activity data II

CRF requires estimation of domestic HFC consumption for manufacturing and of HFC emissions arising on manufacture. Domestic consumption (C_{manu}) is no function of new ships running under German flag but of the number of new A/C systems fitted and charged at domestic shipyards no matter what the future flag of the ship is. Table 6 shows the number of new ships annually built on German shipyards. There are only ships considered whose size and destination make an A/C system on board sure. The majority of the figures are regularly published for the previous year by VSM, Verband für Schiffbau und Meerestechnik (German Shipbuilding and Ocean Industries Association).

Table 6: 1997-2002 Refrigerant charge of A/C systems in kg and annual number of domestically built ocean-going and inland ships (with A/C), in units

Ship category	Charge in kg	1997	1998	1999	2000	2001	2002
1. Ocean-going cargo	100	76	73	54	49	48	57
2. Cruise liners	1,000	2	2	2	2	2	2
3. Inland excursion	100	15	13	17	10	11	7
4. Inland cabin boats	250	0	1	1	3	7	4

Sources: Section 13. Before 1997, HFCs were not used for air-conditioning.

From the data in Table 6 annual domestic HFC consumption for charging new ship A/C systems can be derived (HFC consumption per year = newbuildings x charge). The consumption figure in tonnes is entered in Table 7.

11. Emission factor of domestic manufacturing

Upon first charging of A/C systems, a loss of 1% in relation to HFC consumption is assumed. This emission factor (EF_{manu}) of 1% does not represent a fixed loss per one A/C system whatever its size is, but must be related to varying charges.

In addition to annual HFC consumption for domestic first fill of ship A/C systems (line 1), Table 7 contains the emission factor of charging (EF_{manu}) in line 2, and in line 3 charging emissions (Em_{manu}) in absolute terms (kg/y).

12. Domestic consumption for ship A/C systems and manufacturing emissions

Domestic consumption for charging of new ship A/C systems as well as charging emissions can be calculated from the data given in sections 10 and 11.

Table 7: 1997-2002 Domestic consumption, emission factor of charging, and manufacturing emissions at all ship A/C systems, in t/y

	1997	1998	1999	2000	2001	2002
1. Domestic cons. t	11.1	10.9	9.4	8.7	9.7	9.4
2. Emission factor %	1	1	1	1	1	1
3. Manuf. emission t	0.11	0.11	0.09	0.09	0.10	0.09

Sources: Table 6 and data previously given.

Domestic consumption and manufacturing emissions show a slight downtrend, resulting from the reduction in new-built ocean-going cargo ships. Though Germany ranks fourth in worldwide shipbuilding, its share in that amounts to sheer 5%, far behind South Korea, Japan, and P.R. of China.

13. Collection and sources of information of activity data/emission factor II

The German Shipbuilding and Ocean Industries Association (VSM) annually report deliveries from German shipyards for ocean-going and inland waterway vessels for the previous year. Of special importance in these reports is the Table "Ships completed world-wide broken down by building country", which in turn has its source in Lloyd's Register-Fairplay. There, exclusively ocean-going vessels over GT 100 are listed, i.e. of a size that makes air-conditioning sufficiently sure.

Source of information about annually completed large cruise liners in Germany is the shipyard Meyer-Papenburg. Cruise liners are not listed separately in the VSM statistics.

For inland waterway vessels for which air-conditioning comes into question, data are not so readily accessible. This is because before 2001 VSM had not broken down the overall number of completed ships into ferries/passenger ships and other vessels (cargo ships, towboats, police boats, harbour boats, etc.). Air-conditioning is common practice only in case of the former. Even from 2001 onwards, passenger ships are not yet distinguished into excursion boats and cabin boats. The latter have A/C systems larger in size. The statistics show a low export rate of 8 to 15% for shipyards in case of inland waterway vessels. In other words, almost 90% of domestic newbuildings are destined for the inland fleet, so that in the absence of data on HFC composition for domestically new-built passenger ships, alternatively structure and number of new passenger ships coming under German flag (excursion boats and cabin boats) are taken over from Table 1 (lines 5 and 6) and applied to domestic newbuildings..

The emission factor of manufacturing (EF_{manu}) was inquired of the equipment suppliers.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Verband für Schiffbau und Meerestechnik e.V. (VSM) www.vsm.de Hamburg, VSM-Annual Reports 1997 to 2002 can be downloaded from www.vsm.de.

Jos. L. Meyer GmbH www.meyerwerft.de, Papenburg, 28.11.03. Details on large passenger ships built on this shipyard are available on the homepage.

Noske-Kaeser GmbH, Hamburg, 23.10.02.

14. Quality control and uncertainty assessment of data II

Safety of activity data that is of importance for the filling process in principle relies on safety of activity data that underlies operating emissions. This applies to the categories and minimal sizes of ships with air-conditioning, to the refrigerant type, and to the refrigerant charges. The numbers of annual newbuildings are very reliable regarding ocean-going ships, for inland ships (passenger ships), however, data certainty is lower, because alternatively to newbuildings the ships adding to the inland fleet are used to estimate domestic HFC consumption. The resultant margin of error has to be estimated at annually one or two ships possibly being omitted by that procedure.

The emission factor 1% per charged quantity is an estimated value given by the leading ship A/C equipment suppliers. As long as a more exact value is not available, the 1% factor is used as standard value.

15. Relation to IPCC method II

Like any other default emission parameters, the First-Fill emission rate of MACs is completely oriented towards passenger cars in IPCC GPG (Table 3.23). Its current version does not provide special guidance for other mobile A/C systems.

16. Entry in CRF II

The CRF Table where the data "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered is Table 2(II).Fs1. The data on HFC-134a are entered into row 89, into columns B and H.

F-Gas Sheet 14: Rail Vehicle Air Conditioning

F-Gas	**HFC-134a**
Application	**Rail Vehicle Air-Conditioning**
Reported Years	**1995 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**

Background

At the Deutsche Bahn (German Railway Operator) air-conditioning of railway passenger cars, locomotive driver's cabs, and sleeping cars dates back to the early 1980s. This is why at the beginning of the 1990s the Deutsche Bahn had to convert more than 3,000 A/C systems from R-12 to R-134a. After this activity had been finished in 1998, virtually every year between 700 and 900 new rail vehicles equipped with HFC A/C systems were placed into service, thus increasing the refrigerant bank.

In addition to intercity and regional trains, more and more suburban trains (S-Bahn) in large cities are equipped with air-conditioning systems. This trend is still going on.

Since 1996/97, all new rail vehicles of the Deutsche Bahn AG and of smaller railway operators have been being equipped with A/C systems.

I. Bank and operating emissions from bank

1 Activity data I. Annual domestic HFC input

1.A Annual acquisitions of new rail vehicles with A/C

Since 1996, the Dt. Bahn acquires virtually every new rail vehicle with air-conditioning. In line 1, Table 1a contains the annual number of new passenger cars placed into service (ICE 2, double-deckers, diesel powered multiple-units, electric powered multiple units), and in line 2 the number of new air-conditioned S-Bahn cars in seven large cities, with Berlin and Hamburg being the focal points[1]. New locomotives are of minor importance (line 3). From 2000 onwards, private operators are buyers on the market (line 4) Additionally, Table 1a shows the average refrigerant charges (in kg) of the A/C systems. They have remained constant since 1996.

Table 1a: 1996-2002 Domestic acquisitions of air-conditioned vehicles by Dt. Bahn AG, in units

Vehicle category	Charge	1996	1997	1998	1999	2000	2001	2002
1. Passenger cars	18 kg	100	257	486	546	677	755	729
2. S-Bahn cars	10 kg	66	290	350	520	470	504	425
3. Locomotives	2.2 kg					15	16	8
4. Private operators	18 kg					100	100	100
5. Total		166	547	836	1,066	1,262	1,375	1,262

Sources: see section 3.

1.B Conversion of existing R-12 systems at the Dt. Bahn, 1991 to 1998

Compared with S-Bahn trains, which started being air-conditioned first recently, air-conditioning of railway has a long tradition. Before the ICE era, already some 15% of the somewhat 15,000 passenger cars and lots of locomotive drivers' cabs had A/C systems with R-12. Starting in 1991, thereof (and of ICE-1) 200 to 500 units per year were converted to HFC-134a, so that at the end of 1994 already 1,000 HFC-containing A/C systems were in service, making up an HFC bank of 16.5 tonnes. By 1998, the conversion of the remaining 2,500 old systems was completed. Technically seen, the majority of converted vehicles can be used until 2005, at least. Conversions and respective refrigerant charges are entered in Table 1b.

Table 1b: 1991-2000 Conversions of old A/C systems to HFC-134a in rail vehicles of Dt. Bahn AG, units

Vehicle category	Charge	before 1995	1995	1996	1997	1998	1999	2000	2001/2002
1. Passenger cars	18 kg	1,020	500	400	400	320			
2. Sleeping car	26.3 kg			70	71			- 71*	
3. Traction units	2.2 kg			412					
4. Total		1,020	500	882	471	320		-71	

Sources: see section. 3. * In 2000, 71 sleeping cars retired from the inventory (negative number). They were not scrapped (no disposal emissions) but sold to Romania.

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[1] Main Steps in long-distance traffic (DB Reise & Touristik) are as follows. From 1996 to 1998 ICE-2 (ICE-3 was equipped with air cycle systems) and from 1998 to 2000 ICE-T and –TD. Air-conditioning was not common practice in regional traffic (DB Regio) before 1997. From 1997 to 2003, 760 double-deckers, 1,460 vehicles of several VT type series (diesel powered), and from 1999 to 2003, 700 cars of ET type series (electric powered multiple-units) were taken into service. In addition, the new S-Bahn trains in Berlin (type series 481) were equipped with A/C as of 1996, in Hamburg (type series 474) as of 1998, and in the cities of Munich, Frankfurt, Stuttgart, Hanover, and Düsseldorf (type series 423) as of 2000.

1.C Annual HFC input through rail vehicle A/C systems

To calculate annual input (In_{bank}) of refrigerant 134a to the existing bank, separately for new and for former R-12 systems, unlike ship air-conditioning there is no intermediate model of specific A/C quotas necessary. This is because in Tables 1a and 1b solely vehicles with air-conditioning are listed, both by number and together with their specific refrigerant charges. By weighting of the annual number of units with their respective charges, the annual HFC quantity in new-charged A/C systems can be determined, separately for new systems and converted old ones. Table 2 contains this data.

Table 2: 1994-2002 Annual HFC input through new and converted old A/C systems of rail vehicles of the Dt. Bahn, in t/y

System type	before 95	1995	1996	1997	1998	1999	2000	2001	2002
1. New systems			2.5	7.5	12.2	15.0	18.7	20.5	19.2
2. Old systems	16.5*	9.0	9.7	8.8	5.8		-1.6		
3. Total	16.5*	9.0	12.2	16.4	18.0	15.0	17.1	20.5	19.2

Sources: Tables 1a and 1b. * HFC bank at the end-of-year 1994.

2. HFC bank in A/C systems of rail vehicles

The HFC end-of-year bank in A/C systems (EB n) changes annually by the balance of domestic input (In_{bank} n) and domestic output (De_{bank} n). In view of a 15-year-lifetime for old systems, a decrease in the bank because of decommissioning will not occur before 2006, in case of new systems with lifetimes of 25 years not before 2020. For the time being only inputs (In_{bank}) have to be considered (De_{bank} = 0).

The average domestic bank B n is half the sum of the previous end-of-year bank (n-1) and the current end-of-year bank n. This is the equation:

$$B\,n = \frac{EB\,n\text{-}1 + EB\,n}{2} \qquad \text{Where:} \qquad EB\,n = EB\,n\text{-}1 + In_{bank}\,n$$

The average annual bank (B n) is split into old and new systems. This is because the emission factors are different for old and new system types. From Table 2 average annual banks are derived following the above equation and are shown in Table 3.

Table 3: 1995-2002 Average HFC bank in A/C systems of rail vehicles, in old and new systems, in tonnes

System type	1995	1996	1997	1998	1999	2000	2001	2002
1. New systems	0	1.2	6.2	16.1	29.7	46.6	66.2	86.0
2. Old systems	21.0	25.8	30.6	37.9	40.8	40.0	39.2	39.2
3. Total	21.0	27.1	36.8	54.0	70.5	86.6	105.4	125.2

Sources: Calculation based on data in section 1.

Comment on time series

Since 1995, the average annual (overall) bank of HFC-134a has steadily increased. The bank in old systems peaked at 40.8 tonnes in 1999. In 2000, the bank in new systems was larger for the first time, with 46.6 tonnes. Annual HFC input through old systems stopped in 1998 when the conversion programme for R-12 systems had been completed. HFC input through new systems likewise decreased in 2002. The decreasing number of annual acquisitions of new railway and new S-Bahn cars caused lower quantities of new HFCs. If annual acquisition level of some 600 new cars (thereof 125 S-Bahn cars) continues, the average HFC bank in new systems will peak in 2020 at calculated 214 tonnes. (Old systems will be decommissioned then).

3. Collection of activity data and sources of information

Data on new acquisitions and on inventory of rail vehicles of the Dt. Bahn are taken from sources open to the public, which can be found in the Internet on several web-sites (model railway experts, railway hobbyists, etc.) and in annual reports of the Dt. Bahn AG. The complicated time of R-12 conversion had been researched by ÖR previously within the scope of a special study for the German Umweltbundesamt that was published with their results.

Data of relevance for air-conditioning of old and new vehicles (number and type of air-conditioned and converted vehicles per year, refrigerant charges) were directly inquired of experts from the Dt. Bahn. With this respect, the most important expert was Mr Klaus Reum at the Dt. Bahn head office in Frankfurt am Main.

Sources of information on activity data (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Personal Communications

R-12-replacement 1991-1998: Deutsche Bahn AG, 16.07.98.

Öko-Recherche: R 12 replacement in existing equipment from 1996 to 1998, Report on the Umweltbundesamt (in German), August 1998. http://www.oekorecherche.de/deutsch/berichte/volltext/vollR12.pdf

New vehicles as of 1996: Deutsche Bahn AG, Hauptverwaltung Frankfurt, 23.07.98, 11.03.99, 24.10.02, 28.10.02, 26.09.03.

Connex Verkehr GmbH, Berlin, 08.09.03.

Written Sources

A.V. (Andrea Voigt): Kühle Träume mit ISCEON 49. Am 26.3.1998 wurde der 100. Schlafwagen auf ISCEON 49 umgerüstet, in: DIE KÄLTE & Klimatechnik 5/1998, 292-294.

Adolph, Ulrich: Entwicklungsstand und Tendenzen der Klimatisierung von Schienenfahrzeugen, in: Ki Luft- und Kältetechnik 3/1998, 134 ff.

4. Factor of operating emissions

The factor of operating emissions from new HFC systems of rail vehicles figures 15%/y. Operating emission factor of converted old systems is significantly higher with 25%/y.

5. Sources of information on operating emission factors (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

There are no studies available on emissions from A/C systems of rail vehicles. The 15% used here for new systems are based on expert judgements from the Dt. Bahn (Klaus Reum, DB head office) and from special companies dedicated to construction of rail car A/C systems. The latter experts (Michael Sonnekalb, Ulrich Adolph) refer to the exposition of rail vehicle A/C systems to extremely hard vibrations caused by running on metal rails. Especially the long refrigerant pipes through the passenger rooms are mentioned to suffer from this manner of riding, the more the faster the train runs. These experts consider 15% to be an "optimistic" value.

According to Mr Adolph, for old systems 60% annual refrigerant loss were empirically ascertained by means of recordings of annual R-12 refills carried out in a large railway maintenance plant, at the beginning of the 1990s. Meanwhile these figures are no longer up-to-date due to much more careful handling of HFC-134a refrigerant. Converted old systems in service, however, are not deemed as leak-tight as new systems specifically designed for the use of 134a. Therefore, 25% annual operating emissions can be taken for a realistic value in case of old equipment.

Deutsche Bahn AG, Hauptverwaltung Frankfurt, 26.09.03.
HFG Hagenuk Faively GmbH & Co KG) Schkeudiz, 26.05.99.
Dr. Ulrich Adolph, Entwicklungsberater Kälte- und Klimatechnik, Leipzig, 21.11.03.
Konvekta AG, Schwalmstadt, 21.11.03.

6. Operation HFC emissions from bank

Operating emissions in a particular year n are arrived at by applying the factor of operating emissions (EF_{op}) to the average bank of year n (B n), which has been built up by several annual HFC inputs over the past time – see section 2.

$$EF_{op} \text{ (in \%)} \quad \times \quad B\ n$$

Because of EF_{op} of 15% and 25% in rail vehicle A/C systems, the specific equation for operating emissions is as follows:

$$EF_{op} \text{ (15\%, 25\%)} \quad \times \quad B\ n$$

Annual operating HFC emissions from bank are shown in Table 4 in tonnes/year.

Table 4: 1995-2002 Operating emissions from HFC banks in rail vehicle A/C systems, in t/y

	1995	1996	1997	1998	1999	2000	2001	2002
1. New systems	-	0.2	0.9	2.4	4.5	7.0	9.9	12.9
2. Old systems	5.2	6.5	6.7	9.5	10.2	10.0	9.8	9.8
3. Total	5.2	6.6	8.6	11.9	14.7	17.0	19.7	22.7

Sources: Calculation from the data of Table 3, applying emission factors of 15% and 25%.

Comment

Since 1995, operating emissions have risen proportionally to the growth in the average annual HFC bank in all rail-vehicle A/C-systems. Taking old and new systems together, the resulting emission factor amounted to 23% in 1997. It has dropped to 18% by 2002. In 2001, operating emissions from new systems exceeded the level of emissions from old systems for the first time. If the average HFC bank in new systems grows to roughly 214 tonnes by 2020, the then operating emissions will amount to 32 tonnes/year.

7. Quality control and uncertainty assessment of data I

Activity data. Safety of data on number and charges of rail vehicle A/C systems can be rated very high. This applies to conversions (from 1991 onwards) as well as to new acquisitions as of 1996. For the most part, information is based on internal statistics of the operator Dt. Bahn. Even departures via selling vehicles abroad (sleeping cars) are considered.

Emission factors. The emission factor of 15% for new systems is a conservative expert estimation from both operators and manufacturers as well as from design engineers of rail vehicle A/C systems. The higher figure in case of old systems (25%) is empirically based in railway internal surveys of the top-up quantities of R-12 in the early 1990s.

8. Relation to IPCC method I

In IPCC GPG, emissions from mobile air conditioning are generally dealt with under "3.7.5 Mobile air-conditioning sub-source category". There are, however, no special comments on systems of rail vehicles. ÖR follows the requirements stated in Box 3 of the Decision Tree for Actual Emissions, "Calculate emissions by vehicle class and age, using country-specific bottom-up emission factors."

In Equation 3.49, estimation of Operating Emissions is proposed as follows:

$$\text{Operating Emissions} = (\text{Amount of HFC-134a Stock in year t}) * (x/100).$$

In the equation, x/100 is the emission factor. As default emission rate 10 to 20% are suggested. However completely oriented towards passenger cars, the 10 to 20% nevertheless make up the range in which the emission factor of ÖR for new rail vehicle A/C systems is situated.

9. Entry in CRF I

The CRF-Table to enter data on operating emissions from rail vehicle A/C systems is Table 2(II).Fs1, row 88, columns C u. I.

II. Domestic HFC consumption and manufacturing emissions

10. Activity data II

CRF requires estimation of domestic HFC consumption for manufacturing and of HFC emissions arising on manufacture. New A/C systems of rail vehicles are charged in the country of the vehicles' destination, so that there is no foreign trade with charged systems. Consequently, there is no difference between HFC input (In_{bank}) and HFC consumption for manufacturing (C_{manu}). C_{manu} can be taken directly from Table 2 in Part I (HFC input through new and old systems). New information on activity data is not required, and new aspects concerning data safety do not emerge either.

The HFC input quantity in Table 2 is taken over in Table 5 as consumption quantity. The annually charged old and new A/C systems (units) are also entered again in Table 5.

11. Emission factor of domestic manufacturing

For rail vehicle A/C systems, a charging loss of 0.2% (in relation to a full system) is assumed. It is the common estimated value, given by the same experts who were interviewed about operating emissions. Only 2 grams loss per system like in automatic charging of passenger car A/C systems is not considered realistic in view of manual filling of rail vehicle A/C systems.

Table 5: 1995-2002 Domestically assembled rail vehicle A/C systems by HFC consumption, number of units, loss per charging (in %), manufacturing emissions in t/y

	1995	1996	1997	1998	1999	2000	2001	2002
Dom. consumpt. t	9.0	12.2	16.4	18.0	15.0	17.1	20.5	19.2
A/C systems units	500	1.048	1018	1151	1066	1191	1375	1262
Manuf. loss	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Manuf emiss. in t	0.018	0.024	0.033	0.036	0.030	0.037	0.041	0.038

Sources: Calculation based on previously given data.

Manufacturing emissions ranged from 18 to 41 kg/y between 1995 and 2002.

12. Quality control and uncertainty assessment of data II

Data safety of activity data is discussed in Part I. The estimated value for charging emissions was given by the same experts who estimated operating emissions.

13. Relation to IPCC method II

Like any other default emission parameters, the First-Fill emission rate of MACs is completely oriented towards passenger cars in IPCC GPG (Table 3.23). Its current version does not provide special guidance for other mobile A/C systems.

14. Entry in CRF II

The CRF Table where the data "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered is Table 2(II).Fs1. The data on HFC-134a are entered into row 88, into columns B and H.

F-Gas Sheet 15: PU Rigid Foam

F-Gases	**HFC-134a, HFC-152a, HFC-365mfc, HFC-227ea**
Application	**PU Rigid Foam**
Reported Years	**1998 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**

Background

Since a couple of years, in the three largest application areas of polyurethane (PU) rigid foam with annual 50,000 tonnes foam production each (domestic appliances, flexibly faced insulating panels, and rigidly faced sandwich panels) hydrocarbons such as pentane have been used as blowing agents but hardly fluorinated fluids like HCFC-141b or HFCs. There is only one case known in these three applications where a considerable quantity of HFC-134a is used in order to support the water-CO_2-reaction. This happens in one out of several plants of the German market leader for constructional sandwich panels, where HFC-134a was introduced in 1998 with a mass share of 3% (related to 1 m^3 PU foam). According to information from this plant, conversion to pentane as blowing agent is already planned for 2004.

The situation is otherwise for smaller PU rigid foam sectors. By 2002, in a considerable number of open (spray foam, injected foam, and other on-site applied foams) or small and discontinuous applications (block foams, small-series insulating foams, cold storage cells, and refrigerated vehicles) the hardly combustible HCFC-141b was still in use. As soon as this blowing agent is no longer permitted (as of 2004 at the latest), frequently the new liquid HFC-365mfc comes into question as subsequent fluid, which is not as easily inflammable as pentane.

In 2002, several prospective users carried out trials with HFC-365mfc for the first time. This liquid HFC competes with HFC-245fa, which shows similar properties. As series production had not occurred yet , consumption and emissions of HFC-365mfc were still low. To lower the risk of fire, generally 7% of HFC-227ea are added to HFC-365mfc.

I. Domestic HFC consumption and manufacturing emissions

1. Activity data I. Domestic HFC consumption for manufacturing and tests

Annual domestic HFC consumption for manufacture (C_{manu}) of PU rigid foam products was from 1998 to 2002 as shown in Table 1.

Table 1: 1998-2002 Domestic HFC consumption for manufacturing PU rigid foam

	HFC-134a	HFC-365mfc	HFC-227ea
1998	220 t		
1999	220 t		
2000	220 t		
2001	220 t		
2002	220 t	62 t	4.7 t

Sources: Manufacturer and HFC producer. Details see Part II. 7.

The manufacturer of sandwich panels produces annually some 73,000-m3 PU rigid foam (raw density 41 kg/m^3) with 3 kg HFC-134a per 1 m^3. For that, he needs 220 t HFC-134a, annually. The quantities manufactured have been constant over the years - see Table 1.

According to the HFC producer, domestic tests with the new blowing agent HFC-365mfc for PU rigid foam manufacture required 62 t (plus 4.7 t 227ea) in 2002, for the first time.

2. Manufacturing emission factor

Manufacturing loss includes that HFC fraction of the consumption that is released on and after manufacturing within one year at the latest (first year loss). It is expressed as a percentage of domestic HFC consumption for manufacturing (C_{manu}), and is abbreviated "EF_{manu}". For PU rigid foam a value of 10% is used for both HFC-134a and HFC-365mfc (with 227ea). The reciprocal (here 90%) represents the HFC quantity to remain in the cells of the foam product as an insulating gas.

3. Manufacturing emissions of 134a and 365mfc

Given HFC consumption for manufacturing (Table 1) and the factor of manufacturing emissions (EF_{manu} = 10%), the absolute amount of domestic manufacturing emissions (Em_{manu}) can be estimated for the two HFC types. The 10% annual emissions (related to consumption) of 134a as well as of 365mfc plus 227ea are entered in Table 2.

Table 2: 1998-2002 Manufacturing emissions (Em_{manu}) of 134a and 365mfc from domestic PU rigid foam manufacturing, in t/y

	HFC-134a	HFC-365mfc	HFC-227ea
1998	22 t		
1999	22 t		
2000	22 t		
2001	22 t		
2002	22 t	6.2 t	0.47 t

Sources: Table 1 and the 10% factor of manufacturing emissions (EF_{manu}).

Comment on time series

Manufacturing emissions (Em_{manu}) go proportionally with the annual HFC consumption. To date, the latter has been constant on a moderate level in case of HFC-134a. There is a chance that these emissions will end by 2004. On the other hand, a strong increase is to be expected in HFC-365mfc from 2003/2004 onwards, unless legal countermeasures are taken. Future annual domestic consumption of up to 1,500 t is deemed realistic over the medium term, and thus emissions of up to 150 tonnes per year.

4. Data collection and sources of information. Quality control and uncertainty assessment of data I

Collection of data and sources of information on activity data and emission factors will be discussed in Part II (bank and emissions from bank). The same applies to quality control and uncertainty assessment of data.

5. Relation to IPCC method and entry in CRF I

The relation to the IPCC approach as well as the entry in CRF will be discussed together with bank and bank emissions in the second part, too.

II. HFC bank and operating emissions from bank

6. Activity data II. End-of-year bank and average bank

6.A HFC input to the bank in PU rigid foam

The HFC end-of-year bank in PU rigid foam (EB n) changes annually by the balance of domestic input (In_{bank} n) and domestic output (De_{bank} n). In view of lifetimes of at least 20 years, a decrease in the bank because of decommissioning will not occur for the time being.

Starting with domestic consumption for manufacturing as discussed in Part I (C_{manu}), domestic annual HFC input in year n follows equation 1.

Equation 1
Input In_{bank} n = (C_{manu} – Em_{manu}) n x (100% - Export quota in %) n

Explanation. C_{manu}: Domestic consumption of HFC-134a/-365mfc for manufacturing. Em_{manu}: Manufacturing emissions as fraction of C_{manu}, pursuant to EF_{manu}. Export quota relates to HFC quantity in finished products, which is defined as C_{manu} minus Em_{manu}. Export quota would be negative in case of import surplus, and equal to zero in case of equality of exports to imports.

Following the interviewed experts, foreign trade with HFC-134a-containing sandwich panels is negligible. Export and import are at least balanced. Therefore, the domestically manufactured rigid foam can be considered fully to increase the domestic bank. The same applies to HFC-365mfc-containing foam products having been blown in the course of tests. They were not planned for sale, anyway.

Annual HFC input (In_{bank}) shows the time series as per Table 3 (EF_{manu}: 10%, Export quota 0%).

Table 3: 1998-2002 Annual HFC input (In_{bank}) to the bank in PU rigid foa			
	HFC-134a	HFC-365mfc	HFC-227ea
1998	198 t		
1999	198 t		
2000	198 t		
2001	198 t		
2002	198 t	55.8 t	4.2 t

Sources: Table 2 and equation 1.

6.B The average HFC bank

Adding up annual HFC inputs (In_{bank}) from 1998 onwards, the end-of-year bank in year n (EB n) is arrived at. Operating emissions (Em_{op}), however, relate to the average bank in year n (B n). The average domestic bank B n is half the sum of the previous end-of-year bank (n-1) and the current end-of-year bank n. This is shown in equation 2:

Equation 2
$B\ n = \frac{EB\ n\text{-}1 + EB\ n}{2}$ Where: $EB\ n = EB\ n\text{-}1 + In_{bank}\ n$

The average bank shows the following time series from 1998 onwards (EF $_{manu}$: 10%, Export quota 0%).

Table 4: 1998-2002 Average annual HFC bank (B n) in PU rigid foam, in t			
	HFC-134a	HFC-365mfc	HFC-227ea
1998	98.8		
1999	296.3		
2000	493.9		
2001	691.5		
2002	889.0	27.9 t	2.1 t

Sources: Table 3 and equation 2.

Comment on time series of activity data

In 1998, for the first time an annual average domestic HFC-134a-bank in PU rigid foam could be assessed (1998 input x 0.5). In 2002, for the first time a small bank of HFC-365mfc (plus 227ea) arose. If the manufacturer of sandwich panels implements his plan to switch over to the blowing agent pentane by 2004, the 134a-bank will come to a standstill at somewhat more than 1,000 tonnes. Forecasting development of the HFC-365mfc-bank is rather difficult, now. The consumption of this HFC type has a market potential of some 1,500 t/y, extrapolating the recent sales quantities of its predecessor HCFC-141b. Thus, the long-term bank of HFC-365mfc in foam products is likely to grow to over twenty thousand tonnes. Given unchanged political and legal conditions, by 2020 the bank might exceed some 25,000 tonnes.

7. Collection of activity data

Domestic consumption of HFC-134a for manufacturing PU rigid foam was directly inquired of the user himself. Supplementary information was given by the blowing-agent-experts from the supplier of raw material, Bayer, and from the supplier of blowing-agents, DuPont Deutschland. Data on lifetime of sheet steel coated PU rigid foam came from the Industrial Association Polyurethane Rigid Foam (IVPU).

Information on the quantities of HFC-365mfc and HFC-227ea used in 2002 for testing originates from the expert for foam blowing agent at the producer Solvay Fluor.

Sources of information on activity data (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

<u>Personal communications</u>
Thyssen Bausysteme GmbH, Werk Hof, 19.11.02; 23.01.03; 22.9.03.
Solvay Fluor GmbH, Hannover, 24.09.03.
Bayer AG, Leverkusen, 08.02.02; 08.03.02; 18.11.02.
DuPont Deutschland GmbH, Bad Homburg, 17.02.99; 31.03.99; 02.11.02.
IVPU – Industrial Association Polyurethane Rigid Foam, Stuttgart, 27.05.99.

<u>Written Sources</u>
AFEAS; Final Report prepared for AFEAS on the Development of a Global Emission Function for Blowing Agents used in Closed Cell Foam, submitted by CALEB Management Services, Bristol (UK), September 2000.
GDI: Gesamtverband Dämmstoffindustrie, GDI-Baumarktstatistik 1996-2002 (Angaben in 1.000 m^3 , Frankfurt am Main, 01.04.2003.

Bayer AG: Herstellung von Polyurethan (PUR)-Hartschaumstoff. Autoren: Dr. Manfred Kapps, Siegfried Buschkamp, Geschäftsbereich Polyurethane, Strategisches Marketing Insulation, Leverkusen, Technische Information Nr. 12/2000.

8. Factor of operating emissions from the bank

Operating HFC emissions from the bank in PU rigid foam are estimated at 0.5% per year for HFC-134a and at 1%/y for the HFCs 365mfc and 227ea (EF_{op} = 0.5%, 1.0%).

9. Estimation and sources of information on emission factor (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

The value 0.5% for operating emissions of 134a from the bank is the same as in IPCC GPG. The blowing-agent experts from the raw material producer Bayer as well as from the HFC suppliers DuPont Deutschland and Solvay Fluor confirmed it.

Emissions during the use-phase are low. This is because the rigid foam is on both sides covered with steel sheets limiting diffusion to a high degree.

In the absence of specific data about the new HFC-365mfc (plus 227ea) an emission factor of 1% is applied to test products, for the time being.

The manufacturing emission factor (EF_{manu}) in the order of 10% is likewise identical to the default value in IPCC GPG. The blowing-agent experts from Bayer, DuPont, and Solvay have also confirmed it. Comprehensive investigations on this issue are not yet available.

Bayer AG, Leverkusen, 08.02.02; 08.03.02; 18.11.02.
DuPont Deutschland GmbH, Bad Homburg, 17.02.99; 31.03.99; 02.11.02.
Solvay Fluor GmbH, Hannover, 24.09.03.
AFEAS; Final Report prepared for AFEAS on the Development of a Global Emission Function for Blowing Agents used in Closed Cell Foam, submitted by CALEB Management Services, Bristol (UK), September 2000.

10. Operating emissions of HFC-134a and -365mfc from bank

Operating emissions in a particular year n are arrived at by applying the operating emission factor (EF_{op}) to the average bank in year n (B n), which has been built up over the previous years by several inputs (In_{bank}) to the bank - see section 6.B.

$$EF_{op} \text{ (in \%)} \quad \times \quad B\ n$$

Because of EF_{op} of 0.5% and 1.0% for domestically used PU rigid foam the specific equation for operating emissions is as follows:

$$EF_{op} \text{ (0.5 \%)} \quad \times \quad B\ n$$

The time series of operating HFC emissions from PU rigid foam is shown in Table 5.

Tab. 5: 1998-2002 Average bank and operating emissions of 134a and 365mfc					
	HFC-134a			HFC-365mfc	
	Average Bank	Emissions		Average Bank	Emissions
1998	98.8 t	0.49 t			
1999	296.3 t	1.48 t			
2000	493.9 t	2.47 t			
2001	691.5 t	3.46 t			
2002	889.0 t	4.45 t		27.9 t *	0.28 t **

Sources: Table 4 and the EF of 0.5% and 1.0%. * + 2.1 t HFC-227ea. ** + 0.021 t HFC-227ea.

Comment

Because of the low emission factor, operating emissions from the bank are very small compared to manufacturing emissions, today. They will not increase much more in case of HFC-134a, if the only domestic user actually changes to pentane, and if no HFC-134a containing rigid foam is supplied from anywhere else. However, in case of HFC-365mfc a steep rise in emissions is to be expected. If the bank should have grown to more than 25,000 tonnes by 2020, the then operating emissions would amount to some 250 tonnes annually.

11. Quality control and uncertainty assessment of data II

Activity data. Manufactured quantities of PU rigid foam and used quantities of HFC-134a in the 1998-2002 period were inquired directly from the using plant. The HFC producer Solvay Fluor GmbH gave data on the quantity of HFC-365mfc plus 227ea used for testing. As the market is still transparent enough, the data reliability is high. Regarding manufacturing losses, the quantity of which is needed for estimating activity data II (bank), the used 10% are a general practice value being more or less shared by the interviewed experts. In recent professional literature on behalf of the Association of HFC producers AFEAS (Caleb 2000), lower default values are presented for the "First year release" in the application sandwich panel (PU Continuous Panel), namely only 7.5%. ÖR considers this value equivalent to 10% or even 12.5%, particularly since it depends to a high degree on individual circumstances how much blowing agent is actually released upon manufacturing (foaming, confection, assembly). It should be noted that less emissions in the first year means more emissions in the following years (from the bank).

Emission factors. The factor of manufacturing emissions in the first year has been discussed in section 9. The operating emission factor for 134a (0.5%) given by the interviewed experts is situated in the region of the usual literature-values. Up to now, both IPCC (GPG) and AFEAS (Caleb 2000) are using this value. In case of HFC-365mfc, manufacturing emissions of 10% and operating emissions of 1% are rated pretty low facing the fact that the new fluid is largely used for spray foaming, which is an open application.

