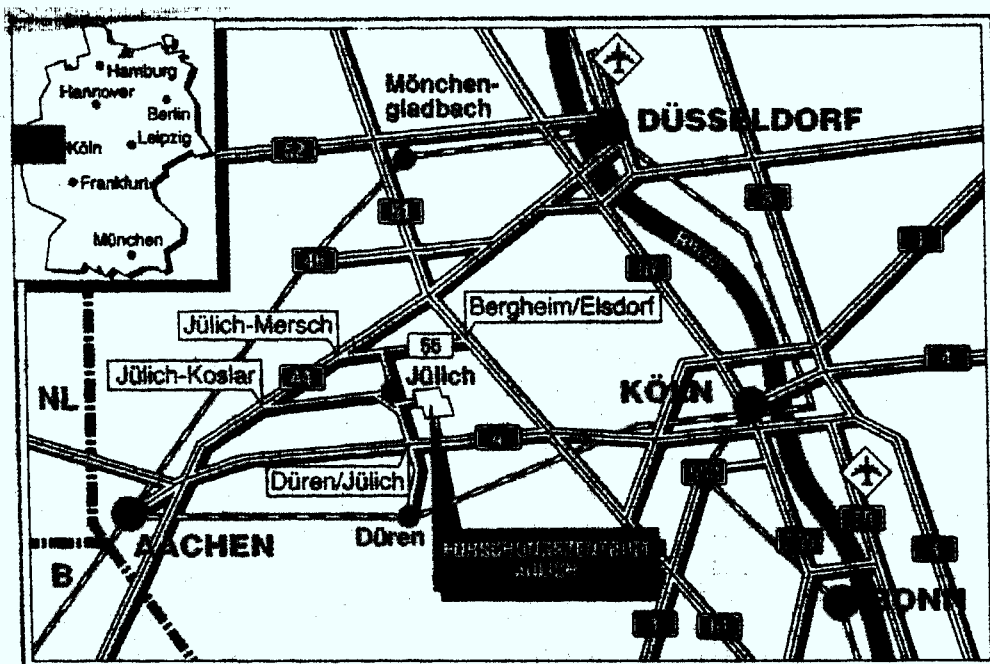


Programmgruppe Technologiefolgenforschung

**Internationale
Treibhausgasverifikation Nr. 9**

**International Greenhouse Gas
Verification
– Elements and Institutions –**

J. C. di Primio W. Fischer H.-J. Hoffmann
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Studie im Rahmen des Projekts IKARUS, Teilprojekt 9.

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PREFACE

About 150 states, among them the Federal Republic of Germany, signed the Framework Convention on Climate Change at the United Nations Conference on Environment and Development in Rio in 1992. This convention is the first step on the way to a climate protection regime: Further protocols should be negotiated and signed by as many states as possible in order to freeze their CO₂ emissions or even reduce them by a defined amount and to progressively terminate the destruction of the forests. Other greenhouse gases such as methane (CH₄) and nitrous oxide (N₂O) can be included in further protocols at a later date. A model for such international action is the "Vienna Convention for the Protection of the Ozone Layer", its "Montreal Protocol" and the following amendments.

In negotiations on these treaties the states will have to clarify whether they intend to take the legal, institutional and instrumental steps required in order to verify whether all state parties have really met their obligations with respect to emission reduction and protection of the forests (verification of compliance).

On the German side, preparatory work for a verification system is being carried out inter alia within the framework of the BMFT/IKARUS project set up in October 1990 for a period of four years. The aim of the project is to develop tools for national climate gas reduction strategies. These tools comprise a data base with technical, ecological and economic data on present and future components of the German energy system as well as a simulation and optimization model drawing on this data base. KFA-TFF is responsible for the overall project management and for Subproject 9 "International Greenhouse Gas Verifications", which forms a link between the IKARUS project and international efforts at emission reduction.