12. Relation to IPCC method II

In IPCC GPG, emissions from closed-cell foam are addressed under "3.7.3 Foam sub-source category". ÖR meets the requirements stated in Box 3 of the Decision Tree for Actual Emissions (Tier 2), "Calculate emissions by substance and foam type, using national data, disaggregated country-specific parameters, and the Tier 2 equation, incorporating end of life data if available". (Here, decommissioning at end of life remains disregarded yet).

The equation appropriate to Tier 2 is 3.38. In its first part, it defines manufacturing emissions ("First-year Loss"):

(Total HFCs Used in Manufacturing New Closed-cell Foam in year t) x (First-year Loss Emission Factor)

In its second part, equation 3.38 defines operating emissions from the bank:

(Original HFC Charge Blown into Closed-cell Foam Manufacturing between year t and year t – n) x (Annual Loss Emission Factor)

Qualitatively, the ÖR approach is in full accordance with equation 3.38.

In Table 3.18 of IPCC GPG, quantitative recommendations are given about 134a emission factors to be used as default values if country-specific data are not available. The First-year Loss of 10% and the Annual Loss of 0.5% in the application "Polyurethane - Continuous Panel" are in accordance with the values used by ÖR. Additionally, in Table 3.19 default emission factors for HFC-245a/365mfc are shown for various applications (source: Ashford 1999). The breakdown of the German 2002 consumption into different applications is unknown. Therefore, that Table could not yet be used, but might be useful in the future. As HFC-365mfc is mainly used for open applied spray foam, the ÖR First-year Loss of 10% as well as the ÖR Annual Loss of 1.0% might be too low.

The lifetime of rigid foam in sandwich panels (134a) is indicated to be 50 years. This value is important to determine the time of decommissioning. It is, however, not yet relevant for the compilation of data over the 1998-2002 period.

13. Entry in CRF II

The CRF Table where data on "Filled in new manufactured products", "Average annual stocks", "Emissions from manufacturing", and "Emissions from stocks" for HFC-134a for PU rigid foam are primarily entered, is Table 2(II).Fs1, row 92, columns B and C, H and I. HFC-365mfc has not yet been taken account of in CRF (state 2003). Therefore the data on HFC-365mfc and HFC-227ea are preliminarily entered in rows 93 and 94.

F-Gas Sheet 16: PU Integral Skin Foam

F-Gases	**HFC-134a, HFC-365mfc, HFC-227ea**
Application	**PU Integral Skin Foam**
Reported Years	**1996 - 2002**
Emission Type 2	**Open Application (direct)**

Background

The main application of PU integral skin foam, in which, since 1996, small quantities (1-2%) of HFC-134a have been added as auxiliary blowing agent in order to improve product quality (i.a. formation of smooth surfaces), is the manufacture of soles for sports and leisure shoes and of automotive parts.

As integral skin is open-cell foam, upon foaming the blowing agent is released completely apart from a small residue. About 5% remain in the foam cells and diffuse from there over a period whose length is controversial amongst experts. Estimated diffusing time ranges from some weeks up to two years. The domestic experts consulted suppose the diffusion to be quite quick and consider this application as open in a sense that they disregard a short time HFC bank to be built up in ready products.

This means methodologically that there is no need for estimating an HFC bank and operating emissions from this bank.

Of importance, however, is the factor of manufacturing emissions ("First Year Loss Emission Factor" or "Product manufacturing factor") of 100% related to domestic HFC consumption for manufacturing. In other words, the HFC consumption emits completely on manufacturing.

Domestic HFC consumption with complete emission

1. Activity data (domestic consumption) and emissions

The method of data collection used by ÖR considers the manufacture of PU integral skin foam a completely open HFC application. That means that domestic HFC consumption for manufacturing (C_{manu}) is equal to domestic emissions (Em_{manu}) on manufacturing. In other words, the emission factor of manufacturing (EF_{manu}) figures 100% of that consumption.

Annual consumption (C_{manu}) or emissions (Em_{manu}) of HFC were from 1996 to 2002 as shown in Table 1 (tonnes/year).

Table 1: 1996-2002 HFC consumption/HFC emission upon manufacture of PU integral skin		
	HFC-134a	HFC-365mfc*
1996	60 t	
1997	70 t	
1998	70 t	
1999	70 t	
2000	70 t	
2001	70 t	
2002	70 t	15 t *

* To lower the risk of fire, seven percent by weight of HFC-227ea are added to HFC-365mfc. The 15 t consumption/emission consist of 13.95 t HFC-365mfc and 1.05 t HFC-227ea.

Comment

Starting in 1996 with 60 t, annual consumption and emissions of HFC-134a have constantly remained at just 70 tonnes, from 1997 onwards. The manufacturing technology (HFC used as co-blowing-agent) is not so common in Germany as in other countries. Additionally, users such as e.g. the shoe industry do not represent sectors of economic growth. In 2002, the new liquid HFC-365mfc (mixed with HFC-227ea) was tested for manufacturing integral skin foam in a quantity of 15 t. In other European countries series production with HFC-365mfc has been taken up the same year. Now it is not yet foreseeable whether in Germany HFC-365mfc will displace HFC-134a or if even more sectors of integral skin will change over to application of HFCs.

2. Collection of activity data and sources of information

According to industrial producers of polyurethane raw materials, manufacturers of PU integral skin foam parts are some hundreds in number in Germany (hard, half-hard, and soft integral skin). A minority of them uses HFCs. Thus, only experts from such companies can be expected to survey the market appropriately, which themselves supply components of the foaming process to the users. In Germany, by far the leading supplier of raw materials to manufacturers of integral skin foam is the BASF subsidiary Elastogran. The annual estimations of HFC-134a consumption stem from Elastogran. These estimations were compared with those of the supplier of blowing agents, DuPont.

Information on the 2002 consumption of HFC-365mfc for tests was given directly by the producer of this HFC, Solvay Fluor GmbH.

Sources of information on activity data (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Personal Communications
Elastogran GmbH, Lemförde, 20.07.99; 20.02.03; 23.09.03.
Solvay Fluor GmbH, Hannover, 24.09.03.
Bayer AG, Leverkusen, 08.02.02; 08.03.02; 18.11.02.
DuPont Deutschland GmbH, Bad Homburg, 17.02.99; 31.03.99; 02.11.02.

3. Emission factor and sources of information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

For open applications, normally no estimation of the level of the emission factor is necessary. However, because both in IPCC (GPG) and in AFEAS (Caleb 2000) the emission profile "95% First year release" – "2,5% Annual Loss (2 years time to total release)" is presented, in the following at least those domestic experts shall be named who consider an emission factor of 100% adequate.

Personal Communications (100% EF)
Bayer AG, Leverkusen, 08.03.02.
DuPont Deutschland GmbH, Bad Homburg, 17.02.99; 31.03.99; 02.11.02.
Solvay Fluor GmbH, Hannover, 24.09.03.

Written Sources (95% EF in first year)
AFEAS; Final Report prepared for AFEAS on the Development of a Global Emission Function for Blowing Agents used in Closed Cell Foam, submitted by CALEB Management Services, Bristol (UK), September 2000.

4. Quality control and uncertainty assessment of data

Activity data. The market leader Elastogran, whose market share in supplying components to manufacturers of integral skin foam is much more than 50%, estimated annually applied quantities of HFC-134a. Such a high market share generally guarantees high data competence. In the event of the HFC-365mfc, the source of information is Solvay Fluor, who is so far the only possible. Only Solvay produces this HFC type. Solvay has recorded the testing with that HFC carried out in Germany in 2002 and has communicated the figures to ÖR.

Emission factor. The national experts assuming complete emission of the used HFC quantity over the year of application (EF_{manu} = 100%) are competent under a professional aspect. Incidentally, even if manufacturing emissions really were just 95% in the first year of application, data certainty would be sufficiently high and acceptable when calculating with 100%.

5. Relation to IPCC method

In IPCC GPG, emissions from open-cell and closed-cell foam are dealt with under "3.7.3 Foam sub-source category". While there "Polyurethane – Integral Skin" is assigned to "Closed-cell Foam", for which two specific emission factors are presented, namely First Year Loss (95%) and Annual Loss (2.5%), ÖR classifies integral skin foam as open-cell foam. This is why there is no need for estimating operation emissions as all emissions occur over the first year. This difference has been mentioned in section 3, so that further remarks can be left undone here.

6. Entry in CRF

HFC consumption for integral skin foam is entered under "amount of fluid filled in new manufactured products". This is because the alternative entry in "amount of fluid in operating systems (average annual stocks)" is even less appropriate to match the use of HFCs in manufacturing these PU foam products.

The CRF Table where data on quantities "Filled in new manufactured products" and on "Emissions from manufacturing" (not "Average annual stocks" and "Emissions from stocks") are primarily entered for HFC-134a, HFC-365mfc, and HFC-227ea in case of PU integral skin foam, is Table 2(II).Fs1, rows 95-97, columns B and H.

It should be noted that HFC-365mfc is not yet considered in CRF Tables (state 2003).

F-Gas Sheet 17: PU One Component Foam

F-Gases	**HFC-134a, HFC-152a**
Application	**PU One Component Foam**
Reported Years	**1995 - 2002**
Emission Type 3	**Open Application (indirect)**
Emission Type 1	**Manufacturing Emissions**

Background

In can-dispensed polyurethane (PU) one component foam (OCF) is used by professional craftsmen and – to a smaller extent – do-it-yourselvers in order to mount doors and windows and to fill and insulate different kinds of open joints and crevices. One single standardised 750-ml can contains between 180 and 240 ml (130-180 g) propellant gases. Different from other rigid PU foam products the propellant does not serve as an insulation agent, but is a solvent, a viscosity reducer, a foaming aid, and expels the foam from the can. The propellants are either blends, consisting of HFCs (134a, 152a) and flammable gases (propane, butane, dimethyl ether), or flammable gases without HFCs. The propellant escapes from the foam upon application, except for small residues that remain for at most one year in the hardened foam. Therefore HFC propelled OCF is considered an open HFC application.

Since the 1993 switch from HCFC-22 to chlorine-free propellants (initially mainly HFCs), the quantity of HFCs used for OCF has constantly decreased. There are two reasons to name. Firstly, a trend of replacing HFCs by low-cost gases like hydrocarbons set in soon after the switch to HFCs. Instead of at most 50 g halogen-free flammable gases initially, about 100 g of flammable gases were used in the average can by 2002. Secondly, within the HFCs a shift has occurred away from HFC-134a that at first had been the only HFC in OCF cans, to HFC-152a, meanwhile amounting to half of the HFC volume in the cans.

In Germany, which is the world largest individual OCF market, there are five filling plants meanwhile (2002) manufacturing more than 30 million cans annually. The domestic market ranges between 17 and 26 million cans per year mainly corresponding to business cycles in the construction industry. Half the domestically sold cans are imported from Belgium, Switzerland, and The Netherlands. Foreign trade and German exports are important.

I. Domestic input and complete emission on application

Introduction. Activity data (annual domestic input) equals emission

The cans with contents of from 300 to 750 ml are intentionally emptied on application, with the HFC propellant being entirely released. Thus, the emission factor is 100%, and the HFC quantity in sold cans equals to emissions even on condition that they completely arrive in the atmosphere several weeks after[2].

The domestically sold cans are assumed to be speedily applied after purchase so that emissions in year n (Em n) can be related to sales/purchases (S = Sales) of the same year n (S n). The equation is:

Em n = S n x 100% or: Emission n = Sales (sold cans) n x 100%

Reference quantity for emissions is not the sum of half the sales (purchases) in year n-1 and half the sales (purchases) in year n. This way of estimation would be appropriate if not sold but manufactured cans were the data source, and if there were a lot of time for transport and storage between manufacture and application.

1. HFC input to domestic market and emissions on application

Annual input to domestic market (In_{bank}) as well as speedily following domestic emission is arrived at for the two HFCs 134a and 152a from three pieces of information:

1) Number of domestically sold cans (standardized to 750 ml),
2) HFC content per can in grams, and
3) Ratio (in percent) between the two HFC types 134a and 152a.

Table 1 shows the raw data "sold cans", "HFC content", and "ratio 134a/152a" in the columns 2, 3 and 4, 5. The two columns to the right contain input/emissions of 134a and 152a as results calculated by means of the data in those four columns to the left.

Table 1: 1995-2002 HFC sales in cans and domestic application emissions

1. Year	2. PU cans million units	3. HFC content in g	4. Share 134a	5. Share 152a	6. Sales/Emissions in t	
					134a	152a
1995	20	90	60%	40%	1,080	720
1996	22	85	60%	40%	1,122	748
1997	24	80	60%	40%	1,152	768
1998	26	70	60%	40%	1,092	728
1999	24	65	50%	50%	780	780
2000	23	62,5	50%	50%	719	719
2001	22	60	50%	50%	660	660
2002	17	50	50%	50%	425	425

Explanation: Sales/Emissions per year in tonnes of HFC-134a or 152a in columns 6 and 7 are the result of the multiplication of column 2 by column 3 and by either column 4 or 5.

[2] The EF of 100% is not affected by the circumstance that practically the cans are never emptied completely as a small residue of some 5% remains in the can and is not released before can's disposal.

The equation for calculation of input/emissions for any year is as follows:

Emission 134a (t) = Sold cans (million) x HFC content (in g) x share 134a (in %) Emission 152a (t) = Sold cans (million) x HFC content (in g) x share 152a (in %)

Comment

Annual sales of OCF cans increased in Germany until 1998, since then they decreased from 26 million to 17 million by 2002. These figures reflect the dependency of the business activity in the construction industry. Main application area of OCF are sealing of joints and filling of cavities in case of windows, doors, and roller blinds.

The HFC content per can has steadily decreased and almost halved within eight years. There are two main reasons to name. Firstly, the higher cost pressure that favours halogen-free, i.e. flammable propellants despite of relatively high one-time investment for explosion protection of filling equipment as well as of storage tanks. Secondly, the safety concerns have proved to be exaggerated. They were expressed by the voluntary rule to limit the content of inflammable gases to at most 50 grams per 750 ml standard can. This rule was not only a constant controversial subject amongst most of the twelve European fillers in the Working Group of the OCF Industry (AKPU). Moreover, this rule was being broken repeatedly so that it was finally changed into a 100-gram-rule. It is questionable whether this new rule will be adhered to a long time particularly since the OCF fillers have met with criticism in many EU Member States and from the EU Commission on the grounds of the climate impact of their propellants.

Eventually, the quantitative relation between the potent and the less potent greenhouse gases HFC-134a and HFC-152a has shifted in favour of the latter. This is caused by ecological criticism to a certain part. For some years, the OCF application had been the largest single source of HFC emissions in Germany.

Overall, HFC emissions have significantly decreased between 1995 and 2002. This is true both by metric and by CO_2 equivalent tonnage.

2. Collection of activity data and sources of information

The OCF fillers themselves gave numbers of OCF cans sold to the German market as well as indications on the average HFC content per can and on the HFC types used. In the course of two major surveys in 1996 and 1999, ÖR mainly inquired domestic companies involved in filling or marketing OCF. The only foreign company surveyed was the Swiss contract filler Rathor AG. The domestic companies were contract fillers too, aside from the company Henkel which is leading in product development as well as in marketing, and who has their cans charged at a German contract filler.

In 2002 and 2003, extensive conversation took place with the Association of the European OCF industry (AKPU), i.e. with the two representatives Ad van der Rhee and Peter Geboes. They handed over most of the activity data for the 1999-2002 period.

With the help of these two experts, also the data on the previous years was revised.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.).

Personal Communications

Autra Den Braven Aerosol GmbH + Co KG, Reichenberg-Albertshausen, and Soudal NV, Turnhout, letter 22.09.03.

OCF-Meeting at the EU-Commission, DG ENV with Wolfgang Hehn (DG ENTR), Phil Callaghan (DG ENV), Ad. K. van der Rhee (AKPU and Managing Director of Autra den Braven and BÜKA Chemie), Peter Geboes (Soudal NV), Mike Jeffs (ISOPA), Winfried Schwarz (Öko-Recherche), Brussels, 14.11.02.

AKPU Conference with Öko-Recherche: Ad. K. van der Rhee (AKPU and Managing Director of Autra den Braven and BÜKA Chemie) and Dr. Cd. Peter Geboes (AKPU and Manager Research & Development at Soudal NV) and Winfried Schwarz (Öko-Recherche), Frankfurt, 08.08.02.

Polyurethan Dosen Recycling GmbH + Co. Betriebs KG, Thurnau, 12.09.00.

Henkel KGaA, Düsseldorf, 15.03.99; 07.05.99.

Rathor AG, Appenzell, Letters 26.02.99, 05.05.96; 23.05.99.

HAGO Dr. Schirm Chemotechnik, München, 28.06.99.

Henkel KGaA, UBA Conference with Dr. Wolfgang Klauck (Produktmanagement), Hermann Kluth (AWT PU-Schäume), Cornelia Elsner (Umweltbundesamt) and Winfried Schwarz (Öko-Recherche), Düsseldorf 05.03.99.

Ara Werk Krämer GmbH, Unterensingen, 11.04.96.

Czewo Aerosole GmbH, Donaustauf, 02.10.96.

Hago Chemotechnik Vertriebs GmbH, Landsberg, 28.5.96.

Henkel KGaA, Düsseldorf, 23.05.96, 11.6.1996.

FLM-Holding (Rathor AG u. Fomo-Polypag AG), Appenzell, 28.05.96, 12.06.96.

P.D.R. GmbH+Co. Betriebs KG, Thurnau, 12.06.96.

Written Sources

HFCs in one component foams, Ch. 4.6, in: Costs and the impact on emissions of potential regulatory framework for reducing emissions of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride (final report). Prepared on behalf of the European Commission (DG ENV) by Jochen Harnisch (Ecofys) & Winfried Schwarz (Öko-Recherche), February 4, 2003, p. 34-39. http://www.oekorecherche.de/english/berichte/volltext/leakage_rates.pdf.

COCON-Rapport-Nr. CL 1662: 1K PU und der Treibhauseffekt, Verf.: A.K. van der Rhee, COCON ARKEL B.V., 29.05.1996; zugesandt mit einem Begleitschreiben von M.F.A. van Diessen, Arbeitskreis PU-Dämm- und Montageschäume, Tilburg.

AKPU (Working Group of the EU OCF Industry) (Eds.), Wichtige Informationen über PU-Schäume, Tilburg/Stuttgart o.J.

P.D.R. (Polyurethan Dosen Recycling), Pressemappe, Wiesbaden 01.10. 96.

3. Quality control and uncertainty assessment of data I

Safety of sales data is high, even though reported figures are rounded up or down to next entire million units, and additionally the various can sizes had to be recalculated to 750-ml standard volumes. The small number of medium-sized fillers concentrated to Central and Western Europe implicates a high degree of mutual knowledge about the competitors, i.e. high degree of market transparency. Therefore, information on HFC contents per can as well as on 134a/152a-ratios is reliable particularly since it is no secret that the companies usually analyse competitive products in their own laboratories.

The high data safety has additionally been proved in the course of their revision carried out together with AKPU representatives in 2002 for 1995 to 1998. Although the 1995-

1998 data had been provided to ÖR by just three German (plus one Swiss) filling enterprises, there were no considerable retroactive corrections necessary.

4. Relation to IPCC method I

In IPCC GPG Canned PU Foam or One Component Foam is not dealt with under Aerosols although this would be a plausible classification. OCF is dealt with under "3.7.3 Foams sub-source category", which raises the same questions as the classification of PU integral skin foam, i.e. the question on complete or incomplete first-year loss of 152a applied. Table 3.18 in IPCC GPG on "Default Emission Factors for HFC-134a Applications" suggests default values of 95% for "First Year Loss" and additionally 2.5% for "Annual Loss". The reservation is made that these default values should only applied to the use of HFC-152a. Of course, this advice does not mean that with HFC-134a a First Year Loss of 100% should be applied.

Exactly this is what ÖR does. ÖR uses an operating emission factor of 100% for both 134a and 152a in accordance with all the experts mentioned above in section 2 as far as they were inquired about the OCF emission profile of HFCs.

It should be noted that the 2000 AFEAS study (Caleb 2000) on "Emission Function for Blowing Agents used in Closed Cell Foam" excludes the IPCC values. The study does not give any indications on OCF at all.

Cited written sources
AFEAS; Final Report prepared for AFEAS on the Development of a Global Emission Function for Blowing Agents used in Closed Cell Foam, submitted by CALEB Management Services, Bristol (UK), September 2000.

5. Entry in CRF I

The CRF Table 2(II).Fs1 provides for each HFC type an entry under the four categories "Filled in new manufactured products", "Emissions from manufacturing", "Average annual stocks", and "Emissions from stocks". Clearly, that "Filling/Manufacturing" and "Emissions from manufacturing" are not appropriate headings to subsume OCF application. Firstly, a rubric must be left blank to enter the actual filling process, namely the charging of cans with HFCs in domestic plants. Secondly, the OCF application is no "filling" at all, but much more an emptying.

ÖR has decided to enter annual input of canned HFCs to the domestic market under "average annual stocks" and application emissions under "Emissions from stocks". Surely, this classification is not entirely correct because the application releases the HFCs in one go and does not build up any HFC stock in the hardened foam. However, using some imagination, the filled cans before their application can be interpreted as "stocks" or "bank" and the application itself as "emission from stocks" in order to meet the requirements of the CRF specification.

Therefore, annual HFC sales are entered in column C (Average annual stocks) and application emissions with the same size again in column I. This is done for the HFC-134a in row 98 and for the HFC152a in row 99.

II. Domestic HFC consumption and manufacturing emissions

6. Activity data II

CRF requires estimation of domestic HFC consumption for manufacturing (C_{manu}) and of HFC emissions arising on manufacture (filling). Domestic consumption (C_{manu}) is no function of annual domestic sales of OCF cans but of domestically filled OCF cans wherever the cans are applied.

To estimate both HFC consumption for domestic filling of OCF cans and associated manufacturing emissions the AKPU experts cited in Part I were inquired about the necessary raw data. This was chiefly the annual number of domestically filled cans, the country-specific breakdown of HFCs into the two types, and the specific loss upon charging one can. The answers are reproduced in Table 2.

Table 2: 1995-2002 Raw data for estimating HFC consumption (C_{manu}) and charging emissions (Em_{manu}) on filling OCF cans in Germany

1. Year	2. Filled Cans in million units	3. HFC content in g	4. Share 134a	5. Share 152a	6. Loss per Can
1995	15	90	100%	0%	1.5 g
1996	16	85	100%	0%	1.5 g
1997	18	80	100%	0%	1.5 g
1998	16	70	100%	0%	1.5 g
1999	21	65	100%	0%	1.5 g
2000	25	62.5	100%	0%	1.5 g
2001	28	60	100%	0%	1.5 g
2002	31	50	80%	20%	1.5 g

Sources: Inquiries of AKPU experts mentioned in Part I. 2.

Comment

Table 2 on domestic manufacturing (filling) makes visible considerable differences from the domestic market as shown in Table 1. Firstly, the annually manufactured cans have steadily increased in number. Secondly, HFC-134a had been the only HFC-type used for filling before 2002 when HFC-152a added.

7. Domestic HFC consumption for filling and filling losses

With the help of the data in Table 2, for each year since 1995 domestic consumption of HFCs for filling (C_{manu}) and associated filling emissions (Em_{manu}) can be calculated. HFC consumption follows the equation shown hereafter.

Consumption 134a (t) = Fillings (million) x HFC content (in g) x Share 134a (in %)
Consumption 152a (t) = Fillings (million) x HFC content (in g) x Share 152a (in %)

For 134a, in Table 2 the columns 2, 3 and 4 must be multiplied by each other. For 152a, it is the columns 2, 3, and 5. The 152a-calculation is necessary from 2002 onwards.

Manufacturing emissions (Em_{manu}) follow a similar equation:

Manufacturing loss 134a (t) = Fillings (million) x Share 134a (in %) x 1,5 g
Manufacturing loss 152a (t) = Fillings (million) x Share 152a (in %) x 1,5 g

For 134a, the columns 2, 4, and 6 in Table 2 must be multiplied by each other. For 152a, it is the columns 2, 5, and 6 – from 2002 onwards.

Table 3 shows the resulting quantities of domestic consumption (C_{manu}) and of associated filling emissions (Em_{manu}) in tonnes (recalculated from grams).

Table 3: 1995-2002 HFC consumption for domestic filling and associated filling emissions, in tonnes/year

Year	HFC consumption for filling		Filling emissions in t/y	
	HFC-134a	HFC-152a	HFC-134a	HFC-152a
1995	1,350	0	22.5	
1996	1,360	0	24	
1997	1,440	0	27	
1998	1,120	0	24	
1999	1,365	0	31.5	
2000	1,563	0	37.5	
2001	1,680	0	42	
2002	1,240	310	37.2	9.3

Sources: Calculation from data in Table 2.

Comment

Domestic HFC consumption was rising until 2001 despite of decreasing HFC content per can. This was because the manufactured units were still growing in number. 2002 was the first year when decreasing HFC content per can could no longer be compensated by increasing numbers of filled cans. HFC consumption decreased from 1,680 t to 1,550 t. In contrast, filling emissions went on rising, from 42 to 46.5 t. Since the loss per can is constant with 1.5 grams, filling emissions increase as long as cans grow in number whatever the specific HFC content is.

8. Implied emission factor of charging

The emission factor of 1.5 grams per one can represented a relative loss of 1.66% in 1995 (filling emissions in t/HFC consumption in t). This implied emission factor has grown to 3% until 2002 due to significantly less HFC consumption, with the number of cans still rising.

9. Collection of activity data and sources of information

The raw data on domestic consumption for filling from 1995 onwards, namely number of charged cans, HFC content per can, used HFC-types, and specific filling loss have been inquired of the same experts who are listed in Part I, section 2.

10. Quality control and uncertainty assessment of data II

As the sources of information on domestic HFC consumption are the same as on domestic HFC input, documentation has already been given in Part I, section 3.

11. Relation to IPCC method II

Manufacturing (filling) emissions are not dealt with in IPCC GPG. The reason for that is the classification of OCF as closed-cell foam for which both a First Year Loss (95%) and an Annual Loss (2.5%) is assumed. From a terminological point of view, First Year Loss includes all manufacturing emissions (Em_{manu}), so that the filling of the can is not paid special attention to. In fact, OCF shows common properties both with PU rigid foam and with Aerosols. This fact is not yet sufficiently met by IPCC GPG.

12. Entry in CRF II

In CRF Table 2(II).Fs1, HFC consumption for domestic manufacturing is entered under "Filled in new manufactured products" and the filling loss is entered in "Emissions from manufacturing". This is done for the HFC-134a in row 98 and for the HFC-152a in row 99, each time in columns B and H.

F-Gas Sheet 18: XPS Insulating Foam

F-Gases	**HFC-134a, HFC-152a**
Application	**XPS Insulating Foam Panels**
Reported Years	**2001 - 2002**
Emission Type 1	**Manufacturing Emissions**
Emission Type 2	**Open Application (direct)**
Emission Type 4	**Operating Emissions from Bank**

Background

German manufacturers replaced CFC-12 as a blowing agent and cell gas by HCFCs in 1990, either by 142b or by a mixture of 142b and 22. From 2001 onwards, one of the two large domestic manufacturers completely dispensed with fluorinated gases in favour of a process using CO_2/ethanol. The other large and the two medium-sized manufacturers have replaced HCFCs by HFCs. Additionally to CO_2, the largest manufacturer is using HFC-134a. This blowing agent improves the insulation performance by remaining for the most part in the foam as a cell gas. Aside from CO_2, the two smaller manufacturers use HFC-152a. Although this blowing agent virtually completely emits on manufacturing, it improves the thermal insulation producing a very fine and homogeneous cell structure. (The latter effect is achieved by the manufacturer, who does without HFCs, by means of ethanol-dosage.)

Despite of rather brief experience with HFC-based technologies the three domestic HFC-users have already announced to increase the share of HFC-free processes over the medium-term. At the same time, on a generally reduced level of HFC consumption, HFC-152a is planned to give way to HFC-134a, which shows the ten-fold global warming potential. This plan makes forecasting global warming emissions difficult.

The market leader, who presently uses large quantities of HFC-134a, emphasizes that his Europe-wide product mix is HFC-free to a large extent and that the German site more or less by accident is focused on those product segments (thicker panels), where waiving HFC-134a would mean waiving optimum insulation. Products containing HFC-134a are exported 75%.

I. Domestic HFC consumption and manufacturing emissions

1. Activity data I. Domestic HFC consumption for manufacturing

Raw data for estimating domestic HFC consumption is the total volume of XPS insulating material (in m^3) that is annually manufactured by means of the two HFC-types. These volumes were in 2001 and 2002 as follows (Table 1).

Table 1: Domestic manufacture of XPS foam, in thousand m^3, in 2001 and 2002		
	with HFC-152a	with HFC-134a
2001	383	516
2002	476	625

Sources: Fachvereinigung FPX (Sector Association Extruded Polystyrene).

The input of blowing agent per cubic metre XPS foam amounts to 3.2 kg HFCs in case of 134a and 3.0 kg in case of 152a. From the data on annual XPS quantities in m^3 manufactured with HFCs (Table 1), domestic HFC consumption for manufacturing (C_{manu}) can be derived following equation 1:

Equation 1		
C_{manu} 152a (in kg)	=	$XPS_{(152a)}$ in m^3 x 3.0 kg/m^3
C_{manu} 134a (in kg)	=	$XPS_{(134a)}$ in m^3 x 3.2 kg/m^3

Explanation: C_{manu} 152a/C_{manu} 134a: Domestic consumption of 152a and 134a, respectively. $XPS_{(152a)}$/$XPS_{(134a)}$: XPS foam manufactured with 152a and 134a, respectively.

Thus, domestic consumption (C_{manu}) of HFCs was in 2001 and 2002 as follows (t/y).

Table 2: Domestic HFC consumption for manufacturing XPS foam, in tonnes		
	HFC-152a	HFC-134a
2001	1,150 t	1,650 t
2002	1,428 t	2,000 t

Sources: Table 1 and Equation 1.

2. Emission factor of manufacturing

The "First Year Loss Emission Factor" (EF_{manu}) is expressed as a percentage of annual domestic HFC consumption for manufacturing (C_{manu}). It figures in case of HFC-152a practically 100% as the application is directly open. The gas serves as a blowing agent as well as a "cell-maker", but not as an insulating agent. Only small residual quantities do not emit instantly upon manufacture. These residues remaining in the foam for some weeks or months are not considered further here. The situation is otherwise when using HFC-134a.

Table 3: Emission factors (EF_{manu}) for XPS manufacture by HFC type		
	HFC-152a	HFC-134a
2001	100%	30%
2002	100%	27%

Sources: Part II. 7. Emission factors are percentages of domestic consumption (C_{manu}).

In case of HFC-134a only a certain fraction of the consumption escapes to the atmosphere upon foam blowing, whereas the larger part of blowing agent remains in the product. Empirically the EF_{manu} was ascertained with 30% in 2001 and with 27% in 2002. A reduction to 25% loss of domestic consumption is deemed desirable.

3. Manufacturing emissions of 152a and 134a

From the data in Tables 2 and 3, absolute amounts of manufacturing emissions can be estimated for the two HFC-types. Since 152a is being completely released over the first year, its emissions (in year n) are the same size as its domestic consumption (C_{manu}) in year n. Domestic consumption of 134a, however, is emitting just 30% and 27%, respectively, over the first year. Manufacturing emissions are only a fraction of consumption. This is shown in Table 4.

Table 4: 2001 and 2002 Domestic consumption and manufacturing emissions of HFC-152a and -134a

	HFC-152a			HFC-134a	
	Consumption	Manuf. Emission		Consumption	Manuf. Emission
2001	1,150 t	1,150 t		1,650 t	495 t
2002	1,428 t	1,428 t		2,000 t	540 t

Sources: Data from Tables 2 and 3.

Comment on time series

In principle, manufacturing emissions take course proportionally to domestic HFC consumption. Without further legal measures and under the assumption of an annual growth rate of +2% for XPS panels blown with 152a and with 134a, an increase of 152a (consumption/emission) up to 2,040 tonnes/year is conceivable by 2020. Consumption of 134a might grow under the same circumstances to 2,850 t/y. 25% of this quantity or 714 tonnes would emit to the atmosphere then.

4. Collection and sources of data. Quality control/uncertainty assessment I

Collection of data and sources of information regarding activity data I and manufacturing emission factors I will be discussed in Part II (bank and emissions from bank). This applies also to Quality control and uncertainty assessment of data.

5. Relation to IPCC method and Entry in CRF I

Relation to IPCC approach and Entry in CRF will likewise be discussed together with bank and bank emissions in the second part.

II. HFC bank and operating emissions from bank

6. Activity data II. End-of-year bank and average bank

6.A HFC-134a input to bank in XPS insulating foam

Domestic HFC bank in XPS foam increases annually by inputs (In_{bank}) of 134a in insulating panels. (There are no panels containing 152a). Provided XPS panel lifetime of 50 years, departures from bank (De_{bank}) do not play a role for the time being.

1. Leaving aside foreign trade, HFC input is equal to annual consumption (C_{manu}) minus manufacturing emissions (Em_{manu}). As per Table 3, the latter amounted to 30% and 27%. C_{manu} minus Em_{manu} result in an HFC-134a quantity that potentially increases the domestic HFC-134a bank in XPS products.

2. Foreign trade affects the potential input to a considerable extent. Germany is an important net exporter of XPS foam containing HFC-134a. The corrected export quote of domestic production amounted to 75% in the two reported years. ("Corrected," means the balance of imports and exports of products containing 134a). In other words, only 25% (reciprocal of the export quote) of HFC-134a that is contained in XPS panels after blowing adds to the domestic HFC bank.

Domestic 134a input or production for domestic market (In_{bank}) over the whole year n follows equation 2.

Equation 2
Domestic input (In_{bank}) n = (C_{manu} – Em_{manu}) n x (100% - Export quote in %) n

Explanation. C_{manu}: Domestic consumption of HFC-134a. Em_{manu}: Manufacturing loss in the first year as a percentage of C_{manu}. Export quote relates to HFCs in finished foam (HFC consumption minus manufacturing loss). It would be negative in case of import surplus.

6.B Average HFC bank

The so far defined bank is the bank at the end of year n (EB n). Operating emissions, however, relate to the average bank in year n (B n). The average annual bank (B n) is half the sum of the previous-year (n-1) end-of-year bank and the present-year (n) end-of-year bank. This is the equation (3):

Equation 3
$B_n = \frac{EB_{n-1} + EB_n}{2}$ Where: $EB_n = EB_{n-1} + In_{bank\,n}$

The average annual bank shows the time series presented in Table 5 (EF_{manu} 2001: 30%; EF_{manu} 2002: 27%; export quote: 75%).

Tab. 5: Domestic average HFC-134a bank in XPS insulating foam, in tonnes

	Domestic 134a input	Average 134a bank
2001	288.8 t	144.4 t
2002	365.0 t	471.3 t

Sources: Data in Table 4. Calculation follows equation 2 and 3.

Comment on time series

In 2001, for the first time an average domestic bank of HFC-134a in XPS-foam panels existed (end-of-year bank of 288.8 t x 0.5). Not surprisingly, it has sharply grown in the second year of HFC application.

7. Collection of activity data I and II

The German sector association FPX (Fachvereinigung Polystyrol-Extruderschaumstoff) provided all necessary activity data. These are (a) annual domestic manufacture of XPS foam in cubic metres by used blowing agents 152a and 134a; (b) average specific quantity of HFCs used per cubic metre XPS foam; (c) manufacturing loss for 152a and 134a; (d) lifetime of XPS insulating panels; (e) foreign trade and export quote of XPS panels containing HFC-134a. FPX speaker Otmar Jochum, who represented both the market leader Dow and the European Extruded Polystyrene Insulation Board Association EXIBA, handed the information over to ÖR in accordance with the other German manufacturers.

Sources of information on activity data (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Personal Communications

FPX: Fachvereinigung Polystyrol-Extruderschaumstoff e.V. (German Section of EXIBA, European Extruded Polystyrene Insulation Board Association) http://www.fpx-daemmstoffe.de/ E-Mail: info@fpx-daemmstoffe.de , Frankfurt, 02.12.02; 23.09.03.
Dow Deutschland Inc., Rheinmünster, 28.11.02; 23.09.03.
GEFINEX-JACKON GmbH, Mechau, 19.02.03.
BASF AG, Ludwigshafen, 09.07.99; 11.11.02.
Poliglas Dämmsysteme GmbH (as of 2003: URSA Deutschland GmbH), Queis, 19.02.03.
EXIBA (European Extruded Polystyrene Insulation Board Association), Horgen, Schreiben vom 08.07.99.

Written Sources

E. Boy, Ludwigshafen: Umweltfreundlich Schäumen. Polystyrol-Hartschaumstoff mit CO_2 als Treibmittel, in: Kunststoffe (Carl Hanser Verlag, München) 6/97.
GDI: Gesamtverband Dämmstoffindustrie, GDI-Baumarktstatistik 1996-2002 (Indications in 1.000 m^3 , Frankfurt am Main, 01.04.03.

8. Factor of operating emissions from the bank

The annual operating emission factor (EF_{op}) amounts to 0.66% of the bank.

9. Sources of information on emission factors

1. Manufacturing emissions. The 100% manufacturing emission factor for 152a as well as the manufacturing emission factor for 134a has been communicated by the XPS sector associations on national and European levels (FPX and EXIBA). (The 134a emission factor was lowered from 30% in 2001 to 27% in 2002).
2. Bank emissions. The speaker of the German sector association FPX estimates annual diffusion of enclosed HFC-134a cell-gas from XPS foam at less than 1%, namely at 0.66%. This value bases on an internal BASF study on half-life of the cell-gases CFC-12, HCFC-142b, HCFC-22, HFC-134a, and HFC-152a. Following this study, the diffusion rate of 134a is in the order of HCFC-142b whereas HCFC-22 and HFC-152a

diffuse virtually instantly. The diffusion out of XPS panels depends on their thickness. It can only be assessed for individual diameters. In case of 134a, the half-life in a 70 mm thick panel is about 35 years. The half-life grows exponentially with the diameter. The average annual emission rate of 0.66% for the entire product mix is based on middle-thick panels.

Manufacturing loss for 152a and 134a

FPX: Fachvereinigung Polystyrol-Extruderschaumstoff e.V. (German Section of EXIBA - European Extruded Polystyrene Insulation Board Association) http://www.fpx-daemmstoffe.de/ E-Mail: info@fpx-daemmstoffe.de , Frankfurt, 069-424901, 02.12.02; 23.09.03.

Operating loss from bank (134a)

Dow Deutschland Inc., Rheinmünster, 28.11.02; 23.09.03.

Weilbacher: Ausgasung von Zellgasen, Laborbericht vom 17.08.87 (überreicht von der BASF AG, Ludwigshafen), 09.07.99.

10. Operating 134a emissions from bank as of 2001

Operating (use-phase) emissions in a particular year n are arrived at by applying the operating emission factor (EF_{op}) to the average bank in the same year n (B n), which has been built up by HFC inputs over the preceding years - see section 6.B.

$$EF_{op} \text{ (in \%)} \quad \times \quad B\ n$$

Because of an EF of 0.66% for ready domestic XPS foam (be it installed or still stored), the specific equation for operating emissions is:

$$EF_{op} \text{ (0.66 \%)} \quad \times \quad B\ n$$

Table 6 shows the time series of operating HFC-134a emissions from XPS foam:

Tab. 6: 2001 and 2002 Domestic average bank and operating emissions of HFC-134a from XPS-insulating foam

	Average HFC bank	Operating HFC emissions
2001	144.4 t	0.95 t
2002	471.3 t	3.11 t

Sources: Table 5 in conjunction with EF_{op} of 0.66%.

Comment

Because of the low EF of 0.66%, operating emissions from bank are very small compared to manufacturing emissions. Furthermore, they run proportionally to the HFC-134a bank that is made up only by domestic inputs after subtraction of the export from domestic manufacture. Assuming unchanged circumstances in the future, average bank and operating emissions will keep on growing over the next 50 years due to the long lifetime of XPS panels in use. In 2020, an average bank of 8,600 tonnes will be reached with annual operating emissions of 57 tonnes.

11. Quality control and uncertainty assessment of data II

Activity data. The XPS sector association itself investigated for manufactured XPS quantities as well as for used quantities of both HFCs. The association intends to establish a voluntary agreement on emissions reduction targets. Particularly since there are only three manufacturers using HFCs for foaming XPS, reliability of activity data is out of question. The same applies to export quote and HFC-134a emissions upon manufacturing. Only the asserted 50-year lifetime of XPS panels containing HFC-134a (for 152a-panels the lifetime is irrelevant in the given context) is somewhat arbitrary like any long run forecasting of this kind. This, however, does not affect emissions estimation for the near future.

Emission factors. Manufacturing emissions of 100% on using HFC-152a do not match the IPCC estimations made so far. This factor, however, is realistic according to the German XPS sector association. The instant loss of 30% and 27% respectively on using HFC-134a is based on measurements carried out in the Rheinmünster plant of Dow Deutschland. The operating emission factor of 0.66% is in the order of the usual estimations of 1%. Because there is a laboratory-based study available resulting in some 0.66%, this value is used here as long as values that are more reliable do not exist. Measurement values obtained from used XPS panels were, of course, superior in safety to rules of thumb or laboratory values.

12. Relation to IPCC method

In IPCC GPG, emissions from closed-cell foam are dealt with under "3.7.3 Foam sub-source category". ÖR meets the requirements stated in Box 3 of the Decision Tree for Actual Emissions (Tier 2), "Calculate emissions by substance and foam type, using national data, disaggregated country-specific parameters, and the Tier 2 equation, incorporating end of life data if available". Disposal (end of life), however, is disregarded for lack of relevance in the near future.

The above-mentioned Tier 2 equation is equation 3.38. In its first part, it defines the "First Year Losses from Foam Manufacture and Installation" as follows:

(Total HFCs Used in Manufacturing New Closed-cell Foam in year t) x (First-year Loss Emission Factor)

Equation 3.38 defines the "annual losses from foam use" in its second part:

(Original HFC Charge Blown into Closed-cell Foam Manufacturing between year t and year t – n) x (Annual Loss Emission Factor)

From a qualitative perspective, the ÖR approach fully meets the equation 3.38.

In IPCC GPG, there are not many quantitative recommendations on emission factors to be used as default values when country-specific data are not available. In Table 3.18, there are no indications for the use of HFC-134a for XPS. For 152a, however, a First Year Loss of 40% is proposed followed by an Annual Loss of 3%. On condition that these values are no misprints, ÖR considers them too low for the first year and too high for the subsequent years – in accordance with the national and European XPS experts.

The 50-year Product Life presented in IPCC GPG is deemed acceptable.

13. Entry in CRF

The CRF Table where data on "Filled in new manufactured products", "Average annual stocks", "Emissions from manufacturing", and "Emissions from stocks" are primarily entered for the XPS use of HFC-134a and HFC-152a is Table 2(II).Fs1, rows 100/101, columns B and C as well as H and I.

F-Gas Sheet 19: Fire Extinguishers

F-Gases	**HFC-227ea, HFC-236fa**
Application	**Fire Extinguishers**
Reported Years	**1998 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Filling Emissions (Manufacturing Emissions)**
Emission Type 2	**Open Application (direct)**

Background

Halons, which were permitted for fire protection until 1991, have largely been replaced since then by environmentally friendlier substances. Fixed systems for flooding indoor spaces now mainly use inert gases (nitrogen, argon) instead of Halon 1301. Portable extinguishers for targeted fire fighting now contain powder, CO_2, or foam.

Proposals to use HFCs (HFC-23, HFC-236fa, and HFC–227ea) instead of Halons run against German regulatory authorities, in the beginning. The same applies to several PFCs. For the first time, HFC-227ea was officially approved for flooding equipment in Germany in 1997. In 2001, additionally, HFC-236fa was approved for an array of military uses, and in 2002, HFC-23 was approved, too. The latter, however, has not yet been used by 2003.

The situation is comparable with HFC solvents where during the time of bans on ozone-depleting substances for lack of fluorinated alternatives an array of ecologically less critical fluids and technologies was introduced into the market. When HFCs were eventually approved, their market potential was already limited.

Therefore, consumption as well as emissions of HFCs as fire extinguishers are moderate.

HFC fire extinguishers are being imported, partly from North America, partly from Spain, to be filled in, mostly, fixed installed systems in Germany. Import or export of charged equipment does virtually not occur.

In difference to e.g. passenger-car air-conditioners, annual HFC input to new domestic equipment does not differ from domestic HFC consumption for charging of new equipment.

I. Domestic HFC input and operating emissions from bank

1. Activity data. Input of HFC fire extinguishers

Since 1998, the industry directly communicates the annual quantity of HFC-227ea filled in equipment (In_{bank}) to the Umweltbundesamt and to ÖR. Information on the respective quantities of HFC-236fa is annually given to the Umweltbundesamt by the licensing authority in Freiberg (Saxony). Table 1 contains these data.

Table 1: 1998-2002 Annual HFC quantities filled in domestic fire protection installations, in t		
	HFC-227ea	HFC-236fa
1998	2.429	-
1999	4.294	-
2000	80.256	-
2001	66.997	0.454
2002	32.743	1.998

Sources: Communications from industry and licensing authorities.

2. Average HFC bank in fire protection installations

By adding up all previous annual inputs to domestic fire protection installations, the end-of-year bank in year n (EB n) is arrived at as long as decommissioning of old installations (De_{bank}) does not need to be considered.

Operation emissions in year n relate to the average bank (B n). This is half the sum of the previous-year end-of-year bank n-1 and the current-year end-of-year bank n. The equation is as follows:

Equation

$$B\,n = \frac{EB\,n\text{-}1 + EB\,n}{2} \quad \text{Where:} \quad EB\,n = EB\,n\text{-}1 + In_{bank}\,n$$

The annual end-of-year banks (EB) from 1998 onwards are the sum of new fillings (inputs) as per Table 1. The average bank (B) results from two consecutive end-of-year banks, according to the aforementioned equation. The banks are entered in Table 2.

Table 2:1998-2002 End-of-year banks and average banks of HFCs in fire fighting installations, in t/yr				
	HFC-227ea		HFC-236fa	
	End-of-year bank	Average bank	End-of-year bank	Average bank
1998	2.429	1.21		
1999	6.723	4.58		
2000	86.979	46.85		
2001	153.976	120.48	0.454	0.227
2002	186.719	170.35	2.452	1.453

Sources: Table 1 in conjunction with the above equation.

Comment on activity data

The quantitatively more important fire extinguisher HFC-227ea started slowly in 1998. In 2000, however, a steep rise in consumption took place. The new filling amounted to 80 tonnes. Since then, annual input has been decreasing, and this leads to retardation in building up HFC banks in fire fighting equipment. Presently it is not yet sure, whether this is a temporary trend or an indication of saturation.

3. Operating HFC-227 emissions from bank

The industry reports annual emissions of HFC-227ea in detail. This is why there are absolute data on emission quantities available broken down into four sources (Table 3).

Table 3: 1998-2002 Emissions of HFC-227ea from fire fighting equipment by sources, in t/y

	Total	1. Fire	2. Leakage	3. False alarm	4. Flooding
1999	0.171				0.171
2000	0.512	0.21			0.302
2001	0.780	0.16	0.1	0.106	0.414
2002	0.996	0.175	0.038	0.783	0

Source: Kidde-Deugra.

Comment

The equipment losses (2002 total approx. 1 t) assessed in the course of maintenance arose over the first years mainly on test flooding, which was stopped in 2002. Up to now, intentional loss on fire extinguishing is of minor relevance and smaller than emissions through false alarm.

4. Implied operating emission factors

From the data on average banks of 227ea and 236fa, together with data on operating emissions of 227ea, implied emission factors (EF_{op}) can be calculated.

Table 4 shows for the HFC-227ea in the third column the percentage operating emission factor EF_{op}. It is arrived at by relating absolute operating emissions (Table 3) to the average HFC bank in fire fighting equipment (Table 2). The values drop from 3.7% via 1.1% to 0.6% by 2001.

Table 4: 1998-2002 Bank and operation emissions of HFC-227ea and -236fa, in t/y

Year	HFC-227ea			HFC-236fa		
	Average bank	Op. emiss	EF_{op} in %	Average bank	Op. emiss	EF_{op} in %
1998	1.21					
1999	4.58	0.171	3.7%			
2000	46.85	0.512	1.1%			
2001	120.48	0.780	0.6%	0.227	0.002	1%*
2002	170.35	0.996	0.6%	1.453	0.014	1%*

Sources: Tables 2 and 3 for 227ea. * ÖR estimation for lack of reported data.

Unfortunately, there are no indications on emissions of HFC-236fa (apart from emissions on open test applications presented in Part II). In order to obtain at least preliminary data on operating emissions from installations, alternatively in Table 4 an EF_{op} of 1% has been applied to the average bank of HFC-236fa (last column to the right). This value is in the order of magnitude of the EF_{op} for 227ea (four years averaged). In this way operating emissions of HFC-236fa have been calculated and entered in Table 4, in the second column from right.

Generally, the factor of operating emissions (EF_{op}) from fire-fighting equipment is assumed to range 1% over the medium term.

5. Collection of data and sources of information I (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Since 1998, the market leader Kidde-Deugra directly communicates to the Umweltbundesamt and to ÖR the annual quantities of HFC-227ea filled in equipment as well as emitted from equipment, with emissions being divided into four sources. Aside from the market leader there are two other companies offering this fire extinguisher. One of them purchases it from Kidde-Deugra so that his sales do not need to be reported extra. The market share of the third supplier constantly amounts to somewhat 5%. His sales data are included in the Kidde-Deugra communication by means of extrapolation.

The data on 236fa are given to the Umweltbundesamt by the licensing authority Freiberg in Saxony.

<u>Personal Communications</u>
Kidde Deugra Brandschutzsysteme GmbH, Ratingen, 19.07.99; 15.01.02; 23.09.03.
Amtliche Prüfstelle für Feuerlöschmittel und – geräte bei der Materialprüfungsanstalt für das Bauwesen Dresden, Außenstelle Freiberg, Mitt. an das Umweltbundesamt 02.07.03.

6. Quality control and uncertainty assessment of data I

<u>Activity data</u>. The industry reporting on annual charging of HFC-227ea must be considered highly reliable. Small uncertainties arise only from the "third" supplier whose market share is estimated. The error band should range less than ± 1% at a high confidence level. In case of HFC-236fa, indications of quantities are also deemed correct.

<u>Emission factors.</u> Certainly, within the F-gas monitoring system the reported emissions of HFC-227ea are among the most exact data at all. Interesting is that the implied emission factor is not constant over several years. The indications in absolute terms confirm, however, for the emission factor a magnitude in the order of 1%.

The 1% emission factor for HFC-236fa is derived from the 227ea value; the level seems to be justified. ÖR tends to estimate losses of 236a a bit higher since the fire fighting equipment is not stationary but installed in military vehicles (tanks) for the most part.

7. Relation to IPCC method I

In IPCC GPG, there are special comments under "3.7.6 Fire protection sub-source category". To assess emissions, a rough "sales-based top-down approach" is suggested. A "bottom-up Tier 2 approach" deems "not suitable for the fire protection sub-source category", since the "required activity data do not exist for most countries".

Because in Germany the required activity data are available, ÖR has chosen a “bottom-up approach”.

Obviously, at the time of its publication IPCC GPG was not yet up-to-date. This conclusion suggests itself in the face of the "default emission parameters" in Table 3.26. For flooding from fixed systems 5% emissions are assumed, a value dating back to 1998 (UNEP HTOC Assessment). Surely, a revised version of IPCC GPG will better reflect the situation in the After-Halon era.

The average lifetime of fire protection installations is assumed to last up to 35 years. ÖR agrees on this value.

8. Entry in CRF I

The CRF Table where data on fire extinguishers are primarily entered is Table 2(II).Fs2, rows 10 and 11. The banks made up by successive annual inputs are entered in C ("stocks"), operating emissions are entered in columns I ("emissions from stocks").

II. Domestic HFC consumption and manufacturing emissions

9. HFC consumption for manufacturing and charging emissions

As foreign trade with charged equipment does quasi not occur, annual HFC input shown in Table 1 is in principle identical to annual domestic HFC consumption for charging ($In_{bank} \sim C_{manu}$). In a strict sense, in the absence of foreign trade consumption is always a bit higher than input because of charging emissions. This difference is, however, mostly insignificant and not considered further in this report. Thus, it is unconsidered in connection with fire protection installations, too.

In case of 236fa further emissions come into question. This does not concern emissions from installations but it is about emissions arising on open application in the course of testing.

10. Emission factor of charging installations 0.1%

The leading installer and filler of HFC-227ea fire fighting systems, Kidde-Deugra, estimates loss on filling at “one tenth of a percent”. On querying, company experts indicated five grams per gas bottle. Five grams match 0.1% only if the bottle contains five kilograms. Therefore, this percentage is taken as an upper limit. This is because in reality bottle-sizes range from 3 to 200 kg. Charging emissions (in absolute terms) are arrived at by applying the emission factor (EF_{manu}) of 0.1% to annual inputs (In_{bank}) shown in Table 1 (Part I). These inputs can be taken for consumption quantities for filling and are entered again in Table 5 under the heading "New filling".

Table 5: 1998-2002 New filling and filling emissions of HFC-227ea and -236fa in case of fire fighting equipment, in tonnes per year				
	HFC-227ea		HFC-236fa	
	New filling	Filling emission	New filling	Filling emission
1998	2.429	0.002	-	-
1999	4.294	0.004	-	-
2000	80.256	0.080	-	-
2001	66.997	0.067	0.454	0.0005
2002	32.743	0.033	1.998	0.002

Sources: Table 1 in conjunction with charging emission factors (EF_{manu}) of 0.1%.

11. In addition: Consumption of HFC-236fa for tests in open application

Before introducing the fire extinguisher HFC-236fa, aptitude tests were carried out where no equipment was charged. All HFCs consumed became emissions. These quantities are known (Table 6).

Table 6: 2001 and 2002 Consumption of HFC-236fa for tests, and emissions on open application, in tonnes per year	
	Consumption = Emissions on open application
2001	0.260
2002	0.547

Sources: Licensing office Freiberg (Saxony)

12. Collection of activity data and sources of information II (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Sources of information on domestic HFC consumption for filling have already been discussed in Part I, section 5. Charging loss was indicated by experts from Kidde-Deugra. Data on HFC-236a in open application so far not mentioned in Part I were communicated to the Umweltbundesamt by the licensing authority based in Freiberg.

Personal Communications
Kidde Deugra Brandschutzsysteme GmbH, Ratingen, 15.01.02; 23.09.03.
Amtliche Prüfstelle für Feuerlöschmittel und – geräte bei der Materialprüfungsanstalt für das Bauwesen Dresden, Außenstelle Freiberg, Mitt. an das Umweltbundesamt 02.07.03.

13. Quality control and uncertainty assessment of data II

The emission factor of charging is reliable in the sense of an upper limit (5 grams per bottle). This value was confirmed to ÖR by a further employee with Kidde-Deugra.

14. Relation to IPCC method II

Manufacturing or Filling Emissions do not occur in IPCC GPG because this manual focuses on a top-down-approach to this application.

15. Entry in CRF II

In CRF Table 2(II).Fs2, domestic HFC consumption for charging is entered under the heading "Filled in new manufactured products", and filling emissions are entered under "Emissions from manufacturing". This is done for HFC-227ea in row 10 and for HFC-236fa in row 11, each time in the columns B and H.

Like the HFC-236fa use for filling of equipment, the open use of HFC-236fa for testing is also part of domestic 236fa-consumption. Thus, the openly applied quantity is added in row 11, col. B, to the quantity already entered under the heading "Filled in new manufactured products”. Likewise, emissions from open 236fa application are added to 236fa Emissions from manufacturing already entered in column H. The amount of the added consumption for open application is the same size as the amount of the added emissions from open application.

F-Gas Sheet 20: Metered Dose Inhalers

F-Gases	**HFC-134a, HFC-227ea**
Application	**Metered Dose Inhalers (MDIs)**
Reported Years	**1996 - 2002**
Emission Type 3	**Open Application (indirect)**
Emission Type 1	**Manufacturing Emissions**

Background

Under the exemptions for essential uses under the Montreal Protocol new medical aerosol products containing HFCs are still competing with products using CFCs as propellants. These are permitted for the treatment of asthma and chronic obstructive pulmonary diseases (COPD). In Germany, the first MDI using the propellant 134a came onto the market in 1996. By 2002, already more than twenty products were on the German market, for all classes of medication, so that the CFC phase-out in new products might be completed soon.

The only HFCs used for MDIs are HFC-134a and HFC-227ea. These HFCs must meet special purity requirements (pharmaceutical quality). The formerly more than 400 tonnes CFCs (11, 12, 114) will not be replaced by HFCs in one-by-one relation. This is because modern Dry Powder Inhalers (operating without propellant gases) have succeeded in raising their market share significantly over the recent years.

Prior to 2001, HFC propelled MDIs came onto the German market exclusively from abroad. Since 2001, HFC-MDIs are also filled on the headquarters of the leading pharmaceutical company in the field of respiratory therapy in Germany.

I. Domestic HFC input and emissions on application

1. Activity data. Domestically sold MDIs with HFCs

1.A Annual sales in domestic pharmacies (HFC volume)

By 2003, MDIs were available in four container sizes: 5 ml, 7.5 ml, 10 ml, and 12.5 ml. In the face of the great variety of MDIs differing by active ingredient and manufacturer and, additionally, by pharmaceutical strength, dosage, package size, and price, only sector experts are capable of viewing over the overall domestic market. Since 1997, marketing departments of one or two big pharmaceutical companies have annually provided ÖR with an already prepared dataset on pharmacy sales of all HFC containing MDIs by overall number of units, average volume in ml, and propellant gas used. As the container-volume usually consists approx. 98% of propellant gas and at most 2% of medically active substances inclusive of additives, in the following the entire content of an MDI is considered pure HFC (HFC content ~100%). Table 1 shows the raw data for the years 1996 to 2002.

Table 1: 1996-2002 Annual sales of MDIs in pharmacies by number of units (mill.), average HFC content (ml), and total volume of 134a and 227ea (litres)

	1. MDI 134a mill. units	2. Av. 134a volume ml	3. Litres 134a	4. MDI 227 mill. units	5. Av. 227 volume ml	6. Litres 227ea
1995						
1996	0.037	5.0	0,184			
1997	0.700	9.5	6,637			
1998	2.047	9.6	19,727			
1999	3.038	8.6	26,117	0.516	10	5,164
2000	4.299	8.0	34,373	2.303	10	23,029
2001	8.758	8.8	77,346	2.235	10	22,352
2002	12.624	9.3	116,968	2.512	10	25,116

Sources: Selected pharmaceutical companies. MDI = Metered Dose Inhaler.

The quantity in litres (columns 3 for 134a and 6 for 227ea) is the product of MDIs in million units (columns 1 and 4, respectively) and the average content in ml (columns 2 and 5, respectively).

1.B Domestically sold overall HFC quantity (HFC weight)

1. In order to recalculate volumes (litres) into weight (tonnes) HFC-134a is multiplied by 1.208 (density at 20°C), and the 227ea volume by 1.413 (density at 20°C).

2. Sales in pharmacies account for the vast majority, however not for the total of domestically delivered MDI units. Hospital demand accounts for 10 percent according to expert estimations. Additional three percent do not pass over the pharmacy counter, namely "samples – not for sale" to be handed over to physicians by medical representatives. Therefore, the so far determined weight has to be multiplied by the surcharge factor 113% (100+10+3).

2. Application emission factor

Aside from samples for doctors, the bulk of MDI is obtained in pharmacies (inclusive of hospital drug departments) for instant use afterwards. Thus, the time lag between acquisition in pharmacy and application of MDI is short. As with PU-OCF, emissions associated with MDI application in year n (Em n) are completely related to sales/purchases (Sales = S) in the same year n. The emission factor is 100%. Inhaled HFCs do not react in the respiratory tract but escape unaltered to the atmosphere when being exhaled.

Em n = S n x EF (100%) or: Emissions n = Sales (Sold Cans) n x 100%

Quantity of reference for emissions is not the sum of half the purchases/sales in year n-1 and half the purchases/sales in year n. This approach was adequate if not sold but manufactured MDI cans were raw data, so that notable time for transport and storage had to be taken into consideration between manufacture and application.

3. Domestic application emissions, since 1996

Although sales and application-emissions are not exactly identical, but application follows sales with a delay of some weeks, here they are considered equal to each other in a given year. Table 2 shows for the two pharmaceutical HFCs two identical time series, one for sales and another for emissions:

Table 2: 1996-2002 Sales/Emissions of HFC-134a and –227ea through medical Metered Dose Inhalers, in t/y

Year	HFC-134a		HFC-227ea	
	Sales	Emissions	Sales	Emissions
1995				
1996	0.3	0.3		
1997	9.1	9.1		
1998	26.9	26.9		
1999	35.7	35.7	8.2	8.2
2000	46.9	46.9	36.8	36.8
2001	105.6	105.6	35.7	35.7
2002	159.7	159.7	40.1	40.1

Sources: Table 1. The volumes are multiplied by the densities 1,208 and 1,413 respectively. The products were multiplied again by the surcharge factor 113% for application in hospitals and for the use of samples – not for sale.

Comment

Domestic input of HFCs (In_{bank}) through MDIs for patients with diseased respiratory tracts has risen rapidly since 1996. A steep rise occurred in 2001, because from this year onwards CFCs have been forbidden for he largest single medication, the short-acting Beta Agonist drugs (to dilate the bronchi). Because of the increased share of Dry Powder Inhalation, HFCs might fall short of the formerly used CFC quantities of 400 t/y, at least over the medium term. At the end of 2002, 200 tonnes of HFCs in MDIs were domestically sold. In addition, roughly 100 tonnes of CFCs came still onto the market. They will have to be replaced for the most part by 2005.

4. Collection of data and sources of information I (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

The surveyed overall pharmacy sales of MDIs to end-users are annually prepared by experts from the pharmaceutical industry to the dataset presented in Table 1. Since 1998, the datasets regularly are discussed in the Working Group DPI (API) where ÖR is a standing participant. Data on 1996 and indications on additional MDIs used in hospitals and as doctor-samples were obtained from interviews with experts from companies represented in the API.

Personal Communications from Pharmaceutical Companies represented in API
Orion Pharma GmbH, Hamburg, Fachgespräch 29.10.96.
AstraZeneca GmbH (formerly Astra - pharma stern), Wedel.
Glaxo Smith Kline GmbH & Co. KG, München (formerly Glaxo Wellcome, Hamburg)

5. Quality control and uncertainty assessment of data I

Data safety of sales figures deems generally high. The survey of pharmacy sales, however, is on its own arrived at by means of projection from random samples. Therefore, there is a certain margin of error associated with the survey method itself. The error band can be kept within reasonable limits, as the individual pharmaceutical companies know their own sales figures very well to be enabled to crosscheck the surveyed data.

The surcharge-factor to compensate non-surveyed MDI use in hospitals and doctor-samples may deviate from the assessed 13% by plus or minus 2%. Provided the real total HFC quantity is 111% or 115%, the effective value might be sufficiently well met.

6. Relation to IPCC method I

IPCC GPG explicitly addresses metered dose inhalers - MDIs under "3.7.1 Aerosols sub-source category", in paragraph (i). Methodologically, MDIs are treated like any other aerosol products.

IPCC GPG proposes two years as default value for the lifetime of an aerosol package. That means, GPG distributes the HFC quantity sold in year n over two emission years n and n +1. The default emission factor for the HFC quantity sold in year n is 50% in the same year n and 50% in the next year n+1.

Equation 3.35 accounts for the lag period from time of sale to time of use:

$$\text{Emissions in year } t = \text{HFCs Contained in Aerosol Products Sold in year}_{t} \times 0.5 + \text{HFCs Contained in Aerosol Products Sold in year}_{t-1} \times (1 - 0.5).$$

As set out in section 2, ÖR does not use this equation, deliberately. In the face of a rapidly growing market, emissions in year n would be underestimated if they were set equal to the HFC quantity contained in MDIs sold half a year ago. Such a long delay in use does not deem lifelike. The usual consuming time for MDIs is even in double-packages at most two months from acquisition in the pharmacy. ÖR uses data based on pharmacy sales. That justifies the use of a "country-specific emission factor" in difference from the IPCC proposal. The German emission factor does not claim prevalence for other countries.

Concerning activity data, the ÖR method is a bottom-up-approach. The leading pharmaceutical companies on the German market provided all quantitative data.

7. Entry in CRF I

The CRF Table where data on MDIs are primarily entered is Table 2(II).Fs2, rows 14 and 15. Domestic quantities of 134a and 227ea are entered in column C ("stocks“) with respect to the can content, and in columns I ("emissions from stocks") the same quantities are entered again in respect to emissions from these cans.

II. Domestic HFC consumption and manufacturing emissions

8. Consumption for manufacturing and charging emissions, as of 2000

By 2003, in Germany there was only one filler of HFC containing MDIs (only 134a), who started in 2001. He communicates his annual consumption (C_{manu}) as well as his manufacturing loss (Em_{manu}) to ÖR - see Table 3.

Table 3: 2000-2002 HFC consumption for charging MDIs in Germany and emissions on charging, in tonnes per year

Year	HFC-134a	
	Consumption	Charging emissions
2000	-	-
2001	99.0	1.5
2002	134.2	1.6

Sources: Boehringer-Ingelheim Pharma KG.

9. Implied manufacturing emission factor

Manufacturing loss in the plant is well documented. The implied emission factor is the relation of that measured loss to annual HFC consumption and amounts to approx. 1%. Emissions of 1.5 tonnes can be recalculated to approx. 0.15 grams per 10 ml can. Charging emissions would figure 0.75 tonnes higher if there were no low temperature cold traps (Crysumat) to capture gaseous emissions in order to dispose them of by combustion.

10. Collection of activity data and sources of information II (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

The company in question directly gives information on domestic HFC consumption and charging loss (inclusive of recovery).

Personal Communications
Boehringer-Ingelheim Pharma KG, Ingelheim, Mitt. an ÖR 19.11.02, Schreiben an ÖR 30.09.03.

11. Quality control and uncertainty assessment of data II

Data safety is high. Cross-check is not considered necessary.

12. Relation to IPCC method II

IPCC-GPG does not propose any default values for manufacturing loss.

13. Entry in CRF II

In CRF-Table 2(II).Fs2, HFC consumption for domestic charging is entered under "Filled in new manufactured products", and charging losses are entered under "Emissions from manufacturing". This is done for HFC-134a in row 14, in columns B and H.

F-Gas Sheet 21: General Aerosols

F-Gases	**HFC-134a, HFC-152a**
Application	**General Aerosols**
Reported Years	**1995 – 2002**
Emission Type 3	**Open Application (indirect)**
Emission Type 1	**Manufacturing Emissions**

Background

In Germany there are six categories of general aerosol products with HFCs (without medical MDIs and without novelty sprays) on the market: 1. Compressed-air sprays (30-40%); 2. Freezer sprays (30%); 3. Drain-pipe cleaning sprays (30%); 4. Lubricant sprays (2%); 5. Insecticide sprays (2%); 6. Defence sprays (2%). Because of the large importance of drain-pipe-cleaners, which are used in households, the terms "Technical Aerosols", or "Industrial Aerosols" are avoided in favour of the term "General Aerosols". It should be pointed out here that today fluorinated propellants in aerosol products play a negligible part in the overall aerosol propellant gases compared to the 1980s. Against this time, the quantity applied has been reduced by 99%.

Since 1995, annual domestic HFC consumption for charging aerosol cans constantly figures approx.160 tonnes of HFCs (thereof 95% 134a and 5% 152a). There are three domestic filling plants: IG-Sprühtechnik based in Wehr/Baden; TUNAP Deutschland based in Wolfratshausen/Bavaria; Hago based in Landsberg am Lech. The latter is contract filler who uses HFCs for aerosols only now and then.

The domestic market is also supplied by companies who have their products charged abroad, above all in Belgium. In the field of compressed-air sprays and of freezer sprays, the largest companies of this kind are CRC Kontakt Chemie with German headquarters in Iffezheim, and Electrolube with German headquarters in Cologne.

Imports and exports of general aerosols are balanced so that domestic market (In_{bank}) is equal in size to overall domestic consumption for filling (C_{manu}). According to the majority of the consulted industrial experts, the market has been stable since 1995 with no notable rises in HFC quantities used.

I. Domestic HFC input and application emissions

1. Activity data (quantities used) and emission behaviour

Aerosol cans contain between 150 and 400 ml HFC propellant. The HFCs are emptied on application, and completely become emissions in compliance with their destination. The number of domestically sold cans is supposed to be consumed one half within the same year and the other half within the following year. Considering HFCs in the cans, annual input to domestic market (In_{bank}) is used one half each in year n-1 and in year n. Therefore, in year n application emissions from cans sold in two different calendar years occur: the aforementioned second half of cans sold in year n-1 and the first half of cans sold in year n. The equation for application emissions from general aerosols is as follows:

Equation
Emission n = Domestic Sales $_{n-1}$ x 50% + Domestic Sales $_{n}$ x 50%
Or expressed in other terms:
Emission n = In_{bank} n-1 x 50% + In_{bank} n x 50%

Explanation: n is the current year, n-1 is the year prior to it.

This equation proposed by IPCC GPG is not only applied to household aerosol products (drain pipe cleaners) but also to industrial aerosols the users of which are professionals and certainly faster in consuming cans after acquisition than buyers of drain pipe cleaners (the latter contain some 50 tonnes HFC, namely more than 200,000 cans with 200 ml). The presumably shorter period from time of acquisition to time of use in industrial aerosols does not lead to a different emission calculation like in MDIs.

2. Domestic application emissions, since 1995

Table 1: 1994-2002 Domestic sales and application emissions of HFC-134a and HFC-152a as propellant in general aerosol products, in t/y

Year	HFC-134a		HFC-152a	
	Sales	Emission	Sales	Emission
1994	160		10	
1995	160	160	10	10
1996	160	160	10	10
1997	160	160	10	10
1998	160	160	10	10
1999	160	160	10	10
2000	160	160	10	10
2001	160	160	10	10
2002	160	160	10	10

Sources: Sales data according to IGA. Emissions according to the equation above.

Comment

HFC-152a is chiefly used as additive because 134a would generate on its own an impermissibly high interior container pressure. Domestic market and thus emissions show a constant course for both HFCs from 1995 onwards (160 and 10 tonnes, respectively).

3. Collection of data and sources of information I (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Since 1999, ÖR has inquired the data on general aerosol products (sales figures, HFC types, fields of application) of domestic filling and distribution companies, initially only about industrial aerosols. In 2003, ÖR revised the data thoroughly (even retroactively) together with the sector association of the Aerosol Industry (IGA) with the Association of the Chemicals Industry (VCI), and together with the speaker of fillers at IGA, Mr Lothar Stockert.