In searching for models of international verification systems in other issue areas, arms control inevitably comes to mind and, in particular, the safeguards of the International Atomic Energy Agency (IAEA) under the atomic Non-Proliferation Treaty (NPT) and the new convention on the Prohibition of Chemical Weapons. In analysing these verification areas, three factors of influence seem to be of particular significance, i.e. verification suitability, verification capability and verification density.

- The verification suitability of an object, a sector etc. subject to safeguards is of a systematic nature. This verification suitability results from the structures, characteristics and configuration of the object to be monitored.

- The practical implementation of a verification system finally depends on the availability of qualified staff resources and adequate methods, equipment and tools in order to implement the verification measures with the required sensitivity and accuracy. These requirements are referred to as verification capability.
- The verification density is determined by political driving forces. The greater the certainty is to be that other countries have complied with the provisions of a treaty, the closer must be the verification of their actions. The verification density must be increased.

In order to agree on a practical verification system, these essential factors and peculiarities must be analysed and defined for each individual greenhouse gas and emission sector. In detail, this results in the following tasks:

- defining the political verification requirement
- analysing the characteristics of emission sources
- examining the quantitative recording of greenhouse gases
- reviewing institutional aspects of verification
- identifying and evaluating the verification tools
- providing a synthesis of these activities and developing verification concepts.

In all these areas, studies under the IKARUS project are also carried out in cooperation with institutions abroad and published in the series "International Greenhouse Gas Verification". The following study based on the third interim report for the IKARUS project.

G. Stein

International Greenhouse Gas Verification

1. Introduction (G. Stein)

Two results became particularly obvious at the international Rio Conference in 1992. Firstly, it became apparent that the environmental aspect in general terms has become one of the essential topics of national and international politics. The introduction of new national laws and international treaties increasingly reflects this growing environmental consciousness. On the other hand it can be seen from the protracted negotiations on bringing the international framework convention on climate change into being how complex this issue area is and how controversial the topics are. This complexity and controversy is also reflected in discussions on verification aspects of the international greenhouse gas convention.

The aspect of "International Greenhouse Gas Verification" is the field of work for IKARUS Subproject 9. It thus represents the international link to the national IKARUS project where a suitable set of instruments is being developed for the analysis of national greenhouse gas reduction strategies.

International greenhouse gas verification can be generally assigned to the field of environmental verification. This may be regarded as a verification of obligations undertaken by nations within the framework of international environmental agreements. This is a relatively new problem, the solution to which is subjected to intense dynamics, as can also be established for the process of the framework convention. The 1992 Rio Conference and its results represent an initial culmination of this development, where the status of discussions was fixed for the time being, but which is to be dynamically developed and polished in the further negotiations of INC 94 and 95, as well as in preparation for the first conference of the parties (COP) to be held in Germany in 1995. This also applies to the technical and organizational aspects of greenhouse gas verification. Nevertheless, the Rio results should continue to be regarded as an initial orientation guideline.

Apart from the conditions on verification activities already laid down in the framework convention, additional considerations have thus resulted in the follow-up INC (International Negotiation Committee) conferences. Furthermore, working groups have been established within the framework of the IPCC (International Panel on Climate Change) and OECD (Organization for Economic Cooperation and Development) concerning themselves with the question of verifying the obligations undertaken by states within the framework of the climate convention.

In the first instance, these analyses are focused on obligations to present reports and thus in particular on the technical aspects of the data base to determine greenhouse gas emissions and sinks. The standardization of this data base is regarded as the primary task. Review mechanisms in the sense of a verification will only be discussed to the extent that this declaration is analysed with respect to consistency and transparency, i.e. verification takes place here without an independent review of individual elements of the declared data base.

The second sector of the states' obligation to present reports within the climate convention concerns measures and policies for greenhouse gas reduction. The INC, OECD and IPCC are still in the early stages of determining control elements to implement these reduction measures.