<u>Personal Communications</u>

CRC-Kontakt-Chemie – Technische Aerosole GmbH, Iffezheim, Schreiben an ÖR, 11.8.99.
Electrolube Germany, Köln, Mitt. an ÖR, 17.10. 02.
Industriegemeinschaft Aerosole e.V. im VCI, Frankfurt am Main, Schreiben an ÖR, 04.03.03, 01.07.03.
IG-Sprühtechnik, Wehr, Mitt. an ÖR 02.07.03.
Tunap Deutschland, Wolfratshausen, Mitt. und Schreiben an ÖR, 01.07.03.

<u>Written Sources</u>

Meeh, Peter: Sichere Kältesprays, in rfe – Radio Fernseh Elektronik 5/1998.
Öko-Recherche: Emissions and Reduction Potentials of Hydrofluorocarbons, Perfluorocarbons and Sulphur Hexafluoride in Germany, on behalf of the Umweltbundesamt, October 1999. http://www.oekorecherche.de/english/berichte/volltext/f-gases.pdf

4. Quality control and uncertainty assessment of data I

Data safety of sales figures is generally high. Independently, abroad filling companies and domestic fillers estimated the market for compressed-air sprays and freezer sprays the same size (together 100 tonnes HFC). The drain pipe cleaner is filled by only one single enterprise, and the latter specified the HFC quantity sold in aerosol cans at approx. 50 tonnes annually. The overall 160 tonnes indicated by the sector association (IGA) for these three products together with further three small applications sound plausible to a high degree.

The constancy of the number “160 plus 10 tonnes”, however, suggests that the sales figures have been summarised to figures that do not take account of real market fluctuations. Further data improvement might be possible as a result of the Federal Law on Environmental Statistics (Umweltstatistikgesetz) presently being amended.

5. Relation to IPCC method I

IPCC GPG addresses the aforementioned products under "3.7.1 Aerosols sub-source category", sub "(iv) Industrial Products (e.g. special cleaning sprays, lubricants, pipe-freezers)", and in case of the drain pipe cleaner sub "(iii) Household Products".

IPCC GPG assumes a default value for the lifetime of aerosol packages of two years. That means, GPG distributes the HFC quantity sold in year n, over two emissions years n and n +1. On condition the can consumption is steady-going over the time, the default emission factor for the HFC quantity sold through cans in year n is 50% emissions in year n and once again 50% emissions in year n+1.

The equation 3.35 for the standard case is as follows:

Emissions in year t = HFCs Contained in Aerosol Products Sold in year $_t$ x 0.5 + HFCs Contained in Aerosol Products Sold in year $_{t-1}$ x (1 - 0.5).

ÖR uses this equation.

With respect to activity data, the ÖR method is a bottom-up approach. All the quantity data inclusive of that on (balanced) foreign trade have been given directly by the involved fillers and distributors, and by their sector association.

6. Entry in CRF I

The CRF Table where the data on general aerosol products are primarily entered is Table 2(II).Fs2, rows 17 and 18. The quantities of 134a and 152a for the domestic market are entered in column C ("stocks“) with respect to the can content, and in columns I ("emissions from stocks") the same quantities are entered again with respect to emissions from these cans.

When precise data on domestic sales are available, differences will emerge between stocks and emissions from stocks if the IPCC GPG equation 3.35 is applied.

II. Domestic HFC consumption and manufacturing emissions

7. Activity data and manufacturing emission factor

CRF requires estimation of domestic HFC consumption for manufacturing and of HFC emissions arising on manufacture. Annual domestic consumption (C_{manu}) is no function of annual number of new aerosol cans supplied to the domestic market but of domestically filled aerosol cans, wherever these are used.

In order to estimate both HFC consumption for domestic charging of general aerosols and emissions arising on domestic filling, ÖR interviewed experts representing domestic filling enterprises cited in Part I. They communicated that with respect to HFC quantities and HFC types annual domestic manufacture largely matches the structure of the domestic market itself, particularly as import and export are in balance state. This is why they recommended to set equal domestic consumption to domestic market ($C_{manu} = In_{bank}$).

Manufacturing loss of HFCs is estimated at 1-2% of HFC consumption. This value is possible provided that filling equipment is “adjusted to its optimum.” ÖR applies an emission factor of 1.5%.

8. Consumption for filling and filling emissions, since 1995

Following indications of the domestic fillers regarding equality of domestically filled to domestically sold HFC quantities, the data in Table 1 on domestic sales of HFC-134a and –152a can be directly adopted to assess domestic consumption for filling (C_{manu}). Filling emissions account for 1.5% of the annual consumption. Both data (consumption and filling emissions) are entered in Table 2 as time series from 1995 onwards.

Table 2: 1995-2002 Domestic HFC consumption for charging general aerosol cans and filling emissions, in tonnes per year

Year	HFC-134a		HFC-152a	
	Consumption	Filling Emission	Consumption	Filling Emission
1995	160	2.4	10	0.15
1996	160	2.4	10	0.15
1997	160	2.4	10	0.15
1998	160	2.4	10	0.15
1999	160	2.4	10	0.15
2000	160	2.4	10	0.15
2001	160	2.4	10	0.15
2002	160	2.4	10	0.15

Sources: German fillers for consumption figures and emission factor (EF_{manu} = 1.5%).

Comment

According to indications from manufacturers, in every year the same HFC quantities occur for both consumption and emissions.

9. Collection of activity data and sources of information II

The data on domestic HFC consumption for filling from 1995 onwards as well as on HFC types used and on emissions upon charging come from the same experts, who are already cited in Part I, section 2.

10. Quality control and uncertainty assessment of data II

As the sources of information are the same as in Part I, there is nothing to say that goes beyond the comments there.

11. Relation to IPCC method II

IPCC-GPG does not propose any default values for manufacturing loss in aerosol products.

12. Entry in CRF II

In CRF Table 2(II).Fs2, HFC consumption for domestic charging is entered under "Filled in new manufactured products", and charging loss is entered under "Emissions from manufacturing". This is done for HFC-134a in row 17 and for HFC-152a in row 18, each time in columns B and H.

F-Gas Sheet 22: Novelty Aerosols

F-Gases	**HFC-134a, HFC-152a**
Application	**Novelty Aerosols**
Reported Years	**1995 - 2002**
Emission Type 3	**Open Application (indirect)**

Background

So-called "novelty aerosols" are a small sub-group of the large category of aerosols. Because of their particular end-use, here they are not addressed under general aerosols. These sprays with HFC propellants are partly decoration aerosols and partly pure entertainment products with the boundaries between them being floating:

- Artificial snow sprays;
- Decoration paint sprays;
- Silly string for parties;
- Signal horns for parties and sport events.

An EU Directive (94/48) mandates that substances classified as flammable may not be used in aerosols for entertainment and decorative purposes, so that HFC-134a and small quantities of HFC-152a are used.

The domestic market is exclusively supplied from abroad, especially from other EU Member States.

HFC input to Germany and domestic emissions on application

1. Activity data. HFC use in the EU and input to Germany

Robust data on HFC input to the German market through novelty aerosols or, this is the same, on emissions from their application are not available. National data must be derived from EU-wide data.

According to information from the European Aerosol Federation FEA (Fédération Européenne des Aérosols) roughly 15 fillers produce novelty aerosols in Europe. All of these fillers are located in Spain, Italy, Belgium, The Netherlands, France and the United Kingdom. For the EU study on emissions reduction of F-gases, in 2002 FEA carried out a survey of the HFC quantities and HFC types annually used for novelty aerosols in the entire EU.

This data is available and is presented in Table 1. After consultation with the German Aerosol Association IGA, ÖR estimates the domestic market at approx. 10% of the EU market. This is far less than according to the German share in population or Gross Domestic Product of the EU. However, in this country novelty sprays are not as common as in the above-mentioned countries with own fillers. The sales attributed to the German market are entered in Table 1, to the right.

Table 1: 1995-2002 HFCs sales through novelty aerosols in the EU-15 and in Germany, in t/y

Year	All 15 EU States		Germany	
	HFC-134a	HFC-152a	HFC-134a	HFC-152a
1995	815		81	
1996	838		83	
1997	861		86	
1998	892		89	
1999	915		91	
2000	930	10	93	1
2001	950	50	95	5
2002	950	50	95	5

Sources: Sales in the EU acc. to FEA. Sales in Germany make up 10% of the EU quantity.

Comment

FEA sales estimations for 1995-2002 are based on an annual growth rate of three percent for the time before 2000. From 2000 onwards, the market has grown only to a very small extent if at all. Only since 2000, in addition to HFC-134a, HFC-152a is being used. For Germany, the same trends as in other parts of Europe are assumed.

2. Application emissions, as of 1995

Like in general aerosols, equation 3.35 according to IPCC GPG is applied to estimate emissions from novelty aerosols.

$$\text{Emissions in year t} = \text{HFCs Contained in Aerosol Products Sold in year}_{t} \times \text{EF} + \text{HFCs Contained in Aerosol Products Sold in year}_{t-1} \times (1 - \text{EF}).$$

If as EF the default value 0.5 is used (during the current year half the previous-year sales and half the current-year sales are emitting), the time series of emissions from application of novelty sprays in Germany is arrived at and shown in Table 2 hereafter. Please note, because of the estimation formula sales and emissions are same-sized only when the sales figure the same in two consecutive years.

Table 2: 1995-2002 HFC sales and HFC emissions through novelty aerosols in Germany, in t/y				
Year	Sales in Germany		Emissions in Germany	
	HFC-134a	HFC-152a	HFC-134a	HFC-152a
1994	*79*			
1995	81		80	
1996	83		82	
1997	86		84.5	
1998	89		87.5	
1999	91		90	
2000	93	1	92	0.5
2001	95	5	94	3
2002	95	5	95	5

Sources: Table 1 and equation 3.35 (IPCC). The 1994 value has been recalculated (-3%).

3. Collection of activity data and sources of information

The data collection for Germany by means of the EU estimation has already been mentioned (under 1). Beside of FEA and the German IGA an array of Internet web-sites helped get insight in the market.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Personal Communications

Industriegemeinschaft Aerosole e.V. im VCI, Frankfurt am Main, Schreiben an ÖR, 04.03.03, 01.07.03.

Fédération Européenne des Aérosols (FEA), Brussels http://www.aerosol.org/ Mitt. 30.11.99, 24.01.02.

WECO Pyrotechnische Fabrik GmbH, Eitorf/Sieg, www.weco-pyro.de, Mitt. an ÖR, 15.07.03.

Written Sources

Goodmark Europe BV, The Netherlands, mit den Abfüllfirmen VAC NV, Belgium und GAC (UK) Ltd, UK: http://www.goodmarkgroup.com/indexeur.html

HFCs in novelty aerosols, Ch. 4.7, in: Costs and the impact on emissions of potential regulatory framework for reducing emissions of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride (final report). Prepared on behalf of the European Commission (DG ENV) by J. Harnisch (Ecofys) & W. Schwarz (Öko-Recherche), February 4, 2003, p. 40-44. http://www.oekorecherche.de/english/berichte/volltext/ecofys_oekorecherchestudy.pdf

4. Quality control and uncertainty assessment of data

Data safety and quality is sufficiently good with regard to the EU-wide activities, even though FEA has got involved in this question in 2002 for the first time. In the future, the EU data survey should be improved further. Of course, there is even a higher uncertainty in the country-specific disaggregation of EU data, in that the factor of 10 percent for Germany is a rather rough figure. With the same right factors of 8 or 15 percent for estimating the German market-size could be used. The data was submitted to the German aerosol association IGA to be rated. Though IGA does not dispose of own data either, they at least took them for realistic.

5. Relation to IPCC method

IPCC GPG addresses the aforementioned products under "3.7.1 Aerosols sub-source category", namely sub "(v) Other General Products (e.g. silly string ...).

ÖR uses the IPCC equation 3.35 for emissions estimation:

$$\text{Emissions in year t} = \text{HFCs Contained in Aerosol Products Sold in year}_{t} \times EF + \text{HFCs Contained in Aerosol Products Sold in year}_{t-1} \times (1 - EF).$$

IPCC GPG proposes to use 50% as percentage default emission factors (EF and 1-EF, respectively). ÖR follows this recommendation, as it did in General Aerosols.

In reference of activity data the ÖR method is in principle a bottom-up approach (Tier 2a) as at least the quantity data come from fillers and distributors, indirectly. Nevertheless, estimates are very rough. Well-kept statistics on imports of novelty sprays in the framework of a top-down-approach (Tier 2b) would significantly enhance data quality.

6. Entry in CRF

The CRF Table where data on novelty aerosols are primarily entered is Table 2(II).Fs2, rows 20 and 21. Domestic sales of 134a and 152a are enlisted in column C ("stocks"), the emissions from the cans, which slightly deviate from the sales as a result of the equation used (Sales n x 0,5 + Sales n-1 x 0,5), are entered in column I ("emissions from stocks").

7. Remark on consumption for charging and on charging emissions

All novelty aerosols are imported. In Germany there is no HFC consumption for manufacturing so that emissions on manufacturing do not arise.

F-Gas Sheet 23: Solvents

F-Gas	**HFC-43-10mee**
Application	**Solvent Use**
Reported Years	**1999 - 2002**
Emission Type 3	**Open Application (indirect)**

Background

In some industrial sectors such as electronics, precision mechanics, fine optics, jewellery, the surface of product parts being manufactured is not only very sensitive – sometimes even to water – but also requires an extremely high degree of cleanliness. Thus the applied cleaning agent has to be very mild as well as effective in removing relatively small amounts of organic impurities, and must not leave any residues or spots on the parts' surface when drying. Often, non-flammability is an additionally desired property.

After prohibition of the broadly used CFC-113, in Germany an array of non-halogenated cleaning agents and cleaning technologies came on the market so that the CFC-successor HCFC-141b here, unlike other countries, was virtually not necessary. Anyway, HCFC-141b has been banned by national law from 1990 onwards for surface cleaning.

Whereas presently in many other industrialised countries an HFC solvent (above all HFC-43-10mee) is being introduced to replace the likewise prohibited (as of 2002 and 2009 respectively) HCFC-141b, in Germany the range of HFC applications keeps within narrow bounds because other fluids and procedures have already occupied the application areas in question.

This is the main reason why sales of HFC-43-10mee (brand Vertrel) are rather slow in growing although under the amended 2nd Statutory Ordinance (nov. 2. BImSchV) pursuant to the German Emission control Act from 2001, HFCs are admitted in exceptional cases.

Domestic HFC input and emissions on application

1. Activity data. HFC quantities applied in Germany

By the year 2002, the liquid HFC-43-10mee was the only HFC solvent in use in Germany. HFC-43-10 is provided by the chemical company DuPont under the brand Vertrel. Exclusive sales agency in Germany is the chemicals dealer Biesterfeld headquartered in Hamburg.

Since there is only one supplier of this HFC type, on his request the accurate sales figures must be handled confidentially. The German general distributor hands the data over to ÖR on the condition that this data as such is not made accessible to the public. This restriction should be kept in mind on reporting.

2. Emissions on application, since 1999

For estimating emissions the equation 3.36 in IPCC GPG is used, which deems appropriate for markets with variable annual sales quantities:

$$\text{Emissions in year t} = \text{Quantity of Solvents Sold in year}_{t} \times EF + \text{Quantity of Solvents Sold in year}_{t-1} \times (1 - EF).$$

If the IPCC default value 0.5 is used as EF (during the current year half the previous-year sales and half the current-year sales are emitting), a time series of emissions from solvent application of HFCs in Germany arises and is shown in Table 1 hereafter. Please note, that unlike novelties because of the estimation formula sales and emissions are not equal in one and the same year.

Table 1: 1999-2002 Sales and emissions of the solvent HFC-43-10mee in Germany in t/y

Year	Sales in Germany	Emissions in Germany
1999	confidential	confidential
2000	confidential	confidential
2001	confidential	confidential
2002	confidential	confidential

Sources: Sales figures from the company Biesterfeld. Emissions calculation acc. to equ. 3.36.

3. Collection of activity data and sources of information

The German general distributor handed the data over to ÖR as confidential.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Personal Communications

Biesterfeld Chemiedistribution GmbH & Co. KG, Hamburg, 04.12.03.

DuPont de Nemours International S.A., Geneva, Switzerland. Mitteilung an das Umweltbundesamt Berlin, 30.09.03.

Written Sources
HFCs as surface cleaning solvents, Ch. 4.8, in: Costs and the impact on emissions of potential regulatory framework for reducing emissions of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride (final report). Prepared on behalf of the European Commission (DG ENV) by Jochen Harnisch (Ecofys) & Winfried Schwarz (Öko-Recherche), February 4, 2003, p. 45-48. http://www.oekorecherche.de/english/berichte/volltext/ecofys_oekorecherchestudy.pdf
Öko-Recherche: The state of the art and the potential to reduce VOC emissions from surface cleaning installations, Report on the Umweltbundesamt (German Federal Environmental Agency), FKZ 297 44 906/2, Frankfurt am Main, November 1999 (in German). http://www.oekorecherche.de/deutsch/berichte/volltext/vollVOC.pdf.

4. Quality control and uncertainty assessment of data

Activity data safety and activity data quality is very high as it is usually the case with sales figures.

The percentage emission factor of 50% per half-year is the IPCC GPG default value. External recycling of contaminated solvent, which could extend its lifetime beyond one year, is no practice. The cleaning installations are simple two-chamber-plants for batch operation. Emission containment takes place by means of low temperature radiator coils and by means of a lid that is closed on operation. When feeding and unloading parts, the lid must be opened, and solvent vapour is released. Volatilised or discharged solvent is simply topped up.

5. Relation to IPCC method

IPCC GPG addresses the above-mentioned HFC solvents under "3.7.2 Solvents sub-source category".

To estimate emissions, ÖR uses the proposed equation 3.36 with the IPCC default emission factor of 0.5, and follows the requirements laid down in the Decision Tree (Figure 3.13) for Actual Emissions (Tier 2) from the Solvents Sub-source Category. Box 2 states, "Calculate emissions of each HFC in each end use, using bottom-up sales data and default emission factors."

6. Entry in CRF

The CRF Table where data on solvent use are primarily entered is Table 2(II).Fs2, row 23. Domestic sales of 43-10mee are entered in column C ("stocks"), emissions from solvent installations (Sales n-1 x 0.5 + Sales n x 0.5) in column I ("emissions from stocks"). The data have to be aggregated with other data for confidentiality reasons.

7. Remark on consumption for charging and on charging emissions

The HFC solvent 43-10mee is not produced in Germany, but is imported. It is being filled abroad into transport containers where some emissions arise, which are not attributed to the receiving country (Germany). Therefore there are no entries in CRF Table 2(II).Fs2, columns B and H.

It might be plausible to interpret HFC losses on charging of domestic cleaning installations as "domestic manufacturing emissions". However, the CRF specification "Amount of fluid filled in new manufactured products" clearly indicates that charging of installations (and emissions upon it) are not meant. This is because HFCs are not filled in products but in installations in order to clean them.

8. Confidentiality issue

The data are not allowed to be passed on as such, but only in aggregation with other application data.

To preserve confidentiality in solvents, IPCC GPG suggests under 3.7.2.2. that reporting could be aggregated into the aerosol section, because both are considered 100% emissive applications. In this case, emissions of individual gases should not be specified, and emissions should be reported in CO_2-equivalent tonnes.

ÖR takes this proposal worth considering and goes beyond that.

To maintain the aerosol data entries (CRF) by metric tonnes (HFC-134a, HFC-152a) according to ÖR the possibility should be checked whether the HFC-43-10mee mass from solvent use could be "transformed" into HFC-134a mass from aerosol use. That procedure is relatively easy because of the identity of the GWP values (1300) of 43-10mee and 134a. With respect to climate change, one tonne of 134a and one tonne of 43-10mee are the same.

F-Gas Sheet 24: Production of HFC-134a

F-Gas	HFC-134a
Application	Production of HFC-134a
Reported Years	1995 - 2002
Emission Type 6	Manufacturing Plant Emissions (Fugitive Ems.)

Background

At the beginning of 1995, in Frankfurt am Main the production of HFC-134a restarted after a one-year interruption resulting from a breakdown. The then operator was the Hoechst AG. Midyear 1996, Solvay Fluor und Derivate GmbH took over this only German manufacturing plant for HFC-134a.

1. Activity data. Production of HFC-134a from 1995 to 2002

In 1998, the production sharply increased. It has increased annually ever since. See Table 1.

2. Emissions and emission factor, since 1995

Fugitive plant losses have grown proportionally to the produced HFC output. The implied fugitive emission factor ranges around 0.3%. See Table 1.

Table 1: 1995-2002 Production and plant emissions of HFC-134a in Germany			
	Production in t	Emissions in t	Impl. Emission factor
1995	confidential	confidential	confidential
1996	confidential	confidential	confidential
1997	confidential	confidential	confidential
1998	confidential	confidential	confidential
1999	confidential	confidential	confidential
2000	confidential	confidential	confidential
2001	confidential	confidential	confidential
2002	confidential	confidential	confidential

3. Collection of data and sources of information

The operator of the facility communicates the data on production as well as on emissions to ÖR. ÖR has calculated the (implied) emission factor through relation of emissions to production.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Hoechst AG, Dr. Siegismut Hug Fachgespräch mit ÖR im Frankfurter Stammwerk am 25.3.96.

Solvay Fluor und Derivate GmbH, Fachgespräch mit Dr. Bernd Wilkes (Leiter Produktions-Koordination), Dr. Michael Ruhland (Ökologie), Dr. Hans Bräutigam, Harald Bruhns (Leiter Verkauf Fluorspezialitäten), Hannover 23.04.96.

Solvay Fluor und Derivate GmbH, Confidential communication to ÖR on "Production in Germany, associated emissions and export quantities for HFC and SF_6 of Solvay Fluor und Derivate GmbH (in t)", 04.03.03; 16.10.03.

4. Quality control and uncertainty assessment of data

The activity data on production are reliable from 1996 onwards, because they are based on plant-internal records of Solvay Fluor und Derivate GmbH. Only for the year 1995 (under operation of Hoechst), the indications are merely estimates. The responsible Hoechst experts, however, gave these data.

Emissions are obtained by means of a mass-balance. This means the difference between the plant output as expected from the feedstock and the actual output as filled in tanks, and weighed. The degree of reliability is high, as of 1996. The 1995 value does not originate from the operator Solvay. ÖR has recalculated it using an estimated emission factor. This approach seems to be justified, as it is the same manufacturing plant.

Direct crosscheck of the confidentially communicated production data is not viable. Indirect crosscheck via possibly ascertained sales figures is not feasible, particularly since the manufactured quantity is exported for the most part.

5. Relation to IPCC method

Activity data and emissions. IPCC GPG does not provide guidance how to treat the production of HFCs, apart from of a short remark on "default emission factor of 0.5%" in the Overview of Chapter 3.7. Only for the production of SF_6 (3.5.3.) a "default emission factor of 0.2% of the total quantity of SF_6 produced" is suggested. Even in this case, preferably "detailed data on plant-specific estimates" should be used. Following this approach, ÖR strives for estimates specific to the 134a plant in Germany.

Completeness is given, as there is only one plant in the country.

6. Entry in CRF

The CRF Table where the production of 134a and the entailed emissions (Production of Halocarbons, Fugitive Emissions) are primarily entered is Table 2(II).C.E.

7. Confidentiality issue

The data must be kept confidential. ÖR has obtained the data after entering into a commitment "to handle them with the utmost discretion and to pass them only to directly involved staff members of the German Umweltbundesamt in the framework of coordination and for data aggregation purposes".

F-Gas Sheet 25: Production of HFC-227ea

F-Gas	**HFC-227ea**
Application	**Production of HFC-227ea**
Reported Years	**1996 - 2002**
Emission Type 6	**Manufacturing Plant Emissions (Fugitive Ems.)**

Background

Since 1996, Solvay Fluor und Derivate GmbH also produces the HFC-227ea on the Frankfurt site. Strictly speaking a complete chemical synthesis does not take place there. In Frankfurt, HFC-227ea from the manufacturing plant in Tarragona (Spain) is subject to final distillation to achieve pharmaceutical purity (MDI quality). The distillation involves some fugitive HFC losses.

1. Activity data. Distillation of HFC-227ea

In 1999, according to Table 1 the distilled quantity tripled compared to previous years as a result of raised demand by the pharmaceutical industry. From 2000 onwards, the distillation has been running steadily on the new level. Almost 100% of the production is exported.

2. Emissions and emission factor, as of 1995

The operator of the facility reports production as well as emissions. By relating the latter to the distillation output, an (implied) fugitive emission factor can be calculated, and is shown in Table 1. The emission factor is almost constant, and amounts roughly the level of the emission factor in HFC-134a production.

Table 1: 1996-2002 Production and plant emissions of HFC-227ea in Germany			
Year	Production in t	Emissions in t	Impl. Emission factor
1996	confidential	confidential	confidential
1997	confidential	confidential	confidential
1998	confidential	confidential	confidential
1999	confidential	confidential	confidential
2000	confidential	confidential	confidential
2001	confidential	confidential	confidential
2002	confidential	confidential	confidential

3. Collection of data and sources of information

The operator of the facility communicates the data on production as well as on emissions to ÖR.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Solvay Fluor und Derivate GmbH, Hannover. Confidential communication to ÖR on "Production in Germany, associated emissions and export quantities for HFC and SF_6 of Solvay Fluor und Derivate GmbH (in t)", 04.03.03; 16.10.03.

4. Quality control and uncertainty assessment of data

Activity data on production are reliable, because they base on plant-internal records of Solvay Fluor und Derivate GmbH.

Emissions are obtained by means of a mass-balance. This means the difference between the plant output as expected from the feedstock and the actual distillation output as filled in containers for sale.

5. Relation to IPCC method

Activity data and emissions. IPCC GPG does not provide guidance how to treat the production of HFCs apart from of a short remark on "default emission factor of 0.5%" in the Overview of Chapter 3.7. Only for the production of SF_6 (3.5.3.) a "default emission factor of 0.2% of the total quantity of SF_6 produced" is suggested. Even in this case, preferably "detailed data on plant-specific estimates” should be used. Following this approach, ÖR strives for estimates specific to the 227ea distillation plant in Germany.

Completeness is guaranteed, as there is only one plant in the country.

6. Entry in CRF

The CRF Table where the production of HFC-227ea and the entailed fugitive emissions (Production of Halocarbons, Fugitive Emissions) are primarily entered is Table 2(II).C.E.

7. Confidentiality issue

The data must be kept confidential. ÖR obtained the data after entering into a commitment “to handle them with the utmost discretion and to pass them only to directly involved staff members of the German Umweltbundesamt in the framework of coordination and for data aggregation purposes”.

F-Gas Sheet 26: HFC-23 as By-Product

F-Gas	**HFC-23**
Application	**HCFC-22 Production**
Reported Years	**1995 - 2002**
Emission Type 7	**By-product Emission**

Background

In the synthesis of HCFC-22, HFC-23 inevitably arises as a by-product up to a level of 3%. HCFC-22 itself serves either as refrigerant (regressing) or as feedstock for the plastic PTFE (stable demand). After separation from the reaction mixture, HFC-23 can be captured to a high extent for reprocessing or for direct sale as a finished product.

Before 1995, the main mode of processing captured HFC-23 was brominating it to Halon (1301) or to low-temperature refrigerant R-13 B1. After their prohibition, the importance of marketing HFC-23 as a refrigerant or as fire extinguishant has increased. In addition, small quantities - following further distillatory purification – can be supplied as an etching gas to the semi-conductor industry. As fire extinguishing agents are patented, the only possible channel of distribution for HFC-23 captured in Germany is the international refrigerant market. The capacity of this market is limited so that every HCFC-22 plant faces surplus HFC-23 without commercial utilisation. This is the reason why even separated and captured HFC-23 is frequently released to the atmosphere.

In Germany, two HCFC-22 plants are operating, one in Frankfurt, and another in Bad Wimpfen. Since midyear 1995, the Frankfurt plant, which produces HCFC-22 only as feedstock for PTFE, is connected to the neighboured thermal decomposition plant. The HFC-23 by-product is directly conducted to high-temperature combustion resulting in some reusable components, amongst others hydrofluoric acid. Emissions of HFC-23 are negligible and are not counted further.

Since the end of brominating in 1995, the HFC-23 arising and being captured at the second HCFC-22 plant, has been released to the atmosphere as far as it could not be marketed as a refrigerant. From the end of 1999 onwards, the captured surplus is also being delivered to the Frankfurt decomposition plant. This measure has significantly reduced emissions. Even now, as ever a certain part is not yet captured, so that by-product emissions still occur. In 2002, they amounted to approx. 0.5 % of the HCFC-22 output from this plant. In 2003, again emissions were lowered significantly. Presently, the option of downstream plasma destruction (plasma torch) is under examination, in order to destroy residual emissions to the maximum extent.

Refrigerant marketing and by-product emissions of HFC-23

1. Emissions reduction in two steps since 1995

Disregarding fluctuations, since a couple of years domestic production of HCFC-22 amounts to some 30,000 t/y (rough estimate). In view of the perforce three percent of HFC-23, the emission potential figures roughly 900 t/y. Because of capturing for subsequent decomposition or for sale as refrigerant, direct emissions[3] from manufacturing are significantly reduced.

Table 1 shows for each year since 1995 the ways that the inevitably arising HFC-23 took. Only for 1995 refrigerant sales and emissions from the first plant are entered. They arose before commissioning of the decomposition unit in the course of the year 1995. (In the year before the emissions had been twice this quantity). From 1996 onwards, Table 1 contains only data on the second plant.

Table 1: 1995-2002 Breakdown of HFC-23 into refrigerant marketing and by-product emissions in Germany, in t/y

	HFC-23 as refrigerant	HFC-23 emissions
1995	confidential	confidential
1996	confidential	confidential
1997	confidential	confidential
1998	confidential	confidential
1999	confidential	confidential
2000	confidential	confidential
2001	confidential	confidential
2002	confidential	confidential

Sources: see section 2.

Comment

Over the period from 1995 to 2002, by-product emissions (Table 1, to the right) could be reduced. A significant reduction took place in 1996, when the decomposition unit received HFC-23 from the first plant. The next major step was at the end of 1999, when the second plant also started supplying its surplus HFCs to the Frankfurt decomposition plant. The remaining emissions apparently result from incomplete capture of HFC-23.

Over the same period, marketing of HFC-23 as a refrigerant (since 1996 only from the second plant) has almost quadrupled. Since 1996, the sum of refrigerant and emissions has likewise clearly increased. In the absence of production figures of HCFC-22, it is unknown whether these rises are due to increased production of HCFC-22 or to deliberately changed influence on the chemical reaction.

2. Collection of data and sources of information

For the reporting years 1995-2002, the operator of the second plant estimated emissions above all by means of one annual measurement of the HFC-23 concentration in the plant’s waste gas flow. Aware of the manufactured quantity of HCFC-22 and of

[3] Of course, the refrigerant HFC-23 can emit upon its own application for refrigerating purposes, but here are only meant direct emissions from the manufacturing plant.

the HFC-quantities either sold as refrigerant or supplied to the decomposition unit (as from the end of 1999), he was enabled to calculate emissions by mass balancing. This means, emissions emerge as difference between sold and decomposed quantities on the one hand, and the output of HFC-23 that is expected based on the annually measured concentration in the waste gas, on the other hand.

Concerning 1995 data on the first production plant, ÖR obtained information from the then operator (Hoechst AG), in 1996.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Hoechst AG, Fachgespräch mit ÖR im Frankfurter Stammwerk am 25.3.96.
Solvay Fluor und Derivate GmbH, Fachgespräch Hannover 23.04.96.
Solvay Fluor und Derivate GmbH, Confidential communication to ÖR on "Production in Germany, associated emissions and export quantities for HFC and SF_6 of Solvay Fluor und Derivate GmbH (in t)", 04.03.03; 16.10.03.

3. Quality control and uncertainty assessment of data

Emission calculation via mass balance is deemed sufficiently accurate. The sufficiently high level of accuracy results from actual measurements of waste gas concentration. In addition, like any company-internal documentation the data on marketed refrigerant and on deliveries to the decomposition plant are sufficiently reliable.

4. Relation to IPCC method

According to "3.8 Estimation of HFC-23 Emissions from HCFC-22 Manufacture" in IPCC GPG, the applied approach is a Tier 2 method, because it bases on measurements of the concentration and the mass flow at individual plants. Over the first half-year 1995, this did not apply to emissions from the first plant.

ÖR follows the statement in Box 5 of the Decision Tree (Figure 3.19), "Estimate emissions by aggregating plant-level measurements, and estimates for plants without measurements, adjusting for HFC-23 destruction."

The default emission factor of 4% "tonnes of HFC-23 produced per tonne of HCFC-22 manufactured" (IPCC Guidelines) is not required as the emissions are estimated in a country-specific (CS) manner. An emission factor in the sense of a relation between HFC emissions and HCFC production is not created, as precise data on manufactured HCFC-22 quantities are not available.

Incidentally, it is an open question whether the emissions arising from one plant should be related to the production of both plants or only to the production of that plant which releases HFC-23. The first factor would reflect national efforts in emission reduction; the other would reflect company-specific efforts for this target.

5. Entry in CRF

The CRF Table where data on "By-product Emissions" of "HFC-23" are primarily entered is Table 2(II).C.E.

In addition, in row 16, column C, national production of HCFC-22 (both plants) is entered, which, however, is an own estimation made by ÖR.

The HFC quantity that is captured and marketed as refrigerant is entered in Table 2(II).C.E. Fugitive emissions do not arise, as the "produced" HFC itself is part of (captured) emissions.

6. Confidentiality issue

The data must be kept confidential. ÖR has obtained the data after entering into a commitment "to handle them with the utmost discretion and to pass them only to directly involved staff members of the German Umweltbundesamt in the framework of coordination and for data aggregation purposes".

F-Gas Sheet 27: Production of SF_6

F-Gas	Sulphur Hexafluoride (SF_6)
Application	**Production of SF_6**
Reported Years	**1995 - 2002**
Emission Type 6	**Manufacturing Plant Emissions (Fugitive Ems.)**

Background

The only German manufacturing plant for sulphur hexafluoride is operated in Bad Wimpfen by Solvay Fluor und Derivate GmbH. In the EU, there is only one further manufacturing plant (in Italy), which was operated by Ausimont. This plant, meanwhile, is likewise operated by Solvay Fluor und Derivate.

1. Activity data. 1995-2002 Production of SF_6

Despite of declining domestic demand for SF_6 for use in open and half-open applications the production has been continuously increasing since 1995 (Table 1). The rise results exclusively from the growth in export. Domestic SF_6 sales mainly reach closed applications such as switchgear equipment.

2. Emissions and emission factor, since 1995

The operator of the facility regularly reports on emissions. By relating these to the plant's output, an (implied) fugitive emission factor can be calculated, and is shown in Table 1.

Table 1: 1995-2002 Production and plant emissions of SF_6 in Germany			
	Production in t	Emissions in t	Impl. Emission factor
1995	confidential	confidential	confidential
1996	confidential	confidential	confidential
1997	confidential	confidential	confidential
1998	confidential	confidential	confidential
1999	confidential	confidential	confidential
2000	confidential	confidential	confidential
2001	confidential	confidential	confidential
2002	confidential	confidential	confidential

3. Collection of data and sources of information

The operator of the facility communicates the data on production as well as on emissions to ÖR.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Solvay Fluor und Derivate GmbH, Fachgespräch Hannover 23.04.96.

Solvay Fluor und Derivate GmbH, Hannover. Confidential communication to ÖR on "Production in Germany, associated emissions and export quantities for HFC and SF_6 of Solvay Fluor und Derivate GmbH (in t)", 04.03.03; 16.10.03.
Generell zu SF_6: Solvay Fluor und Derivate GmbH (Hg.), Schwefelhexafluorid, 46-seitige Broschüre, Auflage Hannover 01.92; Neuauflage (50 Seiten) 12.99.

4. Quality control and uncertainty assessment of data

The activity data on production are highly reliable, because they base on plant-internal records of Solvay Fluor und Derivate GmbH.

The emissions are obtained by means of a mass-balance. This means the difference between the plant output as expected from the feedstock provided and the actual plant output as it is filled in tanks for sale, and weighed.

5. Relation to IPCC method

Activity data and emissions. IPCC GPG proposes under "3.5.3. Production of SF_6" to survey plant-specific data as far such data is available. ÖR follows this approach.

It is, therefore, not necessary to use for emissions estimation the "default emission factor of 0.2%". This value in IPCC traces back to estimates from Solvay Fluor und Derivate (Mr Preisegger) in 1999. Meanwhile (2003) this company has carried out new estimations for the Umweltbundesamt resulting in the given fugitive emission factor.

Completeness is guaranteed, as only one domestic production plant exists.

6. Entry in CRF

The CRF Table where data on fugitive losses of SF_6 (Production of Halocarbons, Fugitive Emissions) are primarily entered is Table 2(II).C.E.

7. Confidentiality issue

The data must be kept confidential. ÖR has obtained the data after entering into a commitment “to handle them with the utmost discretion and to pass them only to directly involved staff members of the German Umweltbundesamt in the framework of coordination and for data aggregation purposes”.

F-Gas Sheet 28: Equipment for Transmission and Distribution of Electricity

F-Gas	**SF_6**
Application	**Equipment for Transmission and Distribution of Electricity**
Reported Years	**1995 – 2002**
Emission Type 1	**Manufacturing Emissions**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 5	**Disposal Emissions**

Background

Electrical Equipment for electric power supply is by far the largest individual SF_6 consumption sector in Germany, with more than 400 t per annum. Due to the high export quota of over 80%, only a relatively small part of the gas consumption is supplied in new systems to the domestic SF_6 bank.

SF_6 is used above all in high-voltage (110-380 kV, HV) and medium-voltage (10-30 kV, MV) switchgear and control-gear. Here the gas functions both as an arc quenching and as insulating medium instead of air or mineral oil. It is not commonly used in the low-voltage (< 1 kV) range.

Switchgear, control-gear, and the instrument transformers and bushings usually associated with them are located at the nodal points of electric supply networks, where energy is distributed from higher-level transmission lines to outgoing lines. In addition to switching operating current in sub-networks, switchgear needs to be capable of switching off within milliseconds the high short-circuit currents that result from faults and malfunctions in the circuit and quenching the high-ampere arcs that result at the switch contacts.

The most important high-voltage end-product groups containing SF_6 are metal-enclosed gas-insulated switchgear (GIS), outdoor circuit breakers, and outdoor instrument transformers. They are in use since about 1970. In medium-voltage switchgear, SF_6 insulation was taken up later, in 1980. New Medium-voltage systems are designed to run the whole lifetime without maintenance.

I. Domestic SF_6 consumption and manufacturing emissions

1. SF_6 consumption for manufacturing, since 1995

Since 1997, annual consumption (C_{manu}) has been estimated by the German Manufacturers association ZVEI and is reported under three categories:

1. High voltage: Gas insulated stations (HV GIS).
2. High voltage: Circuit breakers (outdoor version).
3. Medium voltage: Switchgear (MV switchgear).

From 2004 onwards, in the course of a new self-commitment, additionally the SF_6 quantity will be reported which is consumed for components that are either fitted to switchgear (instrument transformers, bushings) or directly delivered to operators (HV outdoor instrument transformers). These are not yet included in Table 1, which shows domestic consumption by up to now reported product groups for 1995-2002 and 1997-2002, respectively.

Table 1: 1995-2002 Domestic SF_6 consumption for manufacturing switchgear and circuit breakers, in kg/y

	HV GIS	HV circuit breakers	MV switchgear	Total
1995				328,520*
1996				345,000**
1997	172,455	65,845	110,131	348,431
1998	169,000	67,810	108,268	345,078
1999	265,668	65,465	95,099	417,232
2000	255,917	58,705	89,950	404,572
2001	155,215	89,730	110,876	355,821
2002	194,874	95,803	121,391	412,068

Sources: ZVEI as of 1997. * The 1995 value was retrospectively estimated by ZVEI in 2004. **The 1996 value was estimated by ÖR in 1999.

Comment

Domestic consumption decreased three times (1998, 2000, and 2001) against previous years. However, through the 1995-2002 period it shows a clear up-trend from 328 to 412 t/y. Each sector takes part in the general up-trend that gets just cyclically broken.

Supplementary remark on components in 1995-2002

The 1997 self-commitment of manufacturers and operators solely includes switchgear and circuit breakers but excludes components for switchgear. Based on own researches carried out in 1996 and 1999, ÖR estimated SF_6 consumption of component manufacturers at additional 61 t/y.

Meanwhile (2004), ZVEI has provided own data on SF_6 consumption 1995-2002 by component manufacturers, as follows: 51 t (95), 51 t (96), 51 t (97), 50 t (98), 50 t (99), 45 t (2000), 55 t (2001), 54 t (2002).

2. SF_6 emissions from manufacturing, as of 1995

Emissions of manufacturers (Em_{manu}) in the factory and on erection sites of domestic operators are separately surveyed (state 2003):

1. Domestic factory losses, mainly arising in development departments and on filling for routine tests (approx. 95% of manufacturing emissions), are distinguished by HV GIS, HV circuit breakers, MV switchgear, and HV/MV components.

2. Domestic site assembly emissions (approx. 5%) arise on commissioning HV GIS, HV circuit breakers, MV switchgear, and HV outdoor instrument transformers. As to components, as far as they are parts of HV GIS (bushings, voltage instrument transformers), all assembly losses are included in HV GIS erection emissions. (As mentioned above, this is otherwise for components' factory emissions; they are not included in GIS factory emissions).

Until 2002 (inclusively), domestic factory and assembly losses have been reported only for HV GIS, HV circuit breakers, and MV switchgear, i.e. for end-products that are directly handed over to domestic or foreign operators. Emissions arising on factory manufacture of components have not been reported, as far as these components (instrument transformers and bushing for HV GIS, MV instrument transformers for switchgear) were purchased by switchgear manufacturers to fit them to their products. The same applies to emissions from manufacturing outdoor instrument transformers. Consequently, factory emissions from components are not included in Table 2.

Table 2 reproduces emissions from manufacturing HV and MV switchgear, which arise both inside the factory (development, routine test) and on domestic sites of erection, as far as they were reported according to the self-commitment from 1997.

Table 2: 1995-2002 Emissions from manufacture of switchgear in the factory and on domestic sites of erection, in kg/y

	HV GIS		HV circuit breakers		MV switchgear		Total
	Factory	On site	Factory	On site	Factory	On site*	
1995							20,048**
1996							18,570***
1997	6,543	1,120	4,300	170	2,622	503	15,258
1998	9,329	603	4,310	190	1,553	570	16,555
1999	3,834	134	5,120	120	1,520	66	10,794
2000	4,798	50	3,014	84	1,464	65	9,475
2001	3,554	3	1,938	54	1,671	88	7,308
2002	3,947	20	2,011	33	1,901	90	8,002

Sources: ZVEI ex 1997. * On first installation of MV equipment loss does not arise. This column shows emissions arising in the course of modifications (mostly extensions) of existing equipment. ** The 1995 value was estimated by ZVEI retrospectively in 2004. *** The 1996 value was estimated by ÖR in 1999.

Comment

Since 1995, emissions from manufacture (Em_{manu}) of switchgear equipment have significantly dropped from 20.0 to 8.0 t/y (right column). The implied emission factor (Em_{manu} related to C_{manu}) has decreased from 6.1% in 1995 to 1.9% in 2002. This is above all a result of significantly reduced factory losses from HV GIS. These losses have dropped between 1998 and 2002 from 9.3 tonnes to 3.9 tonnes, and this is caused by more careful SF_6 handling in the factories, according to manufacturers. Domestic assembly losses ("on site") have been cut for all products, and the sharpest fall can again be assessed for HV GIS (from 1,120 kg down to just 20 kg).

Supplementary statement on components, 1995 to 2002

For the time before 2003, the ZVEI has not given estimates of emissions from manufacturing components. Alternatively, for the 1995-2001 period ÖR applied a constant emission factor to the estimated annual consumption of 61 t (see section 1). This is why in CRF additional SF_6 emissions of 2.6 tonnes were entered per year.

Since 2004, the results of an internal ZVEI survey on SF_6 consumption and emission at component-manufacturers have been available. It emerges that manufacturing loss had been severely under-estimated, because two manufacturers have been using SF_6 in quasi-open applications for foaming and impregnation. Estimated manufacturing emissions are as follows: 16 t (95), 16 t (96), 16 t (97), 14 t (98), 14 t (99), 13.2 t (2000), 14.5 t (2001), 14.4 t (2002).

3. Estimation and sources of information on activity data and emissions I

Within the scope of a self-commitment from 1997, the manufacturer association ZVEI (Section Switchgear, Control gear, Industrial Control Equipment) annually reports for the previous year the data inquired of the member companies about domestic SF_6 consumption and the emissions arising in the course of the consumption. Non-member companies are considered by means of projection.

From 2004 onwards, in the framework of a new self-commitment the manufacturers of components (instrument transformers, bushings) shall be included into the monitoring and reporting system, whether or not they are members of the association.

Sources of Information

Since 1998, data are regularly surveyed and evaluated by the ZVEI (Electrical and Electronic Manufacturer's Association) before handing them over to the Umweltbundesamt. At the ZVEI, in charge of the data survey is Mr Johannes Stein, speaker of the Section Switchgear, Control gear, Industrial Control Equipment, Stresemannallee 19, 60596 Frankfurt am Main.

4. Quality control and uncertainty assessment of data I

There are only roughly ten domestic manufacturers of equipment (incl. of components like bushings and instrument transformers). Thus, the SF_6 consumption data is reliable, particularly since it is purchase figures, of which is internally kept account. As to emissions, their determination is not so easy because in factories there are mostly several emissions sources each of which is rather small. Gas losses arise on filling equipment for tests, on emptying after tests, on opening of defective goods, in the development department, etc. Meanwhile all domestic manufacturing plants use the same questionnaire in which all kinds of emissions can be entered. Therefore, the accuracy of the survey ultimately relies on measuring accuracy. (The latter is in the region of ±10% of individual data surveyed).

5. Relation to IPCC method I

In terms of the IPCC Good Practice Guidance document (GPG), the present monitoring system is essentially based on the highest Tier 3 (3.b). It, however, also contains elements of Tier 2a (emission factor approach), so that it should be referred to as a modified Tier 3b system. The Tier 3 mass-balance approach has proven to be not feasible to meet handling emissions amounting to just 0.5 or 1.5%, which are typical magnitudes in the sector. Small gas losses cannot be determined by mass balancing, because even in simple measuring (scales, flow meters, gas-bottles, and gas compartments) statistical margins of error exceed the amounts of emissions themselves. Therefore, the present monitoring system is being updated in order to achieve the highest possible degree of accuracy by proper combination of mass-balance approach and emission-factor approach.

The German manufacturers intend to present their updated monitoring systems to the IPCC to be checked if generally applicable to industrialised countries.

6. Entry in CRF I

The CRF Table where the data on SF_6 "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered is Table 2(II).Fs2, row 32, columns B and H.

In 2004, it is planned to conduct a recalculation of all to date reported years as of 1995. Disaggregating by High and Medium Voltage is not required by CRF.

II. Domestic SF_6 input and emissions from bank

The SF_6 end-of-year bank in the entirety of domestic electric equipment in a particular year n (EB n) is annually changed by the balance of input (In_{bank} n) and output (De_{bank} n). Sporadic departures (High Voltage) have been registered since 1997. In the face of assumed 40-year-lifetime, systematic retirement of complete annual cohorts is not anticipated to happen before 2010.

Operating bank emissions (Em_{op}) refer to the SF_6 bank that has been cumulated by annual inputs to switchgear equipment from 1970 onwards, strictly speaking, they refer to the average bank in year n. This average bank (B n) is half the sum of the previous end-of-year bank (EB n-1) and the current end-of-year-bank (EB n).

$$B\,n = \frac{EB\,n\text{-}1 + EB\,n}{2} \quad \text{Where:} \quad EB\,n = EB\,n\text{-}1 + In_{bank}\,n - De_{bank}\,n$$

Three particularities should be borne in mind when reporting on switchgear.

1. General condition for ascertaining the size of a bank is that for the end-of-year bank in any year n the end-of-year bank or input of the previous year n-1 is known. From that follows a regress back to the first year of SF_6 use. This procedure ceases to apply to switchgear because operators/manufacturers have estimated the SF_6 bank for 1995, namely separately for HV and MV (770 t and 157.6 t, respectively).

2. In HV equipment, bank and bank emissions are not estimated by means of the above equation but by means of regular direct surveys of the approx. 100 domestic operators who are members of the Association of German network operators (VDN). These are inquired about the current SF_6 stock in operating equipment (HV GIS, outdoor circuit breakers and instrument transformers) as well as about annual top-ups to compensate for operation losses. It must be noted that industrial grid operators are not included in the survey. Their share in the national SF_6 bank in HV equipment is estimated at additional 5%.

3. MV switchgear is run by numerous and at the same time very heterogeneous operators. Direct surveys are practically not feasible. The manufacturers of MV switchgear have committed themselves to update the domestic bank by means of their own sales data, annually. Emissions estimation is possible because MV equipment is virtually maintenance-free and exhibits only minimal emissions (if any then due to external impacts), which are covered by a fixed all-in operating emission factor.

7. SF_6 bank and emission in High Voltage

In High Voltage (VDN members), bank and bank emissions are surveyed simultaneously. That is why it suggests itself to present both time series in one Table. Although bank and operating emissions from HV GIS, HV circuit breakers and HV instrument transformers are estimated separately, they are aggregated in Table 3, for simplicity. In addition, the Table lists the implied emission factors resulting from relating emissions to banks.

In contrast to manufacturing (Part I), the HV bank includes all kinds of equipment incl. components. However, equipment of industrial operators is not included.

Table 3: 1995-2002 Bank, operating emissions and implied emission factors in HV transmission and distribution equipment (only VDN members)			
	HV Bank in t	Emissions in t	Impl. emission factor
1995	769.881	6.733	0.87%
1996	*788.440*	*6.938*	*0.88%*
1997	807.000	7.101	0.88%
1998	851.776	7.428	0.87%
1999	881.384	7.830	0.89%
2000	855.307	6.980	0.82%
2001	880.528	7.219	0.82%
2002	905.337	7.424	0.82%

Sources: VDN 2004 for 1995, 1997-2002. The 1996 values (italics) are interpolated by ÖR.

Comment on time series

Bank and thus emissions from bank show a basic up-trend, since 1995. In 2000, however, an abnormal development took place, namely a decline both in bank (by 25 t against the year before) and in emissions (by 0.85 t). The decline that traces back to HV GIS (600 t to 567 t) cannot be explained by decommissioning of equipment, still being of little importance. According to the Association of German network operators (VDN) being in charge of annual operators' surveys, there is both a statistical and an organisational problem behind it. At the end of the 1990s, dramatic restructuring took place at the operators in the course of liberalisation of the electricity market, as there were mergers and changes of ownership of entire business-sections. That is why the personal responsibilities for the equipment in question were changing repeatedly. Therefore, neither multiple counting for 1999, nor omitted reporting of equipment in 2000 can be excluded.

8. SF_6 bank and emissions in Medium Voltage

SF_6 bank in MV switchgear is determined by means of sales of equipment manufacturers to the domestic market. To date, systematic decommissioning of installed equipment does not yet occur, but only sporadic replacement of externally damaged plants. Thus, average SF_6 bank in current year n (B n) is an outcome of current year's SF_6 input (In_{bank} n) to the average bank of the previous year (B n-1). The average bank was definitely estimated at 157.6 tonnes, by 1995. Table 4 shows the development of (average) bank and of emissions from this bank.

Table 4: 1995-2002 SF_6 average bank (previous year), input, average bank (current year), emission factor, and operating emissions from MV equipment					
	B n-1 (t)	In_{bank} n (t)	B n (t)	EF_{op}	Em_{op} (kg)
1995			157.600	0.15 %	236
1996	157.600	24.354	181.954	0.14 %	255
1997	181.954	42.046	224.000	0.13 %	291
1998	224.000	46.754	266.046	0.10 %	266
1999	266.046	37.205	312.800	0.10 %	313
2000	312.800	35.641	350.005	0.10 %	350
2001	350.005	45.626	385.646	0.10 %	386
2002	385.646	51.077	431.272	0.10 %	431

Source: ZVEI 2004.

Comment on time series

In contrast to High Voltage, Medium Voltage sector still exhibits strong growth. The bank [col. B n (t)] has increased over the 1995-2002 period from 157.6 to 431.2 t, i.e. by 173%. Since 1998, a constant emission factor (EF_{op}) of 0.1% is applied because as of the middle of the 1990s virtually only such equipment joins the domestic inventory that is deemed not only "closed for life" but also "sealed for life". Older equipment with leakage levels in excess of 0.1%/y thus becomes less important. Therefore, emissions (Em_{op}) rose only by 82% over the same period, on a throughout low basic level. The very small gas losses are partly because MV equipment is only slightly pressurised with just 1.3 to 1.5 bar abs., in contrast to HV equipment that constantly runs under pressure of 5 to 7 bar.

9. Preliminary data supplementation in High Voltage

In High Voltage (Table 3) data on equipment is considered as far as it is operated by members of the Association of German network operators (VDN). In addition, there is HV-equipment installed at energy-intensive industrial plants, data on which are not included in VDN data. The industrial operators, represented by the Federation of Industrial Consumers and Self producers (VIK), are ready to conduct surveys of their present and past SF_6 bank (incl. top-ups) as soon as the new Voluntary Agreement enters in force. This is to be expected by 2005 at the earliest.

As long as this is not the case, industrial operators are taken account of through an additional all-inclusive share of 5%, with respect to bank and operating emissions in High Voltage. This is why ÖR does not directly use the figures listed in Table 3, for international reporting (CRF) or national estimation. For these purposes, ÖR increases the VDN data by 5% to get a complete picture.

10. Collection and sources of information of activity data and emissions II

In MV switchgear, the SF_6 bank is annually estimated via updating from manufacturers on their sales to the domestic market. Operating emissions estimation is based on a constant factor that is assumed to be in the order of 0.1% (from 1998 onwards). This factor is supposed to allow for any gas losses over the use phase, notably resulting from mechanical destruction and lightning strike. The ZVEI is in charge of data collection (see section 3).

In High Voltage, the Association of German network operators (VDN) are in charge of data collection on banks and bank emissions from operating High Voltage equipment. To date, this association has conducted three major surveys, namely for the year 1995, for the years 1998/1999, and recently for the years 2000/2001. The year 1997 was estimated retrospectively, the data on 2002 are extrapolated based on the surveyed years 2000/2001.

The survey for the years 2000 and 2001 was a total survey. It addressed all approx. 100 enterprises that operate networks of 110 kV and more. The feedback amounted to 100%, according to VDN.

The survey for 1998/1999 had not yet focused exclusively on High Voltage. It addressed the 130 "most important" enterprises, 75 of which were operating HV equipment in addition to MV equipment. According to VDN, the feedback was in excess of 90%. The reported data were projected to 100%.

The survey for 1995 addressed 95 electric utilities, which then operated between 75% (in Medium Voltage) and 100% (in High Voltage) of the networks. Answers from 67 enterprises were evaluated and projected to the totality.

Sources of Information

The High Voltage operator surveys are carried out by the VDN.

11. Quality control and uncertainty assessment of data II

Activity data. In Medium Voltage, the data is highly reliable like any data based on sales figures. Each manufacturer keeps records of the annual number of his sales to the domestic market, including not only the number of units sold, but also the respective nameplate capacities (proper full SF_6 charges).

In High Voltage, firstly the abovementioned share of industrial operators must be pointed as a source of uncertainty, as this figure is only roughly estimated, to date. Of greater importance are, however, potential sources of error, which are associated with the estimation approach of directly surveying. In the comment on time series on High Voltage (section 7), we already referred to the frequently changing personal responsibilities on operators side over the past years. Furthermore, up to 2002, total surveys had been implemented only for two out of eight reporting years. For the other years, projections from partial surveys were made, with the samples always being large. From a statistical perspective, every projection shows insufficiencies to a grater or lesser degree. However, due to the fact that always leading experts of the operators association were entrusted with the surveys (partial and total ones), the errors regarding sample representativeness, etc., could be well kept within bounds owing to the plausibility checks these experts were conducting whenever doubts arose. Thus, bank data is to be expected to deviate by less than ± 10% from the effective values.

Emission factors. The Medium Voltage emission factor of 0.1% can be rated acceptable for the banks over the recent years. To date, the VDN surveys have included the question on top-ups of MV switchgear run by VDN members, so that crosschecks are possible. The VDN records revealed for MV switchgear (switchgear with switch disconnectors) SF_6 losses of only 0.06% for the years 1998/1999.

Emissions in High Voltage are determined via annual refills carried out by operator's staff or by the manufacturer. (Topping-up occurs when the charge falls below 90% of the norm capacity, which is indicated by the equipment itself). This approach of emissions estimation via recorded refills is deemed very safe, which is to say deviations from the effective value vary somewhat ± 10%. All surveys carried out to date resulted in emission factors very near to each other, ranging from 0.82% to 0.88%.

12. Relation to IPCC method II

In High Voltage, emissions estimation by operators themselves conforms to the Tier 3a/3b approach envisaging mass balancing on the "utility-level". Emissions estimation by means of refilled gas quantities, as it is exercised by the VDN, meets the Tier 3a/3b requirements. The 2004 VDN questionnaire will be even better suited in this respect.

In Medium Voltage, estimation of banks and operating emissions via sales data of manufacturers matches the Tier 2a approach, "Equipment use emissions are estimated by multiplying the total nameplate capacity of installed equipment by a 'Use Emission Factor'".

The approach used in Germany exceeds the requirements stated in IPCC GPG insofar as it distinguishes the equipment by the two voltage levels and additionally disaggregates equipment by the major types.

13. Entry in CRF II

The CRF Table where data on "Amount of fluid in operating systems" and "Emissions from stocks" are primarily entered is Table 2(II).Fs2, row 32, columns C and I.

CRF does not call for a distinction into HV and MV equipment.

III. SF_6 disposal and disposal emissions

14. The quality of disposal data

Despite of the long lifetime of switchgear, in High Voltage sporadic cases of decommissioning already take place now. Then, used SF_6 is removed from old equipment. Because of internal SF_6 recycling, decommissioning of old equipment does not result in corresponding disposal of used gas at all times. Rather, operators frequently use SF_6 from old equipment to top up emission losses from other active equipment. On balance, neither such a refilling of operating equipment nor such a decommissioning of old equipment leads to changes in the operator's SF_6 stocks, so that both events often remain undetected. This refers to the necessity of surveying the gas handling activities on the utility-level even more precisely.

Before 2004, the VDN operators' survey had not even put the question about SF_6 disposal. The update version of the questionnaire contains this question. For the past years, there are only rough estimates available about the SF_6 quantities from HV equipment due for disposal. These estimates amount to constant three t/y.

Yet, the manufacturer questionnaire has also been imprecise in respect to disposal. In the annual survey, the addressed companies reported under "disposal" any SF_6 gas quantities that they had filled into special (orange-coloured) disposal containers and returned to the gas producer ("ReUse"). At the beginning of 2004, a review revealed that these containers included much more SF_6 from the manufacturing plant (contaminated and according to manufacturers specifications no longer suitable for direct re-using in the factory) than quantities brought back from customers' installations to be disposed of. Waste from production, however, cannot be subsumed under disposal, and the associated gas losses should have already been taken account of in manufacturing emissions.

First from 2004 onwards, quantities due for disposal will be clearly defined as quantities of used gas after extraction from retired equipment. The hitherto monitoring system overstated the quantities for disposal on the one hand (by including manufacture-caused waste), and it understated disposal quantities on the other hand (by ignoring gas from retired equipment that operators refill into active equipment). Retrospectively, it is impossible to correct to date reported indications on disposal quantities. Optimistically assuming that over and underestimations cancel out each other to a certain degree, the previous data (1995-2002) will be used unaltered for that period.

15. Disposal and emissions on disposal

Table 5 lists the above-mentioned uncorrected data as reported by the ZVEI, to date. On purpose, they are not disaggregated into voltage levels and equipment types because of high data uncertainty.

At the same time, the Table reproduces the emissions arising on disposal (Em_{disp}). They were estimated with an all-inclusive emission factor (EF_{disp}) of 2%.

It should be noted that data were appraised for the first time by 1997. In principle, reported quantities due for disposal consist of fixed 3,000 kg/y for direct disposal through operators, whereas the remainder represents both spent gas from old operators' equipment to be disposed of by manufacturers and certain gas quantities from manufacturing plants no longer matching the manufacturer specifications for factory internal use.

Table 5: 1995-2002 Disposal of SF_6 and disposal emissions from electric switchgear equipment

	Disposal in kg	Emission factor (EF_{disp})	Emissions (Em_{disp}) in kg
1995	n. e.		n. e.
1996	n. e.		n. e.
1997	8,288	2 %	166
1998	6,643	2 %	133
1999	4,072	2 %	81
2000	5,363	2 %	107
2001	4,272	2 %	85
2002	3,538	2 %	71

Sources: VDN ZVEI 2003. There are no estimates available for 1995 and 1996.

From Table 5 emerges that the quantities for disposal are low, up to now. However, the declining quantities visible in the first column are certainly no expression of reality but rather due to the low data quality prior to 2003.

16. Collection and sources of information of activity data, and emissions III

Disposal and emission quantities as per Table 5 were communicated by ZVEI. The emission factor of 2% for handling losses (related to nameplate capacities) arising on decommissioning of old equipment is accepted amongst both manufacturers and operators.

17. Quality control and uncertainty assessment of data III

The quality of the activity data and thus the emission data is low. In section 14 the hitherto insufficiencies of the surveys were discussed. The emission factor of 2% of the norm charge is a generally accepted value for handling losses arising during gas extraction from old equipment on site as well as arising on the way to the feeding-in of the spent gas to the "ReUse" process at the SF_6 producer. Plausibility check: When a gas compartment is sucked off from working pressure of 5 bar down to usual 50 mbar low pressure, then, on opening, residual gas emissions arise of 1% (50 mbar/5000 mbar). This on-site process alone accounts already for half the level of the disposal emission factor.

18. Relation to IPCC method III

The procedure of emission estimations follows the Tier 2a approach as outlined in IPCC GPG: "Equipment disposal emissions are estimated by multiplying the nameplate capacity of retiring equipment by the assumed fraction of SF_6 left in equipment at the end of its life. If SF_6 is being recovered, good practice is to adjust the resulting estimate to reflect recovery, by multiplying by (1 – recovery factor). The default factor is zero."

The jointly used monitoring system of manufacturers and operators of switchgear applies a country-specific recovery factor in the order of 98%. This is possible because in Germany the so-called ReUse concept provides appropriate infrastructure for reprocessing spent SF_6.

19. Entry in CRF III

The CRF Table where data on "Amount of fluid remained in products at decommissioning" and "Emissions from disposal" are primarily entered is Table 2(II).Fs2, row 32, columns D and H.

From 2004 onwards, the quantities for disposal shall be estimated for the first time with a reliable degree of accuracy. Recalculation of to date reported years is not intended because such a recalculation is unlikely to be feasible.

F-Gas-Sheet 29: Soundproof Glazing

F-Gas	**SF_6**
Application	**Soundproof Glazing**
Reported Years	**1995 – 2002**
Emission Type 1	**Manufacturing Emissions**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 5	**Disposal Emissions**

Background

In the 1970s, single glazing in windows and glass facades was superseded by double-glazing, into which SF_6 has been filled since 1975 in order to improve the sound-insulating effect in the pane interspace. Compared to glazing filled with air, SF_6 enhances the sound insulating value by additional 2 decibel (dB) in the relevant range to building acoustics of 35-50 dB. Five dB is perceived by people as a halving of noise.

In 1990, six percent of the annually manufactured and installed 26 million-m^2 glazing was sound proof containing SF_6. The boom in building activity caused by the German unification made the double-glazing rise until 1995/97, when 2.5 million m^2 soundproof glazing with SF_6 (which had not been available in the GDR) were installed annually. By 2002, after the end of the boom, the annual production and installation of soundproof glazing has become stabilized with a possible normal figure of 1.9 million m^2.

Since the end of the 1990s, in soundproof glazing a shift in the sound insulating technology has taken place. Instead of SF_6 filled panes, more and more changed glazing structures came onto the market, achieving the same effect without SF_6, and using the interspace entirely for the thermal insulating gas argon.

In Germany, almost 400 enterprises manufacture soundproof glazing and if necessary fill SF_6.

Foreign trade with ready glazing is negligible.

I. Domestic SF_6 consumption and manufacturing emissions

1. Activity data. SF_6 consumption for glazing since 1995

Filling emissions (Em_{manu}) develop in direct proportion to domestic consumption of SF_6 for glazing (C_{manu}); hence, first the consumption quantity as of 1995 is presented.

Table 1: 1995-2002 SF_6 consumption for filling of soundproof glazing, in t/y	
1995	275
1996	204
1997	169
1998	111
1999	96
2000	86
2001	75
2002	42

Sources: Survey of German gas vendors.

Comment on the dropping SF_6 consumption as of 1995

Although the importance of soundproof glazing is maintained, the SF_6 consumption for soundproof glazing has constantly decreased by almost 85% since 1995.

The first reason for this development is the rising requirements of thermal insulation favouring filling with argon, given unchanged glazing design. The average proportion of SF_6 to argon in soundproof windows amounted to 80% in 1995. However, this proportion decreased to 30% by 2000. It may be assumed that this gas composition of 30% SF_6/70% argon will have established itself as a middle-term compromise between acoustic and thermal insulation.

The second reason for the SF_6 drop is the increase in importance of SF_6 free soundproof glazing design. As SF_6 reduces thermal insulation compared to air and argon, more and more soundproof glazing is used which achieves equivalent sound reduction by changed glazing structure (increased interspace, different glass thicknesses, use of laminated panes with cast resin or plastic film as inner layers.)

2. Constant filling emission factor of 33%

Of the annual SF_6 consumption for soundproof windows, roughly 33% arise as filling emissions (overfilling) in the year of fabrication on filling the interspace. Filling losses occur exclusively in the year of fabrication and are directly proportional to annual SF_6 consumption. The emission factor (EF_{manu}), therefore, is 33% (of C_{manu}).

Both in hand-held equipment and in automatic gas filling presses, turbulence in the interior is unavoidable, so that not only residual air but also an air-SF_6 mixture escapes, and all the more the further the filling process progresses. The resultant gas loss, the overfilling, ranges from 30 to 60% of the fill. In relative terms, it is the higher, the smaller the pane surface area is. On average the overfilling amounts to 50% of the effectively filled quantity. This is 33%, related to the quantity applied.

3. Filling emissions since 1995

Filling emissions (Em_{manu}) amount to 33% of annual SF_6 consumption as shown in Table 1. The equation for the calculation is:

$$Em_{manu}\, n = EF_{manu}\,(33\%) \times C_{manu}\, n$$

$Em_{manu}\, n$ are filling (manufacturing) emissions in year n. EF_{manu} is the emission factor for filling. $C_{manu}\, n$ is the domestic consumption for filling soundproof glazing in year n. From that results the time series as from 1995 shown hereafter (in tonnes, rounded). In addition, Table 2 repeats domestic SF_6 consumption from 1995 onwards (in italics).

Table 2: 1995-2002 Filling emissions and domestic consumption of SF_6 for sound proof glazing (emission factor 33%)

	Filling emissions t/y	*Domestic SF_6 consumption*
1995	92	*275*
1996	68	*204*
1997	56	*169*
1998	37	*111*
1999	32	*96*
2000	29	*86*
2001	25	*75*
2002	14	*42*

Sources: Domestic consumption from Table 1. Filling emissions: 33% of domestic consumption.

Comment

Decreasing emissions are a result of decreasing consumption quantities to which the former develop proportionally. Different to bank or disposal emissions, abandonment of filling would end this sort of emissions instantly.

4. Sources of Information I (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

ÖR has surveyed leading producers of sound-insulating glass and of glass filling equipment as well as experts from the German institute for window technology. They provided the technical and economic basic information. The domestic SF_6 consumption figures for soundproof glazing were provided by specialised gas vendors. They were asked to compile and to report their domestic sales to the customer group of glazing producers.

4.A Technical and economic basics

1. Technical literature and science

Derner, P., Schalldämm-Isolierglas, in: Funktions-Isoliergläser: moderne Verglasungen für Fenster und Fassaden, Hg. H.J. Gläser, Ehningen 1992, 45-82.

Huntebrinker, K., Die thermischen Eigenschaften des Mehrscheiben-Isolierglases, in: Mehrscheiben-Isolierglas. Verhalten und Eigenschaften, Hg. H.J. Gläser, Renningen 1995, 25-46.

Holler, G., Die Gas- und Wasserdampfdurchlässigkeit des Isolierglasrandverbundes und die Alterungsbeständigkeit des Mehrscheiben-Isolierglases (MIG), Hg. H.J. Gläser, Renningen 1995, 68-99.

i.f.t. Institut für Fenstertechnik e.V., Rosenheim, Schreiben an ÖR 02.08.99.

2. Leading groups of manufacturers (combined market share over 50%)
VEGLA Vereinigte Glaswerke GmbH, Aachen [now Saint-Gobain Glass], Conference with ÖR, Aachen 15.04.96, u. comm. to ÖR, 02.05.96, 10.06.02.
Flachglas AG, Gelsenkirchen, Conference with, ÖR, Gelsenkirchen 06.05.96.
Isolar Glas-Beratung GmbH, Kirchberg, 02.05.96, 03.07.96, 28.07.99.
Sanco Glas GmbH & Co KG, Nördlingen, 15.05.96, 29.07.99.
Interpane Glasgesellschaft mbH, Plattling, 28.05.96, 29.07.99.

3. The three leading suppliers of glass filling equipment
DCL Glas Consult GmbH [now DGT-Anlagen und Systeme GmbH], Sauerlach, comm. to ÖR 22.05.96.
Lenhardt Maschinenbau GmbH, Neuhausen, comm. to ÖR 23.05.96.
Ratiotechnik GmbH & Co KG, Braunschweig, comm. to. ÖR 03.09.96.

4.B On the filling emission factor [in brackets the respective expert estimate]

Isolar Glas-Beratung GmbH, Kirchberg, 02.05.96, 03.07.96, 28.07.99. [40%]
Interpane Glasgesellschaft mbH, Plattling, 28.05.96. [20-30%]
Sanco Glas GmbH & Co KG, Nördlingen, 15.05. 96 [up to 60%], 29.07.99 [30%]
Glas-Trösch AG, Bützberg, 02.08.99 [>30%]
Unilux AG, Salmtal, 05.06.96 [40%]
DCL Glas Consult GmbH [now DGT-Anlagen und Systeme GmbH], Sauerlach, 22.05.96 [20-50%]
Lenhardt Maschinenbau GmbH, Neuhausen-Hamberg, 23.05.96 [40%]
i.f.t. Institut für Fenstertechnik e.V., Rosenheim, 28.07.99 [>30%]

4.C Annual domestic SF_6 consumption

Ausimont (Deutschland) GmbH, Eschborn, Conference with ÖR 16.04.96, 29.03.99. After 1999 Ausimont did no longer directly supply SF_6 to producers of sound proof glazing.
Messer Griesheim GmbH, Krefeld, 22.04.96, Mitt. an das UBA 17.03.99, Mitt. an ÖR 29.07.99, 10.06.02; 22.09.03.
Chemogas GmbH, Bochum, 21.5.1996, Mitt. an das UBA 22.3.99. For 1998: (Chemogas nun zu Linde gehörig): Linde AG, Höllriegelskreuth, Mitt. an ÖR 29.07.99.
Air Products GmbH, Hattingen, ÖR 29.05.96, 16.08.99, 04.06.02; 22.09.03.
Linde AG, Höllriegelskreuth, 29.04.96, Mitt. an das UBA 15.03.99, Mitt. an ÖR 29.07.99 17.06.02, 17.09.03.
AGA Gas GmbH, Hamburg, 30.05.96, Mitt. an das UBA 16.03.99. Das Geschäft seit 1999 ist in Linde enthalten.
Air Liquide GmbH, Düsseldorf, 02.05.96; Mitt. an das UBA 17.03.99, Mitt. an ÖR 27.5.02; 16.07.03.