The present study deals with the aspects described above as subsectors or the first stage in a comprehensive greenhouse gas verification. In order to handle this general problem, some particularly characteristic structures of environmental verification will first be discussed in comparison with other verification sectors. An obvious difference is immediately apparent from the following table (Tab. 1.1).

Verification Regimes			
Issue Area	International Treaty	Verification Objects and Amount	Fundamental Verification Measure
Nuclear	Non-proliferation treaty	Nuclear material ~ 10^3 t	Material accountancy
Chemical	Chemical weapons treaty	Toxic chemicals ~ 10^6 t	Ad hoc inspections
Climate change	Framework convention on climate change	Greenhouse gases ~ 10^9 t	Examination of plausibility and consistency

Tab. 1.1: Verification systems

The table reveals that in the case of greenhouse gas verification, in contrast to the international verification of other technological fields, such as nuclear energy or chemistry, it is not possible to make a quantitative record and thus undertake veri-

fication by measuring methods. In contrast, for example to international nuclear material safeguards, only plausibility or consistency verification can play the decisive role in greenhouse gas verification. Nevertheless, analyses undertaken in the study reveal that measurements of individual elements in the data base may make a positive contribution towards implementing these plausibility and consistency examinations.

A further essential difference in the environmental issue area from other technological sectors or arms control is to be found in the low significance attached to the security aspect resulting from environmental risks. Consequences for the definition and application of verification elements can be derived from this fact.

These initial considerations enable questions to be identified which must then be answered in the study:

- questions of the necessity of greenhouse gas verification
- questions of verification density
- questions of the feasibility and applicability of verification concepts, methods and techniques
- questions of organization in order to implement these verification measures.

The structure of the study is also predetermined by these questions. The need for verification and the verification density of international greenhouse gas safeguards will be dealt with first, then possible verification measures proposed and assessed, and finally aspects of the institution of a greenhouse gas verification will be discussed. A more extensive and comprehensive analysis of the subject area of greenhouse gas verification thus results in the present study than is possible within the framework of the INC, or indeed the OECD or IPCC, which take a bottom-up approach starting with the declarations and then identifying appropriate verification mechanisms from them. In contrast, this study follows the top-down principle beginning with the political analysis of the need for verification and then concentrating on determining possible verification elements.

The starting point for the discussion of different verification elements in a possible greenhouse gas verification is provided by the obligations which the states undertake in order to achieve predetermined goals. As already mentioned, these obligations may be oriented towards quantitative reduction or stabilization goals for the greenhouse gases, or else include qualitative elements manifesting themselves in the establishment of policies or measures for greenhouse gas verification. The obligation to present reports arises from these commitments on the part of individual

states, the central element of which is represented by the numerical recording of national greenhouse gas inventories. In addition there are lists of greenhouse gas measures intending to serve to reduce or stabilize these inventories. They therefore involve restrictions of greenhouse gas emissions on the one hand and also the construction of sinks on the other. These reports are supplemented by general national information relevant to greenhouse gases in the so-called national report. All this information may be regarded as a declaration in the sense of verification. As already described, the quantitative component of these obligations should be verified on the basis of consistency and plausibility evaluations. This process may in principle take place in two steps:

- internal consistency and plausibility verification exclusively within the declared information basis
- external consistency and plausibility verification also on the basis of additional information obtained independently.

The first step is the subject of previous analyses at the INC, and also discussions held by the IPCC and OECD. The present study will also consider the second stage which means a further step towards a denser verification. For this reason, aspects of a direct measurement of greenhouse gases and also the general applicability of existing pollutant measuring networks will be investigated.

As a verification element, implementation control is concerned with the qualitative element of the obligations, that is to say the measures and policies for climate protection. Apart from the impact analysis, methods for performance review are also proposed, by means of which the desired introduction of these elements of the greenhouse gas convention may be verified and evaluated. In particular, sector-specific energy models, as also developed within the framework of the IKARUS project, should be applied for the impact analysis. However, in the discussion and evaluation of this method it must be remembered that this is an extension of the classical verification concept.