5. Quality control and uncertainty assessment of data I

Activity data. The data on consumption (domestic sales of gas vendors) was obtained by means of a top-down-survey. It is sufficiently reliable and complete like any commercial sales figures. Purchase data on the side of manufacturers, which could be used for a bottom-up crosscheck, is not available for viability reasons as the number of manufacturers is too high with some 400. However, the method of calculation of bank and disposal emissions (see Part II and III) can be used for plausibility control of annual domestic SF_6 consumption (see hereafter). The year 2001 may exemplify. In this year, gas vendors reported sales of 75 t to producers of insulating glass.

Plausibility check for 2001 by means of the calculation method:

1. New soundproof glazing with SF_6 (estimate)	1.750.000 m^2
2. Interspace from pane to pane	16 mm = 16 Litres (16 l) per m^2
3. Molar mass SF_6	146.05 (g/mol)
4. Theor. SF_6 maximum per m^2 glazing	104.32 g (146.05 g*16 l/22.4 l)
5. Real SF_6 maximum per m^2 (10% residual air!)	93.9 g (104.32 * 90%)
6. SF_6 per m^2 glazing with blend SF_6 30/Ar 70	28.17 g (93.9 * 30%)
7. SF_6 in all the new SF_6 glazing	49,292 kg (1.75 million* 28.17 g)
8. 33% overfill (50% of effective fill)	24,646 kg (49,292 kg / 2)
9. Consumption (filling + filling loss)	73,938 kg (Sum of 7. + 8.)

This technical validity check suggests for the activity data a high degree of safety, because the calculated 73.939 tonnes SF_6 are very close to the reported 75.0 tonnes. The calculated consumption, in turn, relies above all on the glazing surface area that base on expert estimates (here: made by ÖR).

Emission factor. The EF for filling (overfilling) cannot reasonably be measured in the face of the multitude of influencing factors. ÖR interviewed in 1996 and 1999 ten sector experts from glazing manufacturers, gas filling equipment, and a scientific institute. According to their estimates, a conclusion about the average filling loss other than "between 30% and 40%" hardly seems possible.

The following values were given (the respective companies are named above sub 4.B):

20%-30%	1x
30%	1x
> 30%	2x
20%-50%	1x
40%	4x
< 60%	1x

It seems to be justified to conclude from these estimations a value of 33% to be close to reality. According to IPCC-GPG data safety for "filling emissions" amounts to 50 ± 10%. (The 50% are related to the new fill (In_{bank}) and are equivalent to 33% when being related to the consumption (C_{manu}).

6. Relation to IPCC method I

Activity data. IPCC GPG proposes under "3.5.2 Other sources of SF_6" for sound-proof windows the use of a top-down approach on the base of sales data from SF_6 distributors to this application. The ÖR method is in full accordance with that.

Emission factor. The same applies to the establishment of the emission factor. The latter is proposed in equation 3.24 "Assembly Emissions = 0.33 x Window Capacity".

7. Entry in CRF I

The CRF Table where data on SF_6 for soundproof glazing is primarily entered is Table 2(II)Fs2, row 37.

II. Domestic SF_6 input and emissions from bank

In a particular year n, the SF_6 end-of-year bank in the domestic total of soundproof glazing (EB n) changes by the balance of domestic input (In $_{bank}$ n) and domestic output (De $_{bank}$ n). In view of lifetimes of 25 years, departures from the bank systematically occur first since 2000. Until 1999 only inputs (In $_{bank}$) had to be considered (De $_{bank}$ = 0).

Operating emissions in year n from the bank (Em $_{op}$) relate to the average SF_6 bank in year n. The latter has been built up year by year through SF_6 inputs in installed windows from 1975 onwards. The average annual bank (B n) is half the sum of the previous year's end-of-year bank n-1 and the current year's end-of-year bank n.
The equation is:

$$B\,n = \frac{EB\,n\text{-}1 + EB\,n}{2} \qquad \text{Where:} \quad EB\,n = EB\,n\text{-}1 + In_{bank}\,n - De_{bank}\,n$$

General condition for ascertaining the size of a bank is that for the end-of-year bank in any year n the end-of-year bank or input of the previous year n-1 must be known. From that follows a regress back to the first year of SF_6 use. In soundproof windows, this historic recalculation must go much more backward into the past than in HFC systems as SF_6 has already been used for soundproof glazing from 1975 onwards.

In Part I, annual SF_6 inputs (In $_{bank}$) over the years 1995 to 2002 were implicitly discussed, namely in Table 2 as differences between domestic consumption (C $_{manu}$) and filling emissions (Em $_{manu}$). Next step is the reconstruction of the preceding SF_6 inputs over the years 1975 to 1994.

8. Reconstruction of SF_6 inputs through glazing 1975 - 1994

Continuous statistical documentation of annual SF_6 consumption (C $_{manu}$) for soundproof glazing (from 1975 onwards) would be helpful, but does not exist. Alternatively, the data have to be reconstructed with the help of experts. For qualified estimation, only such experts came into question, which were able to combine a good overview of the market with long experience in the sector.

1. The head of marketing fluorine products of Ausimont Deutschland GmbH, since 1967 active in selling SF_6 to the German market, had not only the required market knowledge but had also disposal of the company-owned archive with the sales figures from that time (direct marketing as well as supply to domestic gas trade). In 1996, by means of projection from this data ÖR and this Ausimont expert elaborated a time series of the overall domestic SF_6 sales to the soundproof glazing sector, which goes from 1976 (year of entrance of the SF_6 producer into the glass business) to 1994.

2. This time series was confirmed in an expert talk of ÖR with the Pilkington Flachglas AG based in Gelsenkirchen. In 1996, this company was not only the domestic market leader in soundproof glazing (brand Phonstop) but also possessed statistics on the German overall annual production of soundproof glazing from 1990 onwards (in square metres).

During the 1975-1994 period, the development of domestic SF_6 sales for soundproof glazing exhibits following tendencies.

- The installed area of SF_6 containing soundproof glazing starts with 50,000 m^2 in 1975 and 100,000 m^2 in 1976. Until 1990, it steadily increases on previous year by 100,000 m^2, and achieves 1.5 million m^2 in 1990. After, the rise in installed glazing area is even steeper until 1994 with then 2.4 million square metres.
- From 1975 to 1990, the average pane interspace grew from 12 to 16 millimetres, and afterwards it remained constant. (The interspace contains only 90% SF_6 as 10% residual air cannot be eliminated during the filling process).
- From 1975 to 1986, the filling gas was exclusively SF_6. From 1987 to 1994, the share of SF_6 in the mixture with argon dropped to average 82%.

The annual consumption derived from the model throughout ranges in the order of the projection made from the Ausimont sales figures over the same time.

Time series of annual domestic SF_6 input 1975-1994

The reconstruction results in the following time series on the effective annual new fills (In_{bank}) in tonnes. Please note that input is not identical to consumption but is smaller by the filling loss (Em_{manu}) of 33%.

Table 3: 1975-1994 Reconstruction of SF_6 inputs to the bank in soundproof glazing, in t/y

1975	3.5		1985	86.0
1976	7.2		1986	96.4
1977	14.7		1987	104.4
1978	22.5		1988	112.0
1979	30.7		1989	116.4
1980	39.1		1990	119.7
1981	47.9		1991	132.4
1982	57.0		1992	149.3
1983	66.3		1993	166.3
1984	76.0		1994	175.5

Explanation: SF_6 input equals SF_6 consumption minus 33% filling emissions.

Comment

The – reconstructed – time-series for the 1975-1994 period shows an unbroken and continuous rise. The rise keeps, as discussed in Part I, until the year 1995 peaking then at 183 tonnes (275 tonnes minus 92 tonnes). Afterwards the new fills (In_{bank}) have sharply dropped. They amounted to only 28 tonnes by the year 2002.

Sources of Information on reconstruction of the 1975-1994 period (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Ausimont (Deutschland) GmbH, Eschborn, Conference with ÖR, 16.04.96.
Flachglas AG, Gelsenkirchen, Conference with ÖR, Gelsenkirchen, 06.05.96.

9. Emission factor 1% per year for operating losses from bank

From the SF_6 cumulated in installed soundproof glazing constantly a small amount escapes. A DIN standard (DIN 1286, T 2) prescribes for gas losses through the edge seal during the use phase a maximum limit of 1 percent. All surveyed experts stated unanimously that the real SF_6 gas loss in intact glazing is below this permissible limit. However, further gas losses through glass breakage do occur, which can happen during transport, installation, and the 20-30-year use phase. Moreover, in the course of ageing the edge seal exhibits more and more leakiness. All in all, 1% operating gas losses per year (EF_{op} = 1%) is considered realistic.

10. End-of-year bank and average bank of a current year

Operating emissions in year n (Em_{op} n) follow the general equation:

$$Em_{op}\, n = EF_{op}\,(1\%) \times \frac{EB\, n\text{-}1 + EB\, n}{2}$$

However, information gained this way is insufficient to estimate operating emissions for any year from 1975 onwards, and particularly for the individual years from 1995 onwards. This is because neither end-of-year bank nor average bank of a particular year can be solely defined by the total of preceding inputs (minus departures). In case of soundproof glazing the SF_6 bank itself (be it end-of-year or average bank) is affected by operating emissions arising over the previous years. This point requires further explanation.

It is true that the SF_6 end-of-year bank in a particular year n (EB n) consists of all the cumulated inputs (In_{bank}) having taken place since 1975. The annual increase in bank, however, is not equal to the annual input to the bank but somewhat smaller. For, it must be considered that in every year (since 1975) operating emissions (Em_{op}) have left the bank. This is why the equation "bank in year n = sum of all the inputs since 1975" must be modified.

Differently from refrigeration or air-conditioning where operating emissions are not considered to reduce banks, and the emission factor (EF_{op}) always relates to full banks, in case of soundproof glazing, the emission factor is a quota of the current gas fill in the interspace and not a fraction of its initial fill. The technical reason for this approach is that in difference from refrigeration or air-conditioning systems the pane interspaces on principle cannot be topped up to compensate for use-phase emissions.

The size of the end-of-year bank in year n, therefore, is only preliminary but not yet terminally ascertained as long as only the end-of-year bank of the previous year (EB n-1) as well as input (In_{bank} n) and output (De_{bank} n) of the current year are known. Thus, in the equation hereafter EB n changes to – preliminary - EB n [prel].

$$EB\, n\, [prel] = EB\, n\text{-}1 + In_{bank}\, n - De_{bank}\, n$$

The end-of-year bank (EB n) is completely estimated after consideration of the reduction as a result of operating emissions in the same year n (Em_{op} n):

$$EB\, n = EB\, n\text{-}1 + In_{bank}\, n - De_{bank}\, n - Em_{op}\, n$$

Including the bank-reducing effect of operating emissions, the size of the end-of-year bank in any current year is not determined until the previous end-of-year bank is increased by the net input (In_{bank} n - De_{bank} n) of the current year <u>and</u> decreased by the operating emissions (Em_{op} n) of the current year. End-of-year bank without or before consideration of operating emissions is <u>preliminary</u> end-of-year bank (EB n [prel]). The latter is a relevant figure, because the average bank, to which the operating emission factor relates, originates from halving the sum of the preliminary end-of-year banks of the previous and the current year: B n = (EB n-1 [prel] + EB n [prel]) x 0.5.

11. End-of-year banks, average banks, and operating emissions since 1975

End-of-year and average banks of following years are not only based (as shown in section 8) on all preceding end-of-year banks and net inputs since the starting year 1975, but are also influenced by all operating emissions from 1975 onwards.

Table 4: 1975-2002 Inputs, end-of-year banks (EB), average banks, and operating emissions of SF_6 from soundproof glazing, in t/y

	Input	**End-of year bank n [prel]**	**Average bank***	**Operating emissions**	**End-of-year bank****
	In_{bank} n	EB n-1 + In_{bank} n	B n *	1% x B n	
1975	3.5	3.5	1.8	0.018	3.5
1976	7.2	10.7	7.1	0.07	10.6
1977	14.7	25.3	18.0	0.18	25.1
1978	22.5	47.7	36.5	0.36	47.3
1979	30.7	78.0	62.8	0.63	77.3
1980	39.1	116.4	97.2	0.97	115.5
1981	47.9	163.4	139.9	1.40	162.0
1982	57.0	218.9	191.1	1.91	217.0
1983	66.3	283.4	251.1	2.51	280.8
1984	76.0	356.9	320.1	3.20	353.7
1985	86.0	439.8	398.3	3.98	435.8
1986	96.4	532.2	486.0	4.86	527.3
1987	104.4	631.7	581.9	5.82	625.8
1988	112.0	737.9	684.8	6.85	731.1
1989	116.4	847.4	792.7	7.93	839.5
1990	119.7	959.2	903.3	9.03	950.2
1991	132.4	1082.6	1020.9	10.21	1072.4
1992	149.3	1221.7	1152.2	11.52	1210.2
1993	166.3	1376.5	1299.1	12.99	1363.5
1994	175.5	1539.1	1457.8	14.58	1524.5
1995	183.2	1707.7	1623.4	16.23	1691.5
1996	135.9	1827.4	1767.6	17.68	1809.7
1997	112.7	1922.4	1874.9	18.75	1903.7
1998	74.0	1977.6	1950.0	19.50	1958.1
1999	64.1	2022.2	1999.9	20.00	2002.2
2000	57.2	2059.4	2040.8	20.41	2036.2
2001	50.0	2086.2	2072.8	20.73	2059.9
2002	28.2	2088.1	2087.1	20.87	2055.8

* B n = (EB n-1 [prel] + EB n [prel]) x 0.5; ** EB n = EB n-1 + In_{bank} n - Em_{op} n - De_{bank} n. In anticipation of III.14, disposal (De_{bank} n) until 1999 = 0. In 2000: 5.6 t; 2001: 11.4 t; 2002: 17.5 t.

Table 4 gives an account of the inputs, preliminary and conclusive end-of-year banks, average annual banks, and of operating emissions for the years 1975 to 2002. Decommissioning and disposal occur from 2000 onwards.

Comment

Though annual operating emissions from the bank have continuously grown since 1975, their level has exceeded the filling emissions not before 2002, when the latter began to drop yet. Since the year 2000, the growth in operating emissions has significantly decelerated, as both the start of decommissioning and the reduced input (In_{bank}) have almost stopped the growth in the average SF_6 bank. In 2002, for the first time a reduction in the end-of-year bank can be assessed (EB n = 2055.8 t), which leads to a reduction in the average bank (B n) and with that of operating emissions ex 2003.

Over the medium term, the average bank will no longer rise as both the inputs will be smaller and the departures by disposal will be larger. Despite of that, operating emissions will decrease only slowly. Even at "input = 0" ex 2005, they would amount to more than six t/y by 2020.

III. SF_6 disposal and disposal emissions

SF_6 is not captured from old soundproof glazing at decommissioning and scrapping. The disposal emission factor (EF_{disp}) amounts to 100% of the SF_6 quantity ready for disposal. This circumstance is not controversial. However, it has to be clarified how much of the initial gas filling in new glazing is left at the time of disposal. As shown in Part II, during the use-phase a certain quantity constantly emits. Given the factor of operating emissions of 1% per year, the SF_6 remainder in the glazing due for disposal depends on the lifetime of the glazing.

12. Lifetime of soundproof glazing 25 years

The surveyed experts estimate normal lifetime of double-glazing at 15 to 30 years. The durability of soundproof windows depends primarily upon the adhesive and sealant of the edge seal design, specifically upon the stresses imposed upon these by weathering and UV/IR irradiation with subsequent cracking. As a result, humidity can penetrate in the interspace as well as water vapour from moist window frame material. There is a point when the capacity of the desiccant to bind humidity is exceeded, so that in case of low temperature irreparable inside condensation sets in. Therewith it is clear that normal lifetime of insulating glazing depends upon geography and climate, too. The experts surveyed stated unanimously that the average lifetime for Germany was 25 years. Although they claimed that the normal lifetime had been prolonged compared to the first installation years, above all due to better sealing, none of them was able to determine the additional years. Thus, in the following, a constant lifetime of 25 years is applied.

Sources of Information on lifetime and on operating loss from bank (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

<u>Written Sources</u>

Holler, G., Die Gas- und Wasserdampfdurchlässigkeit des Isolierglasrandverbundes und die Alterungsbeständigkeit des Mehrscheiben-Isolierglases (MIG), Hg. H.J. Gläser, Renningen 1995, 68-99.

DIN 1286, Teil 2, Mehrscheiben-Isolierglas gasgefüllt. Zeitstandsverhalten, Grenzabweichungen des Gasvolumenanteils, Mai 1989.

<u>Personal Communications</u>

VEGLA Vereinigte Glaswerke GmbH [jetzt Saint-Gobain Glass], Aachen, Conference with ÖR, Aachen 15.04.96, and communication to ÖR, 02.05.96.

Pilkington Flachglas AG, Gelsenkirchen, 18.04.96.

Isolar Glas-Beratung GmbH, Kirchberg, 02.05. 96.

Flachglas AG, Gelsenkirchen, Conference with ÖR, Gelsenkirchen, 06.05. 96.

Sanco Glas GmbH & Co KG, Nördlingen, 15.05. 96.

13. Disposal emissions

Every year soundproof glazing looses 1% gas against the year before. Therefore, an annual glazing cohort contains no longer the entire initial filling after 25 years but 25 annual gas losses less. Given the annual operating emission factor (EF_{op}) amounting to 1% (0.01 compared to 1), the SF_6 content in the year of disposal is only 77.78%, namely $(1 – 0.01)^{25}$ of the initial filling. As there is no capturing, the entire quantity for disposal becomes emission (EF_{disp} = 100%). This is the equation:

$$Em_{disp}\ n = EF_{disp}\ (100\%) \times In_{bank}\ n\text{-}25 \times (1 - EF_{op})^{25}$$

Explanation. Em_{disp} n: Disposal emissions in year n. In_{bank} n-25: New fill (input) 25 years before the year of disposal. EF_{op}: Factor of operating emissions (0.01).

14. Time series of disposal emissions

Assuming a 25-year-lifetime, for the first time in 2000 a whole installation year, namely 1975, was ready for disposal. In 2001, the second year followed, namely 1976, and so on. Inputs to the bank dating back 25 years (In_{bank} n-25) become quantities for disposal in year n. They can be read off from Tables 3 and 4. Please note that the quantity due for disposal, which becomes disposal emission, is reduced by 25 consecutive annual operating losses of 22.22% in total (100% - 77.78%).

Disposal emissions 2000: input 1975 (3.5 t) x 77.78% = 2.7 t
Disposal emissions 2001: input 1976 (7.2 t) x 77.78% = 5.6 t
Disposal emissions 2002: input 1977 (14.7 t) x 77.78% = 11.4 t.

Comment on time series of disposal emissions

Disposal emissions will go on rising steadily because new fills (inputs) peaked only in the year 1995. This is why the disposal losses are going to peak not before 2020 no matter whether and how much SF_6 will be used for new soundproof glazing. By 2020, disposal emissions alone will amount to 142 t/y.

15. Quality control and uncertainty assessment of data II

1. Operating emission factor 1% of the bank

DIN 1286, part 2, prescribes for gas losses through the sealing a maximum limit of 1%. All six experts surveyed in 1996 agreed that the diffusion from intact glazing is far below this permissible limit in reality. Nevertheless, the experts unanimously estimated the operating loss at an order of approx. 1% when considering glass breakage after fabrication of the glazing. The reliability of the estimated operating emission factor is deemed sufficiently high. Following IPCC-GPG the data safety for "leakage/breach emissions" is 1 ± 0.5%.

2. Disposal emissions 100% of the quantity for disposal

In Germany, there are no plans for a scheme to recover SF_6 from end-of-life glazing, and this is not considered technically feasible. No doubt, the residual filling gas escapes to the atmosphere completely.

3. Activity data. Reconstructed domestic consumption 1975-1994

The absolute amount of disposal losses and, to a large part, the bank emissions rely on data projected from reconstructed sales figures, which partly date back to more than 20 years, at the time of the expert estimation. This case is unique in the reporting system on fluorinated greenhouse gases. The data from 1975 to 1989 and even the data from the 1990-1994 period may be characterised as well-estimated orders of magnitudes. They are considered "well-estimated" for three reasons:

Firstly, the reconstruction is based on empirically substantiated assumptions of the trends concerning a) pane interspace, b) SF_6 share in total gas filling, and c) installed surface area of soundproof glazing.

Secondly, the interviewed experts are among the best qualified in Germany.

Thirdly, the estimated trend was subject to a comparison with archive data of a very large SF_6 supplier.

The margin of error may amount up to ± 25% for individual annual SF_6 inputs; for the overall trend, the error band is certainly smaller. It should be estimated at ± 10%.

Compared to the reconstructed time-series, the 1995-2002 period is significantly better ensured, as it is based on real sales figures reported by the gas trade. This has already been worked out in detail elsewhere (cf. Part I, section 4).

4. Lifetime of glazing

A further source of uncertainty is related to the lifetime of soundproof glazing and therewith to the level of disposal emissions. It must be repeated here that the 25-year-lifetime is an average of numerous individual values between 15 and 30 years. Apart from the fabrication quality (edge seal), differences in the exposition of the glazing to weather and climate impacts are of decisive importance for the lifetime.

16. Relation to IPCC method

Activity data. Under "3.5.2 Other sources of SF_6" IPCC GPG proposes for soundproof windows the use of a top-down approach based on data from SF_6 distributors. ÖR follows this suggestion as far this is possible for the reconstruction of 1975-1994 data.

The same applies to the determination of the operating emission factor. The IPCC GPG suggests following equation (3.25): "Leakage Emissions in year t = 0.01 x Existing Stock in the Window". ÖR likewise uses this 0.01 emission factor.

Disposal emissions are dealt with in equation 3.26: "Disposal Emissions = Amount Left in Window at End of Life x (1 – Recovery Factor)." This approach is used by ÖR too. The recovery factor for Germany equals zero, so that disposal emissions are the same size as the end-of-life stock in the windows.

17. Entry in CRF II

The CRF Table where data on SF_6 for soundproof glazing is primarily entered is Table 2(II)Fs2, row 37. Annual bank and annual quantity for disposal are entered in columns C and D, operating emissions from stocks in column I, and disposal emissions, which are identical to quantity for disposal in column D, are entered again in column J.

F-Gas Sheet 30: Car Tires

F-Gas	**SF_6**
Application	**Car Tires**
Reported Years	**1995 - 2002**
Emission Type 5	**Disposal Emissions**

Background

In 1995 about 500 of the overall 3,500 domestic tire traders offered to drivers of passenger cars SF_6 instead of air as tire filling gas. This system invented by the tire-manufacturer Continental AG and marketed under the name "AirSafe" promised improved stability of the tire pressure thanks to the large molecules of SF_6. The filling per tire was some 250 g, i.e. for a set of 4 tires about 1 kg. The SF_6 gas was supplied to tire trade retail outlets in 40-kg-bottles. Until 1996, the supplier was the Continental AG itself for a considerable part, and afterwards it was the general gas trade, exclusively. In the top-selling year 1995, Continental and the gas trade supplied SF_6 to the Vergölst-group and the Stinnes Reifendienst with 200 outlets each, as well as to further 100 independent tire traders.

Emissions are substantially disposal emissions. They follow filling with a delay of approx. 3 years. With an average car mileage of 15,000 km per annum and an average tire travel of 50,000 km, tire change is due every three years. When the tires are changed, the filling gas is released completely. Gas capturing does not occur.

SF_6 consumption and disposal emissions

1. Activity data. Consumption, bank and quantity for disposal

1.A Annual consumption for filling

Annual domestic SF_6 consumption for filling (C_{manu}) of car tires from 1992 onwards is entered in Table 1 in the first column.

1.B SF_6 bank in car tires

Method: As there is quasi no foreign trade with filled car tires, annual domestic SF_6 input is in principle identical to domestic consumption for filling, minus losses arising upon filling ($In_{bank} = C_{manu} – Em_{manu}$). Filling emissions themselves are very low, and for simplicity, they are set zero in the following. Then no difference exists between effectively filled quantity (In_{bank}) and consumption for filling (C_{manu}).

At the end of the current year n, the SF_6 bank (EB) in car tires has increased against the previous end-of-year bank (EB n-1) by consumption in the current year n (C_{manu} or In_{bank}). At the same time, it has diminished by the SF_6 quantity contained in dismantled tires (De_{bank} n). This is shown in equation 1.

Equation 1:	$EB\ n = EB\ n\text{-}1 + In_{bank}\ n – De_{bank}\ n$

The quantity for disposal (De_{bank} n) is identical to the SF_6 input (In_{bank}) in that year which dates back by the tire lifetime (n – LT). With a 3-year-lifetime, the disposal quantity in the current year n equals the input three years before (In_{bank} n-3). This is the equation (2):

Equation 2:	$EB\ n = EB\ n\text{-}1 + In_{bank}\ n – In_{bank}\ n\text{-}3$

Condition for equating disposal (De_{bank} n) to the filling having occurred three years ago (In_{bank} n-3) is that over the three-year-usage the initial gas filling has been kept constant. This is, strictly speaking, impossible. Between time of filling and time of dismantling the tires (use-phase), certain gas quantities do emit. Nevertheless, ÖR refrains from ascertaining these operating emissions (Em_{op}) for simplicity due to the simple fact that there are no estimations at all about gas losses resulting from diffusion through the rubber or from mechanic damage. Consequently, ÖR assigns all emissions to disposal emissions, thus implicitly including also operating bank emissions.[4]

1.C The quantity for disposal

Under 1.B, it was discussed and presented in equations that annually the – unaltered – quantity of SF_6 input from three years before is ready for disposal. With a delay of 3 years, disposal quantity (De_{bank} n) follows input quantity In_{bank} n-3 (~ C_{manu} n-3). The equation is (3):

[4] Of course, there are refills during the use-phase. They cannot be estimated separately, but are implicitly included in annual consumption for filling.

Equation 3:	$De_{bank}\ n = In_{bank}\ n - 3$

Table 1 compiles all activity data needed: Firstly, annual inputs, secondly, annual quantities for disposal (identical to inputs from three years ago), and thirdly, the end-of-year banks of SF_6 in car tires. The banks are entered only for the purpose of illustration, as operating emissions from bank are not estimated. (Incidentally, for that the calculation of the average banks were required).

Table 1: Inputs, quantities for disposal, and end-of-year banks of SF_6 in car tires in Germany, in tonnes per year from 1992 to 2002

	Input	Disposal	Bank at end-of-year
	$In_{bank}\ n$	$De_{bank}\ n = In_{bank}\ n\text{-}3$	$EB\ n\text{-}1 + In_{bank}\ n – In_{bank}\ n\text{-}3$
1992	*110*	n.e.	n.e.
1993	*115*	n.e.	n.e.
1994	*120*	n.e.	n.e.
1995	125	110	360
1996	67	115	312
1997	50	120	242
1998	30	125	147
1999	9	67	89
2000	6	50	45
2001	4	30	19
2002	2.7	9	12.7

Explanation: n.e. means not estimated.

Comment

Until 1995, there was a steady rise in filling and hence in disposal quantities until 1998. The withdrawal of Continental from marketing "AirSafe" by its own in 1996, among other things as reaction to ecological critique, lead to halving of the SF_6 sales within one year, particular since at the same time many tire traders began to offer common nitrogen as "environmentally friendly" tire gas in exchange. By 2002, the demand for SF_6 for car tires has been cut to just 2% of the top-year 1995. Because of possible political measures (impeding ban), this SF_6 application is supposed to end soon.

2. Collection of activity data and sources of information

The consumption for filling is estimated by means of enquiries of specialised gas vendors about their domestic sales to tire traders and to other automobile garages.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Communications

Continental AG, Hannover, ÖR 27.03.96.

Messer Griesheim GmbH, Krefeld, 22.04.96, Mitt an das UBA 17.03.99, Mitt an ÖR 29.07.99, 10.06.02; 22.09.03.

Chemogas GmbH, Bochum, 21.5.1996, Mitt an das UBA 22.3.99, Mitt an ÖR 29.07.99.

Air Products GmbH, Hattingen, Mitt an ÖR 29.05.96, 16.08.99, 04.06.02; 22.09.03.

Linde AG, Höllriegelskreuth, 29.04.96, Mitt an das UBA 15.03.99, Mitt an ÖR 29.07.99, 17.06.02. 17.09.03.

<u>Written sources about the technology</u>
Continental AG: Conti/AIRSAFE-Informationsblatt o.J.
Continental AG, Hannover, Schreiben an ÖR, 21.10.96.

3. The emission factor of disposal

Recovery on dismantling does not occur. This is why 100% of the three years before filled SF_6 escapes to the atmosphere, when the worn tire is disposed of. Consequently, the disposal emission factor (EF_{disp}) amounts to 100%.

Emissions in year n are completely equated to filling in the year n-3. This applies on the condition that operating emissions (and refills) during use-phase are not taken into consideration.

4. Sources of Information on emission factor

The complete and unhampered release of the gas content on demounting is not controversial. For the first time this issue was communicated by Continental in 1996.

Continental AG, Hannover, 07.10.96.

5. SF_6 emissions from car tires since 1995

Given the disposal quantity and the emission factor (EF_{disp}) of 100%, emissions are identical to disposal quantities themselves (according to Table 1, column 2). For lucidity reasons, the two – identical – time series are entered again in Table 2.

Table 2: Emissions of SF_6 on disposal of car tires, 1995-2002 in t/y

	Disposal	Emissions
1995	110	110
1996	115	115
1997	120	120
1998	125	125
1999	67	67
2000	50	50
2001	30	30
2002	9	9

Sources: Table 1, left col.

6. Quality control and uncertainty assessment of data

The activity data are rated reliable and almost complete like any commercial sales figures, above all in the face of the manageable number of gas suppliers.

<u>Crosscheck on data safety</u>. In May 1996, ÖR crosschecked the sales of the largest single gas-trader of SF_6 for car tires. The company indicated for 1995 sales of 40 tonnes exclusively to outlets of Stinnes Reifendienst. The Stinnes sales manager, Mr Schreiber in Kaiserslautern, declared on May 22, 1996, that in 1995 the retail chain had received from the gas trader roughly 1,000 bottles with 40 kg SF_6 (in addition to 200 bottles from another gas vendor). The 40 t delivery was completely confirmed by that. This compliance of the supplier's with the customer's indication is exceptional in its

accuracy. Even a smaller degree of consistency would have satisfied high data reliability.

ÖR did not check the time of emissions "three years after filling". It sounds plausible, as it bases on empirical data on average lifetime of car tires. Certainly, there are many SF_6 losses ahead of time, and the true average lifetime of SF_6 filled tires deviates below and above the three-year-time. Of decisive importance is that the emission factor is 100% so that all filling escapes to the atmosphere unaltered after a certain time.

7. Relation to IPCC method

Activity data: Under "3.5.2 Other sources of SF_6", IPCC GPG suggests for applications which use the adiabatic property of SF_6 (car tyres, shoe soles) a top-down approach based on data of SF_6 sales into the respective application. The procedure of ÖR follows that guidance.

This likewise applies to the emission factor in respect to which IPCC GPG has adopted experience from Germany (Schwarz et al., 1996) in equation 3.23:

Equation 3.23:	Emissions in year t = Sales in year t - 3

8. Entry in CRF

The CRF Table, where the data on SF_6 in car tires is primarily entered, is Table 2(II)Fs2, row 39, column D (Fluid for disposal), and the emission column J (Emissions from disposal). The consumption is entered in column B, and the cumulative (three-year) bank in column C. Column H (Emissions from manufacturing) remains empty just as column I (Emissions from stocks).

9. Remark an the order of magnitude of manufacturing emissions

Using a 40 kg bottle completely, approx. 160 times the filling organ must be removed from the valve, and this is always associated with a gas loss. ÖR estimates the total loss at 0.2% or 80 grams per bottle (0.5 grams per filling of one tire). Strictly speaking, the tire traders fill only 99.8% of the purchased SF_6 quantity into tires. For simplicity, OR did not split consumption (C_{manu}) in effective filling (In_{bank} = 99,8%) and filling emissions (Em_{manu} = 0,2%). This lack of exactness is acceptable particularly since filling emissions do not remain unnoticed, but are included in disposal emissions (De_{bank}) three years after.

F-Gas Sheet 31: Magnesium Casting

F-Gas	**SF_6**
Application	**Magnesium Casting**
Reported Years	**1995 - 2002**
Emission Type 2	**Open Application (direct)**

Background

In magnesium casting, SF_6 is frequently used as a protective cover gas over the molten metal in order to prevent oxidation and burning. It is distributed at concentrations of 1 vol.-% in blends with carrier gases such as dry air or CO_2 over the surface of the more than 650°C hot molten metal, which would otherwise ignite at temperatures over 500°C. The SF_6 supplied undergoes only minimum chemical conversion, so that consumption and emissions can be equated.

This position is not held by all experts, some of which point to a considerable decomposition of the cover gas over the hot melt. According to the IPCC guidelines from 2002, ÖR keeps on adhering to the equalisation of consumption to emission.

SF_6 has been used in this application since the mid 1970s, then competing with SO_2, which in concentrations of 0.5-1.5% over the melt forms a protective layer of $MgSO_4$. As SF_6 is simpler to handle than the highly toxic SO_2, it became the cover gas of choice in many new casting companies. By the year 2002, it was being used in 13 out of some 20 domestic magnesium foundries.

Cover gas is used in Germany only to process magnesium that is imported in ingots. When casting the freshly produced metal in these ingots, cover gas is also used in the primary producer countries, and in larger amounts than in German casting companies. In the following, the SF_6 used abroad in primary production is not considered, but only SF_6 usage within Germany.

Domestic SF_6 consumption and total emission

1. Activity data (domestic consumption) and emissions on application

The use of SF_6 as a cover gas is considered an open application. According to the IPCC, all gas being dosed escapes to the atmosphere completely. That means that consumption for domestic application (C_{manu}) and emissions from this application (Em_{manu}) are same-sized. In other words, the application emission factor is 100% of the consumption.

Table 1 shows in the left column for the 1995-2002 period the annual domestic consumption (C_{manu}) which equals to application emissions (Em_{manu}). The right column (metal production) contains as additional information the quantity of finished cast parts for the production of which SF_6 was used.

Table 1: 1995-2002 Consumption/emission of SF_6 as a cover gas in magnesium foundries		
	SF_6 in t/y	*Metal production in t/y (with SF_6)*
1995	7.75	*2,024*
1996	8.14	*6,006*
1997	8.20	*7,083*
1998	9.21	*9,240*
1999	8.64	*10,489*
2000	13.22	*13,109*
2001	17.27	*17,723*
2002	16.01	*20,000*

Comment

The numbers, which exhibit a doubling of annual SF_6 consumption since 1995, conceal two opposite trends. On the one hand, a number of old foundries have converted from SF_6 to SO_2 and others were changing to HFC-134a at the end of 2002; three plants with together 4 t/y accounting for more than half the overall SF_6 use in 1995, meanwhile apply SO_2. On the other hand, several new foundries with focus on automotive industry, which apply solely SF_6 as cover gas, have been established or at least extended. Since 1995, five new foundries have added, consuming together more than 9 t/y SF_6 by 2002.