The element of remote sensing may serve both for the quantitative recording of greenhouse gases as well as for evaluating the implementation of activities, for example in the agricultural or forestry sector. Macro- and also micro-economic models may be regarded as a verification element, by means of which both the quantitative elements of the greenhouse gas inventories, environmental measures and also general information from the national reports may be linked and assessed.

The final chapter "Institutions" deals with possible organizations capable of realizing the proposed verification concepts and elements in practice. In this connection, use is also made of the structures already proposed at the INC.

The enumeration and treatment of the verification elements presented here does not yet represent a consistent system but is in the first instance to be regarded as an exploration of possible subelements in a comprehensive greenhouse gas verification.

2. Need for Verification (W. Fischer)

The development of a verification concept, of procedures and techniques for the framework convention on climate change and its proposed protocols must be preceded by an analysis of the general verification problem and its causes. Although verification, i.e. compliance examination on the part of states in policy issue areas, in this case global protection against anthropogenic climate change, is influenced by the specific political and technical conditions in the issue area, nevertheless it always remains the expression of basic problems of organizing and securing cooperation between states, which in view of global interdependence and increasing pressure to solve problems must enable "governance without government" [Young 92, p. 253] in the "anarchic" international system.

2.1 Verification Problem

Verification problems occur in large numbers, often with different designations, in various issue areas. They can be found wherever government actors are not prepared to rely upon mutual undertakings of compliance (largely contractual by international law) with agreed norms, rules and goals only [Efinger 90]. In these cases there is a need for verification expressed in the desire for information in order to be able to examine compliance. Verification should provide certainty about whether the agreements are being complied with by all states involved or whether violations occur. Certainty is achieved when the need for verification and verification capability can be harmonized, i.e. when states actually receive the information they believe they need. However, verification needs may be different, i.e. states may call for more or less information, and demand more or less verification. If there is a great need for verification and if this is realized in corresponding verification measures which scrupulously examine compliance then this would be defined as a high verification density. A verification system is regarded as having a slight density if it only permits superficial insights into the states' behaviour.

The need for verification and verification capability are therefore not constants but rather dependent politico-technical variables. The need depends on the degree of international suspicion and the political relevance of the contractually regulated issue area. Thus in the issue area of security (disarmament, arms control) the need for verification is very high as a rule, whereas in the issue area of the environment it is perceptibly lower [Ausubel 92]. Verification capability is the term for the technical and other potential for obtaining the information necessary to verify the com-

pliance of the other respective actors. The relation between the need for verification and verification capability determines the extent of certainty that countries may demand about the behaviour of others. If the verification need is high and the capability low there is a lack of certainty; if the need is low but the capability high then absolute certainty is obtained. There are different degrees of certainty between these two extremes (cf. [Efinger 90]).¹ The degree which appears adequate is associated with basic assumptions about the latent (non)compliance of states and is influenced by a political perception process in which the risks must be weighed up. On the one hand, there is the risk that states may violate the treaty provisions without being detected and thus obtain advantages. If states regard this as the greatest risk for their interest then it may be assumed that they would wish to dispense with a treaty. On the other hand, states must consider and weigh up for themselves the negative consequences of a lack of contractual regulation for this problem.

The assessment of the general compliance of the states has a great influence on the need for verification.² If compliance is regarded as fairly high then the need for verification will be lower (and vice versa). In the following section the question will therefore be posed of the knowledge which is available about compliance by states from the perspective of the two most important schools of thought on international relations, neorealism and institutionalism.