The metal output, as far as SF_6 is used for its casting, shows that the quantity of Magnesium parts has not only doubled but also even increased tenfold.

The reference of the applied SF_6 quantity to the annual metal production makes evident that specific SF_6 consumption per tonne magnesium has dropped to a fifth part over the 1995-2002 period, from 3.5 kg SF_6/tonne Mg to approx. 0.75 kg SF_6/tonne Mg.

2. Collection of activity data and sources of information

Since 1996, ÖR has directly inquired four times 18 domestic magnesium foundries about their annual SF_6 consumption. Each time, the inquired foundries represented virtually 100% of the total domestic SF_6 consumption. Their gas input quantities numbered from 40 kg/y (1 bottle) to more than 7,000 kg/y. Until 1999 (inclusively), ÖR also surveyed the metal production of the inquired plants. From 2000 onwards ÖR has estimated the metal production based on statistics from the association of the German non-ferrous metal foundries (GDM) on the magnesium pressure die-casters' production. (The GDM data do not distinguish the metal production by different cover gases used).

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Laukötter GmbH & Co. KG, Wadersloh, 07.10.96. Ex 1996 SO_2.
Zitzmann Druckguß GmbH, Stockheim, 08.03.99. As of 1998 SO_2.
Alcan-Bayerisches Druckguss-Werk GmbH & Co. KG, Markt Schwaben, 07.10.96, 29.09.02, 08.09.03. Until 2001 in Germany, afterwards in Slovenia.
Albert Handtmann Metallgusswerk GmbH & Co. KG, Biberach, 10.10.96, 08.09.03, 08.09.03. Ex 2002 SO_2.
Metallgießerei W. F. Poppe & Sohn KG GmbH & Co., last on 19.03.99. Closed in 2001.
Schweizer & Weichand GmbH, Murrhardt, 15.10.96; 19.03.99, 08.09.03. In 2002/03 switch to HFC-134a.
Honsel-Alumetall GmbH, Nürnberg, 15.10.96, last 03.09.02, 08.09.03.
Dietz-Metall GmbH & Co. KG, Unterensingen, 11.10.96, 15.03.99, 10.09.03.
Druckguss Berlin Weißensee, Berlin, 15.10.96, 23.03.99, last 10.09.03. New name (as of 2001): AMZ-Weißensee Präzisionsguss.
Metallgießerei Wilhelm Funke, Alfeld (Leine), 23.08.02, 10.09.03.
W. Schenk Leichtgußwerke, Maulbronn, 16.10.96, last 09.09.03. New name (as of 2002): Metallwerke Kloß Maulbronn GmbH, same address.
Kolbenschmidt-Pierburg AG, last 29.08.02, 09.09.03.
Takata-Petri AG (until 2000: Petri AG), Aschaffenburg, 15.10.96, 22.03.99, last 02.09.02, 16.09.03.
Volkswagen AG, Werk Kassel, Baunatal, 03.12.96, 25.03.99, last 16.09.03. Mg casting as of 1996.
TRW Automotive GmbH, Aschaffenburg, 02.09.02, 09.09.03. Mg casting as of 1997.
Dynacast Deutschland GmbH, Bräunlingen, 29.08.02, 11.09.03. Mg casting as of 2000.
Druckguss Heidenau GmbH, Dohna, 03.09.02, 09.09.03. Mg casting as of 2001.
HDO-Durckguss- und Oberflächentechnik GmbH, Paderborn, 18.06.02, 12.09.03. Mg casting as of 2001.

<u>Written Sources</u>

Gesamtverband Deutscher Metallgießereien (GDM), Bericht über das Geschäftsjahr 2000, Düsseldorf 2001. Data on 2001 and 2002: http://www.gdm-metallguss.de/

3. Emission factors and sources of information

Since IPCC GPG still assumes (see equation 3.12) that all SF_6 consumption is emitted, there is no need to establish emission factors in addition to the survey on consumption quantities. In opposition to the view of many experts as it is laid down in the IPCC GPG, the 1997 publication of Carli et. al. claims that SF_6 decomposes to a certain degree over the hot melt. The same view is held by other experts, e.g. Bartos et. al. (2003). As long as this debate goes on, the IPCC position from 2000 remains relevant.

Sources of Information

Carli, Stefan; Martin, Andreas; Kluge, Steffen (1997): SF_6-Emissions from magnesium die-casting. In: Proceedings of the First Israeli Conference on Magnesium Science & Technology, 10.-12. November 1997, Dead Sea, Israel.
Bartos et al. (2003): Measured SF_6 emissions from magnesium die casting operations. Vortrag auf dem 132nd TMS Annual Meeting, 2. bis 6. März 2003, San Diego, California.

4. Quality control and uncertainty assessment of data

Activity data. The method of direct inquiry about purchased SF_6 quantities per calendar year is the most reliable estimation method at all, compared with indirect approaches using emission factors such as the coefficient "SF_6 consumption per tonne magnesium produced". Incorrect information, of course, cannot be excluded from direct inquiries.

IPCC GPG estimates the data uncertainty in direct reporting at less than ± 5%.

The metal production (under use of SF_6) is additional information of more illustrative interest within the scope of the estimation approach. Here, the data safety is deemed secondary.

Emission factors. The absence of clarity with respect to the real extent of SF_6 decomposition over the melt causes doubts on the reliability of the 100% emission factor. Provided that amongst professional experts the position becomes accepted that a considerable part is decomposed, and general as well as specific emission factors are available, the latter will be used to recalculate historic emissions.

5. Relation to IPCC method

IPCC GPG addresses "SF_6 Emissions from Magnesium Production" under "3.4". ÖR follows the method outlined in Box 4 of the Decision Tree for SF_6 Emissions from Magnesium Production, "Estimate emissions using the direct reporting method". As all plants directly communicate their SF_6 consumption, there is no need to survey their metal production, additionally.

Concerning emission factors expressing partial decomposition of used gas, ÖR follows IPCC GPG that for the time being this potential decomposition is not yet regarded. The further course in the international debate will be observed closely.

6. Entry in CRF

The CRF Table where data on "SF_6 Emissions from Magnesium Foundries" are primarily entered is Table 2(II).C.E, row 13, column E.

Additionally, the Mg production in tonnes is entered in column C so that from the relation of column E to column C an implied emission factor in kg/tonne would emerge, if the error in CRF was already corrected to call for indication of SF_6 in tonnes where indication in kg were appropriate. SF_6 must be entered in kg (column E) to result in a proper implied EF.

ÖR enters in CRF only that proportion of the overall metal production that is produced with the aid of SF_6. This is because the overall metal production also includes a part (some 20-25%) that is protected with other gases or with salts on casting. This number is an estimate because it is nowhere published and is no longer inquired of the plants by ÖR since 2000.

In fact, reference of SF_6 consumption to the weight of produced metal parts is not meaningful in the eyes of ÖR, as the protective gas covers the surface of the total smelt and not only the some 50% of the smelt resulting in saleable parts with their net weight. The SF_6 consumption also depends on the geometry of the metal parts intended, as it includes the scrap (sprue and gatings, dross, defective parts) which is not destined for sale but for reuse inside the plant (again needing cover gas) or in specialised secondary plants.

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F-Gas Sheet 32: Tracer Gas

F-Gas	**SF_6**
Application	**Tracer Gas**
Reported Years	**1995 - 2002**
Emission Type 2	**Open Application (direct)**

Background

As SF_6 is a trace gas that is both stable and readily detectable even in extremely low concentrations, it is used to study ground level and atmospheric airflows and gas dispersal. Experts estimate that max. 100 kg/year are used for urban climate siting studies (cold air dispersal, fresh air passages, landfill and sewage plant design etc.).

The research sector (large-scale research centres) consumes 200-400 kg annually.

To date, for laboratories a DIN-standard regulates to check extractor hoods with SF_6.

Consumption and emissions are identical, as recovery does not take place.

Domestic SF_6 consumption and total emission

1. Activity data (domestic use) and emissions

The use of SF_6 as a tracer gas is an open application. Therefore, it makes no sense to ascertain domestic bank (B) and associated operating emissions (Em_{op}). All gas applied in a particular year escapes completely. Thus, the emission factor (EF_{manu}) is 100% of consumption ($C_{manu} = Em_{manu}$).

From 1995 to 2002, quantities applied (C_{manu}) or emissions on application (Em_{manu}) of SF_6 were as shown in Table 1 hereafter.

Table 1: 1995-2002 SF_6 consumption/emissions as a tracer gas, in t/y	
1995	0.5
1996	0.5
1997	0.5
1998	0.5
1999	0.5
2000	0.5
2001	0.5
2002	0.5

Comment

The quantities applied and emitted amount constantly to 500 kg/year. There are no indications at present that past usage of 500 kg per annum will change in the future.

2. Collection of activity data and sources of information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Official statistics on the SF_6 use as a tracer gas do not exist, and other comparable records are not available either. Thus, expert judgments were necessary. In the year 1996, the six most important German research centres carrying out tracer gas investigations were inquired about the SF_6 quantities used by them. In addition, they were asked for estimations on the overall domestic SF_6 use as a tracer gas. The rather uniform answer was, "since 1990 constantly 400 to 500 kg/year". In 2003, the research centre (FZ) Jülich, which alone accounted for approx. 50% of the overall SF_6 usage in 1996, was asked again to estimate the overall domestic use. The result was that since 1996 the quantities had been unchanged. (In 1999, the Max-Planck-Institut für Chemie based in Mainz, gave the same answer, facing the same question).

Personal Communications

FZ Jülich, Abteilung Sicherheit und Strahlenschutz, 20.06. 96, 24.09.03.
Zentrum für Umweltforschung der Universität Frankfurt, 20.06. 96.
Max-Planck-Institut für Chemie, Mainz, 21.06. 96, 02.08.99.
TÜV Südwest, Stuttgart, 21.06. 96.
Deutscher Wetterdienst, Offenbach, 19.06. 96.
Universität Gießen, Geographisches Institut, 19.06. 96.

Written Sources

Zenger, A., Rühling, A., Bächlin, W., Lohmeyer, A.: Tracergasuntersuchungen zur naturgetreuen Simulation von atmosphärischen Transport- und Mischungsvorgängen im Rahmen von Umweltverträglichkeitsprüfungen, in: Staub - Reinhaltung der Luft 54 (1994), 51-54.

3. Quality control and uncertainty assessment of data

Activity data/emissions. As all the interviewed national experts show a high degree of harmony in respect to the domestically used SF_6 quantity and its constancy since 1990, data safety must be rated high for the time before 1996. For the time after only one expert was interviewed at intervals of three years. Each time, however, the old value was confirmed for the past three years.

In the future, selected experts should be inquired at regular intervals of three or four years about the overall domestic use. At any rate, the FZ Jülich should be amongst them, being the largest single user.

4. Relation to IPCC method

IPCC GPG addresses under "3.5.2 Other sources of SF_6" the use as "Gas-air tracer in research and leak detectors". It recommends as "good practice", to take as starting point the annual sales to this application, and to determine emissions of year n as the sum of half the sales in year n-1 and year n.

In Germany, expert judgements, not sales records of the gas trade, have produced the above-mentioned data. As this data does not show any differences in annual quantities, IPCC guidelines would not lead to results other than those brought forth by the ÖR approach.

5. Entry in CRF

The SF_6 consumption for the open application is entered in "amount of fluid filled in new manufactured products" because the alternative entry in "amount of fluid in operating systems (average annual stocks)" is even less adequate to match the procedure of using SF_6 as a tracer gas.

The CRF Table where the data on quantities of SF_6 "Filled in new manufactured products" and on "Emissions from manufacturing" are primarily entered with the same size each is Table 2(II).Fs2, row 43, columns B und H.

F-Gas-Sheet 33: Aluminium Cleaning

F-Gas	**SF_6**
Application	**Aluminium Cleaning**
Reported Years	**1995 - 2002**
Emission Type 2	**Open Application (direct)**

Background

For the removal (degasification) of hydrogen, as well as alkaline and alkaline earth metals and solids, prior to casting in aluminium smelts, the inert gases nitrogen and/or argon are introduced to prevent porosity in the cast pieces. While elementary chlorine is usually added to the inert gases in primary melt cleaning because purity requirements upon primary aluminium are very high, inert gases without additives are sufficient for rinsing secondary aluminium smelts.

In a few, usually smaller, secondary aluminium smelters and in laboratories, a purification system of inert gases was used to which SF_6 is added in concentrations of 1 or 2.5 %.

Checking up the market for SF_6 in production of aluminium has lead to the result that this cleaning system is today (2003) no longer applied (no sales into the German market).

Surprisingly, as of 1999 individual secondary aluminium smelters have started using pure SF_6 as a cleaning gas in considerable quantities.

Domestic SF_6 consumption and total emission

1. Activity data (domestic consumption) and emissions on application

The use of SF_6 as a cleaning gas (mixture component or pure) is an open application. The gas dosage escapes completely to the atmosphere (according to so far findings). This means that consumption for domestic application (C_{manu}) and emissions from this application (Em_{manu}) are same-sized. In other words, the emission factor for this application is 100% of the consumption.

Table 1 shows the annual domestic consumption (C_{manu}) or – this is the same – the application emissions (Em_{manu}) of SF_6 from 1995 to 2002 (t/y). (The quantity of finished cast parts for the production of which SF_6 is used is unknown).

Table 1: 1005-2002 Consumption/emissions of SF_6 as a cleaning agent in aluminium foundries

	SF_6 in t/y
1995	0.5*
1996	0.5*
1997	0.5*
1998	0.5*
1999	10.5
2000	14.0
2001	32.0
2002	35.0

Sources: Gas trade and users.
* Before 1999, SF_6 was solely used as an additive to inert gases. It is in use in pure form only from 1999 onwards.

Comment

Until 1999 inclusively, a constant SF_6 quantity of 500 kg per year was consumed as an additive to the inert gases argon or argon/nitrogen. This procedure has been ceased in 1999. At the same time, elsewhere the use of pure SF_6 for cleaning molten mass has started, leading to a sharp rise in SF_6 consumption. Since 2003, users are working on solutions without SF_6.

2. Collection of activity data and sources of information

Since 1996, ÖR has inquired three times both the suppliers of SF_6 containing inert gas mixtures about their sales (only SF_6 content) to domestic aluminium foundries. For the 1995-1999 periods, constant sales were reported. In 2000 marketing stopped. The pure SF_6 that is in use since 1999 is purchased by foundries. These were directly inquired by ÖR about the quantities acquisitioned, and the information was subsequently crosschecked with gas distributors. Discrepancies were not found.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

AGA Gas GmbH, Hamburg, ("Aluclean" 3.5% SF_6 in argon), 09.10.96, 29.07.99.
Linde AG Gas & Engineering, GB Linde Gas, Höllriegelskreuth, 22.09.03.

Messer Griesheim GmbH, Krefeld, 10.06.02; 22.09.03.
Air Liquide GmbH, Düsseldorf, 27.5.02; 16.07.03.
Westfalen AG, Münster, ("Meltabron" 1% SF_6 in nitrogen/argon), 17.10. 96, 28.07.99; 22.09.03.
Targeted survey of several German aluminium foundries, October 2003.

3. Emission factor and sources of information

Presently, the practical identity of consumption and emission of SF_6 in aluminium cleaning is beyond controversy, as SF_6 decomposition and reaction are commonly assumed to be minimal. Interpreting IPCC GPG, the application can be seen "semi-prompt" emissive.

4. Quality control and uncertainty assessment of data

Activity data. The survey of domestic SF_6 sales to the application is obviously complete. This applies both to SF_6 sold before 1999 as a mere additive to inert gases and to SF_6 sold as a pure gas in recent years. After 1999, ÖR inquired the gas dealers active in supplying pure SF_6 to domestic aluminium foundries about their SF_6 sales into this application. The answers completely matched the purchased quantity indicated by the users. Thus, reliability of data is guaranteed.

5. Relation to IPCC method

IPCC GPG addresses aluminium production with the help of SF_6 under "3.5.2 Other sources of SF_6". The comments there may be interpreted as if IPCC takes this application for a “semi-prompt” source, the emissions from which could be estimated according to "Equation 3.22". This is:

Emissions in year t = (0.5 x Amount Sold in year t) + (0.5 Amount Sold in year t – 1)

ÖR thinks a half-year delay between purchase and use of SF_6 too long. Instead, ÖR considers total annual sales/purchases to become emissions over the same year.

6. Entry in CRF

The CRF Table where data on "SF_6 Emissions from Aluminium Foundries" are primarily entered is Table 2(II).C.E, row 12, column E.

The column C for the aluminium production in tonnes remains empty, as data on this quantity are unavailable. Anyway, the implied emission factor resulting from the reference of column E to column C would be only of illustrative interest. Quantifying uncertainties of this emission factor is not deemed target-oriented.

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F-Gas Sheet 34: Aircraft Radar

F-Gases	**SF_6**
Application	**Aircraft Radar**
Reported Years	**1995 - 2002**
Emissions Type 4	**Operating Emissions from Bank**

Background

SF_6 is used as an insulating medium in the radar systems of the 17 large NAEWF (NATO Airborne Early Warning Force) military reconnaissance planes of the Boeing E-3A type (AWACS). Its purpose is to prevent electric flashovers in the hollow conductors of the antenna, in which high voltages of more than 135 kV prevail. All other radar systems for aircraft, be it ground or aircraft radar, primary or passive, are operated at lower voltages (up to 30 kV), so that no SF_6 is necessary, oil (silicone oil) sufficing. AWACS systems are, strictly speaking, not aircraft radar systems, but rather ground radar stations built into aircraft, which must operate at high power while needing little space.

Due to the specific use of SF_6, operating emissions are very high. In order to balance the pressure when taking off, SF_6 is released on purpose and needs to be refilled again by means of an on-board gas container when flying downwards. Apart from intentional emissions unintentional losses from leaks also occur.

Note on the method

It is true that the NAEWF main airbase is located at Geilenkirchen in Northwest Germany, but the planes fly throughout the entire air space of the NATO member states. Thus, normal SF_6 leakage is not attributable to any particular state, not even to that in which maintenance and repair of leaks are carried out.

Differently, the deliberately letting off SF_6 for pressure balance is attributable to a particular territory. That is because the releasing takes place in conjunction with the start of a plane and by that not far away from an airport. Geilenkirchen is the largest of the five NAEWF airports with respect to starts and landings (Main Operating Base). The other four airports (Forward Operating Bases) in Italy, Norway, Greece, and Turkey are smaller, each.

Therefore, SF_6 emissions caused by pressure balancing are attributed to Germany only to a certain extent which, however, is not quantified in this published version of the report.

SF_6 input (consumption) and emissions from bank

At the ascent of aircraft the outside pressure drops. With that the high pressure inside the radar system would grow too high. Automatically, SF_6 is released in order to keep the proper over-pressure constant. Likewise automatically, at the descent of the plane the radar system is refilled again with new SF_6 from the container on board. This tank contains about 13 kg, i.e. roughly the quantity required to fill the whole radar system once. When landed, the SF_6 container is exchanged for a full new one. Over one year's time, for pressure balancing roughly 600 kg SF_6 per aircraft radar is needed to replace these deliberate emissions.

With some 13 kg, the SF_6 filling of an AWACS radar system is rather small. Taken all the seventeen NAEWF planes together, the simultaneous SF_6 bank does not even exceed 220 kg, whereas emissions from the bank amount to some 10,000 kg per year, making up an emission factor due to pressure balancing in the range of 4,500 %. Therefore, this emission type should be compared to that of electrical switchgear only with considerable reservations.

1. Input, bank and operating emissions of total NAEWF fleet

Apart from the abovementioned deliberated emissions, also unintentional emissions occur on operation. Table 1 contains the annual SF_6-input (consumption for refilling of intentional as well of unintentional leakage), the bank, and the intentional plus unintentional operating emissions of the entire fleet.

Table 1: 1995-2002 Input, bank, and operating emissions of SF_6 from radar systems of the NAEWF aircrafts, in t/y (Total fleet)

	Input (Average)	Bank	Op. Emissions (Average)
1995	12.5	0.221	12.5
1996	12.5	0.221	12.5
1997	12.5	0.221	12.5
1998	12.5	0.221	12.5
1999	12.5	0.221	12.5
2000	12.5	0.221	12.5
2001	12.5	0.221	12.5
2002	12.5	0.221	12.5

Sources: See section 2.

Explanations and Comment

In order to compensate for both intentional and unintentional emissions of the entire NAEWF fleet (17 radar systems), annually some 12.5 t SF_6 have been purchased on average, over the recent years.[5] (In this context it is secondary that the suppliers have been German gas dealers.)

- Thereof over 1 tonne is consumed for maintenance at a private aircraft company. Before 1997, this company was Dornier based in Oberpfaffenhofen. As of 1997, the maintenance takes place at the Manching location of EADS (formerly DASA).

[5] In 2003 (Iraq war) the quantities purchased increased by more than 20% to over 14 t.

- Thereof more than 1 tonne SF_6 is used for leakage compensation at the Geilenkirchen base itself.

With respect to these two or three tonnes it should be noted that SF_6 is just refilled in Germany, whereas emissions arise on flights through the total European airspace.

- From the remaining 10 tonnes (8 – 12 t) annually supplied to the Geilenkirchen base, too, over the last ten years every year a certain part (which is not published in this version of the report) has been forwarded to the four foreign airports. There, this SF_6 is used for pressure balancing in radar systems on board.

  In Geilenkirchen remains the larger part of the 10 tonnes (on the average) to refill the radar systems' intentional losses caused by pressure balancing associated with aircraft sorties attributable to Germany.

While Table 1 shows the overall consumption and emissions of the entire fleet, for German F-gas reporting (1) only consumption to compensate for intentional emissions is relevant (10 out of 12.5 t SF_6) and (2) thereof in turn only that part which is attributable to sorties in German air space. This part equals 10 t minus quantities forwarded to military airports abroad and has to be entered in German CRF (see below).

Annual oscillations in refilling are not considered here, as they were impossible to ascertain.

The future annual SF_6 demand of the NAEWF is estimated by experts as constant, no important change is expected to occur.

2. Collection of activity data and emission factors

Basic information on the use of SF_6 was given by the aircraft companies Dornier and EADS as well as directly by radar experts from the Geilenkirchen air base. The annually purchased SF_6 quantities were compared with information from gas distributors. It was radar experts from the Geilenkirchen air base, who explained the complicated ways of using SF_6 in military aircraft radar systems.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

NATO Fliegerhorst AWACS, Geilenkirchen, 24.09.03; 08.01.04.
Dornier Luftfahrt GmbH, Oberpfaffenhofen, 11.10.96.
Dasa (DaimlerChrysler Aerospace AG), Manching, 03.08.99.
EADS (European Aeronautic Defence and Space) Deutschland GmbH, Manching, 23.09.03.
Linde AG Gas & Engineering, GB Linde Gas, Höllriegelskreuth, 22.09.03.
Messer Griesheim GmbH, Krefeld, 10.06.02; 22.09.03.
Air Liquide GmbH, Düsseldorf, 27.5.02; 16.07.03.
http://www.boeing.com/defense-space/infoelect/e3awacs/index4.htm.

3. Quality control and uncertainty assessment of data

In 2003, the data was subject to an intensive check, and with that, former mistakes were removed. Originating from qualified experts, the data must be considered sufficiently reliable. It is possible, that the total quantity of 12.5 t used by the entire NAEWF deviates from the true value by ± 1-2 t. Consequently, calculated annual emissions (intentional plus unintentional) per plane amount to some 740 kg ± 100 kg (= ± 15%). In the Table, only average figures are entered. Anyhow, all the experts interviewed judged the SF_6 supply to have been stable over the last years (at least since 1995).

4. Relation to IPCC method

In IPCC-GPG "Military applications" are addressed under "3.5.2 Other sources of SF_6". However, special remarks are missing. Aircraft radar is not mentioned.

5. Entry in CRF

Domestic consumption, bank, and emissions from bank (according to the German percentage share in 10 t SF_6) are entered in Table 2(II).Fs2, into row 41, columns B, C, and I, together with another SF_6 application, domestic data of which are confidential, too (sport shoe soles).

6. Confidentiality issue (military use)

It is true, that none of the interviewed experts, not even from the Geilenkirchen air base, explicitly raised the question of military secrecy.

However, it is recommended to report this data as far as attributable to Germany together with other data (aggregated) to exclude any complications from the beginning.

F-Gas-Sheet 35: Sport Shoe Soles

F-Gases	**SF_6**
Application	**Soles of Sport Shoes**
Reported Years	**1995 - 2002**
Emission Type 5	**Disposal Emissions**

Background

The world's leading company for sports equipment introduced sport shoes using soles containing gas cushions filled with SF_6 in the early 1990's ("Air"-System). The use of these cushions is one possible technological approach to ensure an elastic attenuation of shocks while combining appropriate support to the foot with wear comfort. Often these cushions are visibly integrated into the soles of the shoes. The resulting requirements for the cushion material are numerous: sufficient gas retention, robustness, elasticity, transparency, weldability, compatibility of surface with other sole materials and acceptable costs. The "air" product series since its peak in the 1990s has maintained a significant share of total company footwear. The "air" technology is protected through a series of different patents.

From 1997 onwards, the company has been replacing SF_6 in the gas cushions by nitrogen, gradually. However, about 20% were not yet deemed replaceable by 2002.

Some of the company's US and international patents have recently expired thus making it possible in principle for other shoe manufacturers to apply the technology.

Under these circumstances, the company began using PFC (perfluoropropane) in place of SF_6 in the production of its cushioning systems for the period from 2003 to 2006. Afterwards greenhouse gases should no longer be used.

Sport shoes with SF_6 filled soles are not manufactured, but widely used in Germany.

Domestic SF_6 input and disposal emissions

1. Activity Data. Input, bank, and amount for disposal

1.A Annual Input of SF_6 through sport shoes

Annual SF_6 input (In_{bank}) through sport shoes since 1992 is entered in the first column of Table 1.

1.B SF_6 bank in sport shoes

All sport shoes containing SF_6 are imported, so that domestic manufacturing emissions (Em_{manu}) do not arise. At the end of the current year n the SF_6-Bank (EB) in sport shoes has increased against the previous end-of-year bank (EB n-1) by the input in the current year (In_{bank} n). Over the same time, the bank has diminished by the SF_6 amount remaining in old shoes to be disposed of (De_{bank} n). The general equation is:

Equation 1:	$EB\ n = EB\ n\text{-}1 + In_{bank}\ n - De_{bank}\ n$

The quantity for disposal (De_{bank} n) equals the input (In_{bank} n-LT). This is the input during that year which dates an average lifetime (LT) back. Assuming a sport shoe lifetime of 3 years, the amount for disposal in the current year (De_{bank} n) equals the input three years ago (In_{bank} n-3). The equation is now:

Equation 2:	$EB\ n = EB\ n\text{-}1 + In_{bank}\ n - In_{bank}\ n - 3$

Condition for equating the quantity due for disposal (De_{bank} n) the input dating three years back (In_{bank} n-3) is that the gas filling has remained unchanged over the three-year-time. Strictly, this is impossible. Nevertheless, this simplification is acceptable. Although during the time from filling to disposal (bank period) constantly certain small quantities of SF_6 are emitting, these use phase emissions (Em_{op}) are not estimated. That is because there are no estimations available how much gas is released due to permeation from inside, and due to mechanical impacts from outside. ÖR attributes all emissions to disposal emissions. In this way, bank emissions are implicitly taken account of.

1.C SF_6 in Sport Shoe Soles for Disposal

Under 1.B it was said and presented in equations that the unaltered input from three years before is disposed of over the current year. With a delay of 3 years, the amount for disposal (De_{bank} n) follows the input (In_{bank} n-3). The equation is:

Equation 3:	$De_{bank}\ n = In_{bank}\ n - 3$

In Table 1, all activity data needed is compiled: 1. annual Input, 2. annual amount for disposal (identical to input quantities dating three years back) and 3. end-of-year banks of SF_6 in sport shoe soles. End-of-year bank and average bank serve for illustration only, as operating emissions are not determined.

Table 1: 1992-2002 Input, amount for disposal, and bank of SF_6 in sport shoe soles in Germany, in t/y				
	Input	End-of-year bank *	Average bank B**	Disposal
	In_{bank} n			De_{bank} n = In_{bank} n-3
1992	confidential	n.e.	n.e.	n.e.
1993	confidential	confidential	n.e.	n.e.
1994	confidential	confidential	confidential	*n.e.*
1995	confidential	confidential	confidential	confidential
1996	confidential	confidential	confidential	confidential
1997	confidential	confidential	confidential	confidential
1998	confidential	confidential	confidential	confidential
1999	confidential	confidential	confidential	confidential
2000	confidential	confidential	confidential	confidential
2001	confidential	confidential	confidential	confidential
2002	confidential	confidential	confidential	confidential

Explanation: * EB = EB n-1 + In_{bank} n – In_{bank} n-3. ** B = (EB_{n-1} + EB_n) x 0,5.
n.e. = not estimated.

Comment

Input and – with a delay of three years – emissions were increasing until 1996 and 1999, respectively. Since then they have dropped. Meanwhile (2003) NIKE has completely converted its manufacture to gases other than SF_6, which is to say to nitrogen for the bulk and to perfluoropropane for the remainder. Therefore, SF_6 emissions may be assumed to run out by 2006. Afterwards, PFC emissions will arise from sport shoe soles for further three years.

2. Estimation of activity data and sources of information

Since 1996, the manufacturer of sport equipment, NIKE, has only published figures of his worldwide use of SF_6 for shoe soles. At a meeting with the EU Commission (DG Environment), the company representative R. Macmillan assessed the EU share in the total SF_6 fill in shoes of this type at 25%, generally. The SF_6 in shoe soles delivered to Germany was estimated by Öko-Recherche at 25% of the EU amount, according to the German share in the total EU population. Data before 1996 stem from an estimation by NIKE's German branch office communicated to Öko-Recherche in 1996.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Nike International, Niederlassung Deutschland, Weiterstadt, Fax to ÖR, 07.05.96.
Nike Inc., Beaverton (USA), Letter to Greenpeace Denmark, 12.09.97; pers. comm. to ÖR, 07.09.99.
Nike European Office, Brussels, 17.06.02.
SF_6 in sport shoes, Ch. 4.3, in: Costs and the impact on emissions of potential regulatory framework for reducing emissions of hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride (final report). Prepared on behalf of the European Commission (DG ENV) by J. Harnisch (Ecofys) & W. Schwarz (Öko-Recherche), February 4, 2003, p. 22-23. http://www.oekorecherche.de/english/berichte/volltext/ecofys_oekorecherchestudy.pdf

3. Emission factor at decommissioning

Recovery on decommissioning does not take place. At the disposal of old shoes 100% of the initial SF_6 filling from three years before is released into the atmosphere. In other words, the disposal emission factor (EF_{disp}) amounts to 100%.

Emissions of year n are equal to filling of year n-3. This is why operating emissions during the use-phase of the shoes do not need additional consideration.

4. SF_6 emissions from sport shoe soles as of 1995

Given a certain SF_6 amount for disposal and the factor of emissions (EF_{disp}) of 100%, emissions are identical to the amounts for disposal themselves (see Table 1). These two – identical – time series are shown in Table 2.

Table 2: 1995-2002 Emissions of SF_6 at the disposal of sport shoes, in t/y

	Disposal	Emissions
1995	confidential	confidential
1996	confidential	confidential
1997	confidential	confidential
1998	confidential	confidential
1999	confidential	confidential
2000	confidential	confidential
2001	confidential	confidential
2002	confidential	confidential

Sources: Table 1, right column.

5. Quality control and uncertainty assessment of data

Activity data. The worldwide figures of SF_6-consumption for shoe soles are deemed sufficiently reliable. The 25% share of the EU member states in this quantity is an estimation made by NIKE itself. However, this estimation is rather rough. This even more applies to the estimation of the German share, which is not only derived from the previous estimation but also simply based on Germany's population. It is conceivable, that the German share, which was calculated at constant 6.25% of the worldwide SF_6 consumption, ranges between 4 und 8% in reality.

The lifetime of 3 years is an average value. Some shoe soles and their gas cushions do not last so long, some do not loose the gas before 10 years' use. The average emission time "three years after filling-in" was not checked by ÖR.

6. Relation to IPCC method

Activity data. Under "3.5.2 Other sources of SF_6" IPCC GPG suggests for applications which use the adiabatic property of SF_6 (car tyres, shoe soles) a top-down approach based on data of SF_6 sales into the respective application. The procedure of ÖR follows that guidance. There was not even a need for interviewing gas distributors, since the only user supplied the data himself.

Emissions. ÖR follows the equation 3.23 of IPCC GPG.

Equation 3.23:	Emissions in year t = Sales in year t –3

7. Entry in CRF

The CRF-Table, where the data of SF_6 in sport shoes are primarily entered, is Table 2(II)Fs2, row 41, columns B (filled in), C (stock), D (fluid for disposal), and the emission column J (Emissions from Disposal). Column H (Emissions from manufacturing) remains empty just as column I (Emissions from stocks). Manufacturing emissions occur only abroad. Operating emissions are not estimated.

8. Confidentiality issue

For confidentiality, this data is taken together with the data on aircraft radar, and the aggregate data is entered in the same row 41.

F-Gas Sheet 36: Particle Accelerators

F-Gas	**SF_6**
Application	**Particle Accelerators**
Reported Years	**1995 - 2002**
Emission Type 4	**Operating Emissions from Bank**
Emission Type 1	**Manufacturing Emissions**
Emission Type 5	**Disposal Emissions**

Background

SF_6 is used in particle accelerators as insulating gas. Different-sized equipment is being used for research at university institutes, Federal institutions, and German research associations (Max-Planck-Gesellschaft, Helmholtz-, Fraunhofer-, Leibniz-Gemeinschaft).

Roughly the same number of equipment serves as "electron beam systems“ in the industry for manufacturing purposes like e.g. polymer cross-linking.

The third category comprises radiotherapy devices that are being used by medical institutions (hospitals etc.). These devices used CFCs before 1996.

The three aforementioned accelerators are "high-energy" devices with voltages of from 0.3 to more than 23 MV. A fourth category is so-called low-voltage systems with less than 0.3 MV. They are exclusively used in industry.

For by far most research and industrial purposes, high-voltage equipment is used where the accelerator is placed together with a high-voltage generator in a tank insulated with SF_6 that is mostly pressurized. The high-voltage source is usually a Van-de-Graaff generator; latterly more compact high-voltage generators with diodes in cascade technique have come in use. For adjustment and repair of the equipment, the tank must be opened. The insulating gas is then pumped into a storage tank. Gas losses occur at accelerator and storage tank in pumping, and when pressure relief valves are actuated.

Research accelerators, operating under varying conditions, usually need to be opened more frequently than industrial electron accelerators. For medical radiotherapy by means of electron and photon irradiation in case of cancer therapy, industrially preset particle accelerators are used. Their so-called hollow conductors, where the particles are being accelerated, are filled with SF_6 insulating gas in order to prevent electric flashovers.

Generally can be said, the SF_6 consumption for first fill of new equipment and re-fill to compensate emissions depends on the size of the equipment, the working pressures, and the operating conditions.[6]

[6] World banked capacity for university and research particle accelerators is roughly estimated to be 500 t with annual emissions of 35 t, world banked capacity for industrial particle accelerators is roughly estimated to be the same size and so are the emissions from this source. World banked capacity for radiotherapy devices is roughly estimated to be less than 5 t with annual emissions of the same size.

I. SF_6 bank and operating emissions from bank

1. The special 2004 survey by Öko-Recherche

At the beginning of 2004, ÖR conducted a total survey of the domestic use of particle accelerators in order to update data dating back to 1996. In the course of this special investigation, both users and manufacturers were primarily inquired about the SF_6 charged in the manifold equipment and about the gas re-filling over the last seven years. Additionally, changes in the bank by acquisition and decommissioning were asked for. Because of this exercise, a clear picture arose. In Table 1, a time-series of the domestic SF_6 bank in five applications is presented. For simplicity, data on the banks are shown here in two-year intervals, and the number of units is presented in just one column (the complete data set is available in external spreadsheet calculation for reporting requirements).

2. SF_6 bank in five applications 1995-2003

Table 1: 1995-2003 SF_6 bank in particle accelerators by five user categories, in kg

User Category	1995	1997	1999	2001	2003	Units 95→03
University Institutes	30,571	30,571	28,467	28,067	28,317	13→11
Research Associations	19,555	19,555	19,305	19,305	19,305	10→9
Industry (high voltage)	13,750	19,700	22,700	24,422	24,422	12→19
Subtotal	**63,876**	**69,826**	**70,472**	**71,794**	**72,044**	**35→39**
Industry (low voltage)	1,600	1,600	1,600	1,600	1,600	14→14
Radiotherapy Institutions	156	162	168	173	178	350→401
Subtotal	**1,756**	**1,762**	**1,768**	**1,773**	**1,778**	**364→415**
Total	**65,632**	**71,588**	**72,240**	**73,567**	**73,822**	**399→455**

Sources: 2004 Öko-Recherche Survey.

Comment

The usually large-volume equipment for research and industrial purposes has slightly increased in number. From 1995 to 2003, four facilities have added the stock that increased from 35 to 39 units (see upper Subtotal line, to the right). Looking closer it can be seen that research equipment has decreased over the eight years by three units (from 23 to 20), whereas industrial equipment has increased by seven (from 12 to 19). As a result, the (subtotal) SF_6 bank has increased from 63.9 t to 72.0 tonnes. Average SF_6 charge of these accelerator types was 1.7 t in 1995 and 1.8 t in 2003.

The low voltage equipment in industry (average charge about 114 kg) has been constant in number with 14 units since 1995. The number of radiotherapy devices with average charges of just 0.44 kg has risen, from 350 to 401 units over the 1995-2003 period. The SF_6 bank in this equipment has slightly risen from 1.75 to 1.78 t.

3. Operating emissions from bank

In large equipment operating emissions are not estimated by means of emission factors but are ascertained based on surveyed annual top-ups by the users. Only for emissions from low voltage industrial systems and from small medical systems, emissions were estimated via emission factors, by experts from the manufacturing companies. Resulting operating emissions are shown in Table 2.

Table 2: 1995-2003 SF_6 Emissions from particle accelerators by five applications, in kg						
User Category	**1995**	**1997**	**1999**	**2001**	**2003**	**Units 95→03**
University Institutes	1,853	1,853	1,703	1,508	1,558	13→11
Research Associations	1,259	1,259	1,196	1,196	1,196	10→9
Industry (high voltage)	958	1,291	1,548	1,722	1,710	12→19
Subtotal	**4,070**	**4,403**	**4,447**	**4,426**	**4,464**	**35→39**
Industry (low voltage)	20	20	20	20	20	14→14
Radiotherapy Institutions	345	359	372	384	395	350→401
Subtotal	**365**	**379**	**392**	**404**	**415**	**364→415**
Total	**4,435**	**4,782**	**4,840**	**4,830**	**4,879**	**399→455**

Sources: 2004 Öko-Recherche Survey.

Comment

In case of the mostly large-volume particle accelerators for research and industrial purposes (first three lines in Table 2) the refilled quantities as (slightly delayed) indicators of operating emissions amount to more than 4 tonnes per year since 1995. From 1997 onwards, they range constantly around 4.4 tonnes/y. In Table 3 (see below), the implied operating emission factors are shown in the region between 6.2% and 6.4% for these first three accelerator applications.

Upon opening the tanks, SF_6 gas is pumped into storage tanks and after that returned. Obviously, this procedure entails considerable gas losses. The surveyed re-fills include emissions from highly emissive breakdowns. Industrial accelerators show (Table 3) relative emissions somewhat higher than research equipment (~7% to ~ 6%).

Following manufacturer indications, operating emission rates are low in small volume low-voltage industrial equipment with average SF_6 charges of 114 kg.

The situation is otherwise for radiotherapy devices at medical institutions. However their average gas charge is just 0.44 kg/device, the annual emission rate figures more than 200%. With a contribution of 0.25% to the overall SF_6 bank of particle accelerators, they contribute 8% to overall operating emissions, in 2003.

The high emission level results from the fact that these devices with high voltage up to 23 MV are opened two times a year when being serviced. At present, the SF_6 gas is not captured but completely released. The service personnel regularly top-up the devices from gas bottles brought with them.

4. Implied operating emission factors

Table 3: SF_6 Emission factors of particle accelerators by five applications, in % of bank					
User Category	**1995**	**1997**	**1999**	**2001**	**2003**
University Institutes	6.1	6.1	6.0	5.4	5.5
Research Associations	6.4	6.4	6.2	6.2	6.2
Industry (high voltage)	7.0	6.6	6.8	7.1	7.0
Subtotal	**6.4**	**6.3**	**6.3**	**6.2**	**6.2**
Industry (low voltage)	1,3	1,3	1,3	1.3	1.3
Radiotherapy Institutions	222	222	222	222	222
Subtotal	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**
Total	**6.8**	**6.7**	**6.7**	**6.6**	**6.6**

Sources: Data in Table 2 related to respective data in Table 1. n. a. = not applicable.

In Table 3, operating emission factors are shown as percentages of the respective banks. The by far most important particle high-voltage accelerators for research and industry show values of from 6.2 to 6.4%/y with a slight downtrend over the last eight years. These emission factors are "implied" factors as they result from enquired figures (bank, annual re-fill) that were really surveyed from all the 39 domestic users.

In contrast, experts from the supplying companies have provided the emission factors for industrial low-voltage accelerators as well as for medical devices. Therefore, these factors are estimated values.

5. Collection of activity data and emissions, and sources of information

At the beginning of 2004, ÖR conducted a total survey of the domestically used particle accelerators in order to update old data. In the course of this special investigation, both users and manufacturers were inquired about the SF_6 charged in their equipment and the gas re-filling over the last seven years. In high-voltage accelerators for research and industry, the new data are exclusively based on users' information.

For the remaining devices, suppliers gave information. In case of low-voltage industrial accelerators, the European market leader ESI provided data. The data on medical devices stem from the three companies supplying the German market: Siemens, Elekta, and Varian.

Sources of Information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

<u>High Voltage Accelerators (> 0.3 MV - > 10 MV)</u>

<u>University Institutes</u>
Uni Augsburg, Inst. f. Experimentalphysik, 08.01.04.
Uni Bochum, Dynamitron-Tandem-Laboratorium, 09.01.04.
Uni Freiburg, Physik. Inst., 09.01.04.
Uni Göttingen, II. Physik. Inst., 13.01.04.
Uni Jena, Inst. f. Festköperphysik, 13.01.04.
Uni Köln, Inst. f. Kernphysik, 09.01.04.
Uni Leipzig, Abt. Nukleare Festkörperphysik, 09.01.04.
Uni Leipzig, Chemie, Inst. f. Oberflächenmodifizierung, 13.01.04.
Uni/TU München, 29.01.04.
Uni Tübingen, Physikalisches Institut, 12.01.04.
Uni Stuttgart, Inst. f. Strahlenphysik, 12.01.04.

<u>Research Associations</u>
HMI Berlin, 16.01.04.
Leibniz-Institute, Dresden, Institut für Polymerforschung, 13.01.04.
FZ Rossendorf, Dresden, 12.01.04.
MPI f. Kernphysik, Heidelberg, 13.01.04.
IPP (MPI f. Plasmaphysik) Garching, 13.01.04.
MPI f. Metallforschung, Stuttgart, Inst. f. Physik, 02.02.04.
FhG INT (Institut f. Naturwiss. Techn. Trendanalysen), Euskirchen, 20.01.04.
PTB Braunschweig, AG 6.43 Ionenbeschleuniger, 13.01.04.

<u>Industry</u>
BASF AG, Ludwigshafen 29.01.04.
BGS Beta-Gamma-Service GmbH & Co KG, Bruchsal/ Wiehl/Saal, 30.01.04.
Continental AG, Hannover, 29.01.04.
Corning Cable Systems GmbH, Hagen (former RXS = Rose Xray Siemens) 30.01.04.

Draka Automotive, Wuppertal, 05.02.04.
Hewing pro Aqua, Ochtrup, 26.01.04.
Nexans Deutschland Industries, Nürnberg, 04.02.04.
Pirelli Kabel & Systeme GmbH, Neustadt/Coburg, 22.01.04.
Sumitomo Electric Schrumpf-Produkte GmbH, Norderstedt, 09.02.04.
TYCO Electronics Raychem GmbH, Ottobrunn, 19.01.04.
Vivirad-High Voltage Corp., Handschuheim (près Strasbourg) 21.01.04. (Supplier)

Industrial Low-Voltage Accelerators (< 0.3 MV)

ESI (Energy Sciences Incorporation), 20.01.04. (Supplier)
Tesa AG, Hamburg, Technology Center, 06.02.04. (User)

Radio Therapy (High Voltage < 23 MV)

Siemens AG, Erlangen, 16.01.04.
Elekta GmbH, Hamburg, 21.01.04.
Varian Medical Systems Deutschland GmbH, Darmstadt, 28.01.04, 04.03.04.
Deutsches Krebsforschungs Zentrum, Abt. W060 Strahlenschutz und Radiologie Dosimetrie, 19.01.04.

6. Quality control and uncertainty assessment of data I

The user data on high-voltage accelerators for research and industry are highly reliable as the equipment is valuable so that institutions/companies with accelerators generally employ experts who take special care of those. The data thoroughly stem from such experts. Regarding data completeness, it can be said that following sector experts no single accelerator is left out so that in the eyes of ÖR at the maximum one unit may be omitted but not more (> 95% completeness of activity data).

The number of low voltage systems and of medical devices is reliable too. The four suppliers keep lists of every single device installed in Germany. Regarding emissions, the factors show, of course, uncertainties, as the factors are not measured values but expert estimations. It should be added, however, that the different suppliers agree on the magnitude of emissions to a considerable extent.

7. Relation to IPCC method I

Under "3.5.2 Other sources of SF_6" IPCC GPG presents some "remaining applications" which include amongst others "equipment used in accelerators". The recommendation is given to treat emissions as "semi-prompt emissions if no specific information is available for this sub-source category". As specific information is available, the approach used here is deemed appropriate.

8. Entry in CRF I

The CRF-Table where stock and operating emissions of SF_6 from accelerators are entered primarily, is Table 2(II).Fs2, row 34, columns C und I. The data are entered together with the data on SF_6 for power capacitors under the common heading "Other Electric Equipment".

II. SF_6 consumption and manufacturing emissions

The 2004 special survey also asked users of high-voltage accelerators for changes in the bank caused by new acquisitions as well as by decommissioning old systems. Over the 1995-2003 period 9 systems have been placed in service for the first time, thereof 7 industrial systems. It is assumed that on first charging a loss of 1% arises. This value is derived from the electricity transmission and distribution sector. In Table 4 both the SF_6 quantities filled in the systems (C_{manu}) and the 1% charging emissions (Em_{manu}) are shown for large volume equipment.

As in the smaller application of low-voltage equipment new systems did not add to the bank nor old systems were decommissioned, there is there no need for documentation.

In the even smaller application of radiotherapy devices, a growth in new systems took place continuously by an annual number of 7 units on the average of the last seven years. As this means that only about 3 kg SF_6 per year add the bank through such devices, total domestic filling loss from these systems may be estimated to range between 30 and 300 g/y if an emission factor of 1% and 10%, respectively, is assumed. For lack of relevance in combination with hardly estimable uncertainties, we refrain from estimating these filling emissions and focus exclusively on high-voltage research and industrial accelerators (Table 4).

Table 4: 1995-2002 Annual SF_6 consumption for new HV accelerators in industry and research, and charging emissions, in kilograms

	1995	1996	1997	1998	1999	2000	2001	2002
Number of new units	0	2	1	2	1	1	1	1
SF_6 consumption	0	4450	1500	2500	1500	1500	222	250
Emission factor /y	1%	1%	1%	1%	1%	1%	1%	1%
Charging emiss in kg	0	45	15	25	15	15	2	2,5

Sources: 2004 Öko-Recherche Survey. In 2003, no new system was taken in service.

III. SF_6 Disposal and disposal emissions

According to the special survey, over the 1995-2003 period six systems have been decommissioned, all of them being research systems. It is assumed that on decommissioning a loss of 4% arises. This value is derived from the electricity transmission and distribution sector, but is set twice as high since the personnel are not familiar with such activity. In Table 5 both the SF_6 quantities due for disposal and the 4% disposal emissions are shown for the large volume equipment. Data on disposal of radiotherapy devices are not available, but would not be significant anyway.

Table 5: 1995-2002 Annual SF_6 disposal from HV accelerators in industry and research and disposal emissions, in kilograms

	1995	1996	1997	1998	1999	2000	2001	2002
Number of old units	1	0	0	2	3	0	0	0
SF_6 for disposal	1,780	0	0	1,100	2,254	0	0	0
Emission factor /y	4%	4%	4%	4%	4%	4%	4%	4%
Disposal emiss. in kg	71	0	0	44	90	0	0	0

Sources: 2004 Öko-Recherche Survey.

There is nothing to say about the activity data, which goes beyond the details given in Part I. The emission factors for charging and for disposal are the only new data in Part II and III. ÖR alone is in charge of their level of 1% and 4%, respectively.

Relation to IPCC method II / III

ÖR does not follow the IPCC GPG recommendation to treat emissions from accelerators as "semi-prompt emissions". As specific information is available, the approach used is deemed more appropriate.

Entry in CRF II / III

The CRF-Table where data on "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered is Table 2(II).Fs2, row 34, columns B and H. Data on "Amount of fluid remained in products at decommissioning" and "Emissions from disposal" are entered in row 34, columns D and J.

The data are entered together with the data on SF_6 for power capacitors under the common heading "Other Electric Equipment".

F-Gas Sheet 37: Power Capacitors

F-Gas	**SF_6**
Application	**Power Capacitors**
Reported Years	**1995 - 2002**
Emission Type 2	**Open Application (direct)**

Background

Since 1995, for gas impregnation of components of power capacitors SF_6 is used in an open process. All SF_6 supplied to the manufacturing plant serves as compensation for gas that has been released to the atmosphere during and after the impregnation process itself.

SF_6 consumption for manufacturing and manufacturing emissions

1. Consumption equals manufacturing emissions

All consumption (SF_6-purchases) is used to compensate for gas that has emitted on and after the impregnation process. In the very process, at most 0.1% of the supplied gas reacts with a plastic film surface to impregnate it. Therefore it is justified to set the SF_6 consumption equal to the SF_6 emission ($C_{manu} = Em_{manu}$), even though the manufacturing emission factor (EF_{manu}) is a little bit lower than 100%.

Table 1: 1995-2002 Consumption and emission of SF_6 on manufacturing power capacitors, in t/y		
	Consumption for Manufacturing	Manufacturing Emissions
1995	0.732	0.732
1996	9.377	9.377
1997	10.065	10.065
1998	12.000	12.000
1999	11.618	11.618
2000	13.443	13.443
2001	12.557	12.557
2002	8.875	8.875

Sources: See section 2.

Comment

From the beginning in 1995, the consumption/emission level rapidly increased to 13.4 tonnes/y in 2000. A significant drop took place in 2002. The users have announced that this application would be phased out in the first decade of the 21st century, because the product itself would be replaced by 2010 at the latest. For the next years, further decrease in SF_6 consumption/emission can be expected.

2. Collection of activity data and estimation of emission factor

In 2003, the data was surveyed the first time by the German Electrical and Electronic Manufacturer's Association ZVEI, and was communicated to ÖR. In the same year the capacitor manufacturers additionally delivered the consumption data on previous years. Regarding the SF_6 emission factor, it must be said that the manufacturers themselves equate consumption to emission.

At the ZVEI, Mr Johannes Stein is in charge of annual data collection from manufacturers.

Address: ZVEI, Stresemannallee 19, 60596 Frankfurt am Main.

3. Quality control and uncertainty assessment of data

The activity data and with that the emissions data are highly reliable. They originate directly from the manufacturers, which are few in number, so that transparency and completeness is guaranteed.

4. Relation to IPCC method

Under "3.5.2 Other sources of SF_6" IPCC GPG presents some "remaining applications" which include amongst others "equipment used in accelerators, lasers and night vision goggles". There is no special advice how to deal with SF_6 in capacitor manufacture.

5. Entry in CRF

The CRF-Table where data on "Filled in new manufactured products" and "Emissions from manufacturing" are primarily entered is Table 2(II).Fs2, row 34, columns B and H. The data are entered together with the data on SF_6 for particle accelerators under the common heading "Other Electric Equipment".

In 2004, in CRF recalculations were implemented for each year since 1995 so far reported in order to update the figures to the state of present-day knowledge.

F-Gas Sheet 38: Manufacture of Printed Circuit Boards

F-Gas	**CF_4**
Application	**Manufacture of Printed Circuit Boards**
Reported Years	**1995 - 2002**
Emission Type 1	**Manufacturing Emissions**

Background

CF_4 has an intentional use in electronics as a plasma etching gas, namely for desmearing in printed circuit board manufacturing.

Desmearing means cleaning of drilled holes in multilayer printed circuit boards in low-pressure plasma chambers. The plastic slivers of epoxy or polyimide resins in the boards, which consist of alternate layers of plastic and copper, are etched away in order to allow improved connection of the copper in the subsequent wiring.

This process is applied instead of wet-chemical processes by one large and several small printed circuit board manufacturers. The plasma gas generally consists of 20-30% CF_4 and 70-80% oxygen. As yet, there are two plants with continuous round-the-clock operation. Their gas throughput is 1.5 litres per minute. The approx. 40 smaller plants are operated discontinuously (batch operation) with gas throughputs of approx. 100 ml per minute.

In the printed circuit board manufacturing industry, there are alkaline exhaust gas scrubbers for capturing the reaction products, but no systems that could destroy unutilized or recombined CF_4 in the exhaust gas.[7]

[7] CF_4 is also used in small quantities for plasma cleaning other than in electronics, namely as an additive to oxygen for degreasing metal surfaces.

Domestic PFC consumption and manufacturing emissions

For many years, domestic consumption quantity of CF_4 for desmearing has been constant at a level of 2-2.5 t/y. Thereof only approx. 15% react chemically in etching, because molecules decomposed in the plasma partially combine again with each other in the waste gas (recombination). The so-called Utilisation Removal Efficiency (URE) amounts to 15%. Given the supplied quantity (annual consumption C_{manu}), the emission factor (EF_{manu}) is the inverse URE, which is to say, 85% (100%-85%) of CF_4 consumption.

In Table 1 not only annual consumption is entered, but also the manufacturing emission factor as well as manufacturing emissions, in absolute terms.

Table 1: Annual consumption, manufacturing emission factor, and emissions of CF_4 from manufacturing printed circuit boards (Desmearing), 1995-2002 in t/y

	Consumption (mean)	EF_{manu}	Manufacturing emissions
1995	2.3	85%	2.0
1996	2.3	85%	2.0
1997	2.3	85%	2.0
1998	2.3	85%	2.0
1999	2.3	85%	2.0
2000	2.3	85%	2.0
2001	2.3	85%	2.0
2002	2.3	85%	2.0

Sources: See sections 2 and 3.

Comment

Experts expect the annual CF_4 requirement for this process to be constant for the time being. There are no indications at present that past usage and emissions will change in the future.

2. Collection of activity data and sources of information (This published version of the report does not give information on personal phone numbers or e-mail addresses.)

Between 1996 and 2003, ÖR has inquired experts from application engineering and from special-gas trade three times independently about the applied quantities of CF_4. The answers were largely consistent with each other, which might be attributable to the manageable size of the domestic market.

Technics Plasma GmbH, Kirchheim bei München, 22.04.96; 08.03.01.
Buck Plasma Electronic, Neuenburg, 22.04.96.
plasonic Oberflächen GmbH, Gerlingen, 28.04.96; 31.03.99; 25.09.03.
Linde AG, Werksgruppe Technische Gase, Unterschleißheim, 29.04.96; 22.09.03.

3. Manufacturing emission factor

For CF_4 supplied to a plasma reactor where it is put through within such a short time that the term "bank" is inappropriate, the same URE as in semiconductor manufacturing is assumed, namely 15%. As there is no downstream exhaust gas abatement, the 85% of the CF_4 gas supplied is emitted unchanged or recombined in the exhaust gas from the plant.

Sources of information on the emission factor (EF_{manu} = 85%)

It depends above all on the Utilisation Removal Efficiency (URE), how much of the CF_4 consumption is released to the atmosphere. There are no fixed values, but at least a certain range within the URE will remain, depending upon the concrete conditions on application. It can generally be stated that URE depends upon molecular stability and – with regard to perfluorocarbons (PFCs) - rises with the number of fluorine atoms. Owing to the small number of fluorine atoms, the utilisation of CF_4 in the process chamber is rather low.

Air Products plc. Walton-on-Thames, 17.08.99.
Air Products plc. Letter 08.07.96; Annex: PFC Consumption Efficiencies for Processes Monitored.
Conners, A. /Raoux, S. (Applied Materials, Inc.): Emission Reduction Using Remote Plasma lean, SEMICON West ETS Technical Seminar, San Francisco, CA, July 1998.

4. Quality control and uncertainty assessment of data

Activity data. The interviewed experts independently estimated the annual supply (consumption) of CF_4 to have been constant over the past. This unanimity also applies to the order of magnitude. The annual quantity of 2.3 tonnes is an average value. The several estimates ranged between 2 and 2.5 tonnes.

ÖR has conducted a plausibility check for control purpose. In Germany, there are two large plants with gas throughputs of 1.5 litres/min and numerous small plants, which together put the same gas quantity through as both the large ones. The annual CF_4 throughput in case of one of the two plants (operated by the company Schöller in Wetter) can be calculated as follows:

Gas throughput per minute:	1,500 ml
CF_4 (share 25%) per minute	375 ml
CF_4 per hour	22.5 litres
CF_4 per year (24 h x 300 d)	162,000 litres
Number Mol (= /22,4)	7,232 mol
1 Mol CF_4	0.088 kg
Throughput in kg (7,232*0,088)	636 kg

One of the two large plants with continuous throughput needs 636 kg CF_4 per year, both of them need 1,272 kg/y. Provided that the further plants need together the same quantity once again, annual CF_4 demand totals 2,544 tonnes. This aligns well with the 2 to 2.5 tonnes from expert estimation.

Emission factor. The URE of 15% is the default value that is worldwide used for low-pressure plasma chambers in the semiconductor industry. In the absence of downstream waste gas abatement, the emission factor of 85% is the inverse URE (100% minus 15%).

5. Relation to IPCC method

IPCC GPG does not take notice of CF_4 in manufacture of printed circuit boards. However, there is a Table (3.15) with "default emission factors from semiconductor manufacturing" providing values for different applications in semiconductor industry. These values range from 0.7 to 0.9, so that they are in the order of the 85% (0.85) used by ÖR.

6. Entry in CRF

In the CRF Table 2(II).Fs2, CF_4 emissions from manufacturing printed circuit boards are entered together with CF_4 emissions from semiconductor manufacturing, in the same row 26 under the heading of column H "Emissions from manufacturing".

To avoid confusion, the consumption quantity is not entered. This is because the semiconductor industry does not report consumption quantities either.

F-Gas-Sheet 39: Semiconductor Manufacturing

F-gases	**PFC (CF_4, C_2F_6, C_3F_8, c-C_4F_8), HFC-23 (CHF_3), SF_6, NF_3**
Application	**Semiconductor Manufacturing**
Reported Years	**1995 – 2002**
Emission Type 1	**Manufacturing emissions**

Background

The semiconductor industry currently emits fluorocarbons (CHF_3, CF4, C_2F_6, C_3F_8, c-C_4F_8), nitrogen trifluoride (NF_3) and sulphur hexafluoride (SF_6) from its manufacturing process. These gases, collectively being referred to as fluorinated compounds (FC) are used in two important steps of semiconductor manufacturing: (i) plasma etching thin films and (ii) cleaning vapour deposition (CVD) tool chambers. In addition, a fraction of the fluorocarbons used in the production process is converted into CF_4.

Emissions cannot simply be derived from used quantities (sales of gas distributors). Two factors determine how much of the FC input is released to the atmosphere unaltered and thus contribute to global warming. The first is the utilisation removal efficiency of FC transformation in the plasma chamber. The second is the prevalence and efficiency of downstream exhaust gas treatment systems to destroy that fraction of the FCs that remains untransformed in the plasma. Moreover, a heel of roughly 10% per gas bottle has to be considered non-consumption.

Domestic FC consumption and emissions from manufacturing

1. Emissions as of 1995

Emissions data of the German semiconductor industry are available with respect to each individual fluid. Emissions are calculated from the annual consumption of each plant (fab) according to a uniform equation. They are aggregated then and reported to the German Umweltbundesamt. Basic data of calculation (consumption, exhaust gas systems saturation rate) are not public nor are the emissions data. They, however, can be seen for reviewing. Since only emissions are reported, but not the consumption they are based on, a judgement is not possible on the real efforts of the semiconductor industry to retain emissions. Table 1 shows the emissions by single gases and years.

Table 1: 1995-2002 F-gas emissions from semiconductor manufacturing, in t/y

	C_2F_6	CF_4	CHF_3	SF_6	NF_3	C_3F_8	C_4F_8
1995	conf.	conf.	conf.	conf.	conf.	conf.	conf.
1996	conf.	conf.	conf.	conf.	conf.	conf.	conf.
1997	conf.	conf.	conf.	conf.	conf.	conf.	conf.
1998	conf.	conf.	conf.	conf.	conf.	conf.	conf.
1999	conf.	conf.	conf.	conf.	conf.	conf.	conf.
2000	conf.	conf.	conf.	conf.	conf.	conf.	conf.
2001	conf.	conf.	conf.	conf.	conf.	conf.	conf.
2002	conf.	conf.	conf.	conf.	conf.	conf.	conf.

Sources: ZVEI 2003.

Comment

The time series shows a continuous emission rise until 2000. This is, amongst others, due to doubling the number of companies from seven to fourteen over the 1995 to 1999 period. The growth in number does not only go back to new-built fabs but also to fabs that were already manufacturing in 1995 but did not take part in the monitoring of that time. Therefore, emissions before 1999 are systematically understated, as projections have never been carried out. Emissions, which significantly lowered in 2001, grew again in 2002. Not only the temporary decrease but also the renewed increase in emissions is attributable to economic influences (fluctuations of semiconductor production) as well as, to a certain degree, to measures having been taken to reduce emissions over the recent years.

2. Estimation of data and sources of information

Reported emissions until 2000 are based on surveys conducted by EECA-ESIA (European Electronic Component Manufacturers Association – European Semiconductor Industry Association). National manufacturers were inquired about production capacities, gas quantities applied, and waste gas abatement systems installed. From 2001 onwards, data of German semiconductor manufacturers are surveyed and evaluated by the manufacturers association ZVEI (Components Division), based on a voluntary agreement. The calculation follows the equation used by the World Semiconductor Council (WSC). At the ZVEI, Dr. Winter and Dr. Pophal are responsible for monitoring and reporting.

3. Quality control and uncertainty assessment of data

Reported emissions are considered relatively precise, as far as precision is possible within the frame of a calculation based on consumption data. Estimating emissions by continuous measurements is currently not viewed as a technically or economically viable means. Data is being checked for plausibility before it undergoes a process of quality assessment, quality control, and verification within the manufacturers association. Understating emissions before 1999 goes back to the fact that the surveys in those early years did not comprise the entirety of the manufacturing (and emitting) plants. Compensating backward projections have never been carried out. (Information: Beatrix Pichl, Texas Instruments Deutschland GmbH, Freising. ÖR suggested that ZVEI should retrospectively estimate actual emissions for 1995 to 1997, in 2004 or in 2005.

4. Relation to IPCC method

The calculation method used by WSC is the FC specific Tier 2c approach as described in IPCC GPG, chapter 3.6. This method calculates emissions for each FC used based on company-specific data on gas purchases and on emission control technologies. It uses industry-wide generic default values for the fraction of the purchased gas remaining in the shipping container after use (h), the fraction of the gas "used" (destroyed of transformed) in the semiconductor manufacturing process, and the fraction of the gas converted into CF_4 in semiconductor manufacture. The Tier 2c method does not distinguish between processes of different types (CVD or etch) but uses default emission factors from Table 3.15.

The WSC equation for FC (PFC) emission calculations is as follows:

$$\text{Emissions for PFC}_i = \text{PFCi}*(1-h)[(1-C_i)(1-A_i)*GWP_i + B_i*GWP_{CF4}*(1-AC_{CF4})]$$

h = fraction of gas_i remaining in container (heel) Default: 10%.
PFC_i = purchases of gas_i = kgs_i
kgs_i = mass of gas_i purchased
GWP_i = 100 yr global warming potential of gas_i
C_i = average utilization factor of gas_i (average for all etch and CVD processes) = $1-EF_i$
EF_i = average emission factor of gas_i (average for all etch and CVD processes)
B_i = mass of CF_4 created per unit mass of PFC_i transformed
A_i = fraction of PFC_i destroyed by abatement = $a_{i,j}*V_a$
AC_{CF4} =fraction of PFC_i converted to CF_4 and destroyed by abatement = $a_{CF4}*V_a$
$a_{i,j}$ = average destruction efficiency of abatement $tool_j$ for gas_i
a_{CF4} = average destruction efficiency of abatement $tool_j$ for CF_4
V_a = fraction of gas_i that is fed into the abatement tools.

5. Entry in CRF

Semiconductor gases can be attributed best to emission type 1 (manufacturing emissions). Thus, emissions are entered in CRF Table 2(II).Fs2, rows 25-30, under the heading of column H "Emissions from manufacturing". Consumption data are not reported.

NF_3 is not yet considered, as its GWP (8000) was not established by IPCC in 1995.

F-Gas-Sheet 40: Production of Aluminium

F-Gases	**PFCs (CF_4, C_2F_6)**
Application	**Production of Aluminium**
Reported Years	**1995 – 2002**
Emission Type 7	**By-product Emissions**

Background

Aluminium smelting is the main source of CF_4 emissions, and generates a considerable part of C_2F_6 emissions. These emissions are not a consequence of any targeted use of the gases in the production process, but arise as a by-product of the electrolytic reduction of alumina (aluminium oxide) to aluminium.

During the process of aluminium electrolysis as such, the combination of carbon with fluorine to form CF_4 and C_2F_6 does not occur. An anode effect occurs when the alumina is fed in the bath not exactly in step with its consumption. Too low concentration can trigger the "anode effect". The anode effect is characterized by a strong rise in voltage. The over-voltage suffices to release fluorine from the electrolyte, so that the fluorine reacts with the carbon of the anode blocks to organic fluorides.

By introduction of new cell types together with computer-controlled alumina feeding technologies (point feeding), the frequency of anode effects could be reduced significantly and with that the PFC emissions.

PFC emissions from aluminium production

1. Development of emissions since 1995

Due to comprehensive modernization of cells in German smelters absolute emissions from this sector dropped over the 1995-2002 period by 72%, although the production of primary aluminium increased slightly over the same time. The specific emission factor (kg CF_4 / t Al) in German smelters dropped from 0.363 to 0.088.

Table 1: 1995-2002 Emissions of CF_4 and C_2F_6 from aluminium smelters in Germany, in t/y

	Emission CF_4 in t/y	Emission C_2F_6 in t/y	Aluminium production t
1995	209	21	575,000
1996	198	20	576,500
1997	145	14.5	571,900
1998	157.2	15.7	610,000
1999	116	12	632,000
2000	48	4.8	643,793
2001	50.1	5	652,796
2002	58,1	5,8	654,502

Sources: See section 2.

2. Estimation of emissions

Data on PFC emissions from production of primary aluminium are available thanks to a self-commitment of the German aluminium industry, which dates back to 1997. Since 1998, the Primary aluminium Chapter in the Federation of German Aluminium Industries has reported for the previous year the development of PFC emissions from this sector. This data bases on two measurement-based surveys of CF_4 emissions in all German smelters, which were carried out in 1996 and 2001. On this basis, typical CF_4 emissions per anode effect were determined for specific types of operation. As anode effects had been recorded in all (five) existing smelters for several years, annual CF_4 emissions per smelter could be determined as the product of number of anode effects and the smelter-specific CF_4 quantity per anode effect in 1996 and 2001, respectively. Emissions of C_2F_6 and CF_4 are assumed to arise in a fixed relationship of one to ten.

It should be mentioned that the 1995 value was estimated by Öko-Recherche 1999.

The monitoring report is annually submitted to the Federal Ministry of Environment by the Primary Aluminium Chapter in the Federation of German Aluminium Industries (Fachverband Primäraluminium im Gesamtverband der Deutschen Aluminiumindustrie, GDA). It is not made open to the public. Address: Fachverband Primäraluminium, Am Bonneshof 5, 40474 Düsseldorf.

3. Quality control and uncertainty assessment of data

Emission data are based on field measurements, which provided smelter-specific relationships between operating parameters such as frequency and duration of anode effects, technologies involved, and the CF_4 emissions. This procedure can ensure a high degree of data reliability as long as measurement programmes are repeated at regular intervals (5 years in Germany). Data certainty is higher compared to using default emission factors that are related to metal production. Accuracy, however, is lower than in continuous monitoring of emissions by direct measurement of PFCs in emissions of the exhaust duct of the smelter.

The fact that C_2F_6 emissions have not been measured, but are estimated by means of a fixed percentage (10%) of CF_4 emissions, might be a source of error, which indeed is not of high relevance as international measurements have sufficiently well confirmed the order of magnitude (10%).

4. Relation to IPCC method

The approach applied in Germany is in accordance with the Tier 3b method calling for "Smelter-specific relationship between emissions and operating parameters based on field measurements" (IPCC GPG, Ch. 3.3). This approach is considered "the most accurate method" together with the method of monitoring smelter emissions continuously (Tier 3a).

5. Entry in CRF

The CRF Table where PFC emissions are entered is Table 2(II), C, and E: for CF_4 emissions the cell E9, for C_2F_6 emissions the cell E10. The production of aluminium is entered in the columns C in the rows 9 and 10.

List of Abbreviations

B_n	Average bank over the current year
C_{manu}	Consumption for manufacturing
De_{bank}	Decrease in bank (Decommissioning)
EB_n	Bank at the end of the current year
EB n-1	Bank at the end of the last year
EF_{disp}	Factor of disposal emissions
EF_{manu}	Factor of manufacturing emissions
EF_{op}	Factor of operating emissions
Em_{disp}	Emissions on disposal
Em_{manu}	Emissions from manufacturing
Em_{op}	Operating emissions (from bank)
In_{bank}	Input to domestic bank
In_{bank} n	This year's input to domestic bank
In_{bank} n-1	Last year's input to domestic bank
LT	Life time (normal)
n	Current year
ODS	Ozone Depleting Substance (CFCs, HCFCs, Halons)
ÖR	Öko-Recherche

Special Acknowledgement

Above all, the author would like to thank Katja Schwaab (German Umweltbundesamt) on whose initiative this report was carried out. Throughout the whole course of this project, he exchanged opinions with her and has taken her ideas and suggested alterations on board almost without exception. It is also thanks to her that this originally internal report underwent necessary revision so that it could be made open to the public.