2.2 Compliance and Need for Verification

Whereas in the issue area of arms control, compliance was regarded as relevant by politicians right from the beginning and was thus a topic for the political sciences [Efinger 90], it has only been systematically analysed in the issue area of environmental protection since the early nineties [Ausubel 92; Fischer 91; EPA 90], without politicians having devoted comparable attention to the subject. The verification of environmental treaties has become relevant for research (and will probably soon receive more interest from politicians) since the number and significance of environmental protection treaties has increased.

1 Even a low-density verification system may therefore create "certainty" since this should not be understood absolutely but rather defined via need and capability. Certainty is thus a subjective definition which also refers to the process of information evaluation and perceptions in the states.

2 Compliance and the effectiveness of an agreement are not identical. A treaty scrupulously observed by all participants cannot solve a problem if the contractual provisions (the material regulations) are not strict enough. On the other hand, strict provisions which are only loosely complied with may nevertheless achieve great efficacy.

Three reasons are given for this [Sands 93, p. 386]: firstly, problem pressure, i.e. a growing consumption of resources has resulted in increasing emissions and environmental pollution to which politicians must react; secondly, pressure of costs, i.e. environmental protection agreements force states to undertake high investments so that bypassing the treaties would lead to competitive advantages (at least in the short run and in certain sections); thirdly, effectiveness, i.e. the nature and scope of the obligations undertaken increasingly influence core areas of economic activity, e.g. the energy sector. Politicians, who are gradually becoming aware of these problems, are reluctantly beginning to devote more attention to the verification problem in environmental protection treaties.

Even if the extent of compliance by states in general and especially in the environmental sector has only been roughly estimated as yet [Chayes 93; Ausubel 92], nevertheless the results are in accordance with the theory that the majority of states fulfil most of their contractual agreements more or less reliably. Whereas all schools of thought basically agree on this point,³ the reasons for it are open to dispute. (Neo)realism and institutionalism are opposed to each other and argue about whether compliant behaviour is influenced at all by treaties and the norms etc. laid down in them ("whether treaty-induced compliance ever occurs", [Mitchell 92, p. 26]). The background to this is a basic lack of agreement between institutionalism and realism concerning the nature and functioning of politico-social systems and the behaviour of actors.

The theory of realism transfers the assumption of economic theories - that all actors are egoistical and wish to maximize their benefits - to the international system: policies and their results, for example treaties, are a reflection of the international distribution of states' interests and their correlation of power. Accordingly, states only comply with treaties as long as it is in their interests to do so or a "hegemonic" state forces the other nations to comply. If in reality there is a high level of compliance then according to this school of thought this only shows how accurately the treaties reflect the international correlations of power and interests or how successful the "hegemon" is: treaties are dependent variables, their existence or the norms laid down in them do not influence compliance.

3 In purely quantitative terms this tendency towards compliance is not surprising in view of the large number of bilateral and multilateral agreements which contain little political dynamite. However, there are also apparently in part serious treaty violations in central issue areas (nonproliferation of nuclear weapons) and generally a lax attitude to contractual obligations in others, including the issue area of the environment.

In contrast, institutionalism assumes the possibility that actors recognize and pursue the public interest or common good and that this orientation is supported by international provisions, treaties and international law in general. Treaties do not only reflect power and interests but they also alter the behaviour of states, their relationships and encourage them to act according to the agreed norms. Accordingly, treaties are independent variables whereas the states' behaviour represents a dependent variable to a certain degree (cf. [Mitchell 92]). Representatives of institutionalism [Chayes 93] specify further reasons for the states' disposition towards compliance:

- It is efficient to follow agreed norms. Since decisions always consume resources, administrations cannot regularly analyse whether a contractual violation would be worthwhile for all agreements. Organization theory reaches the same conclusion when it emphasizes that bureaucratic systems discharge their duties in an established routine also including the implementation of treaties. Deviations from this bureaucratic rationality can only be achieved by great political effort.
- The interests of the states involved are defined in a common learning process also involving international actors before concluding a treaty so that compliance reflects a compromise supported by all parties. If compliance is slight then this expresses an unfair balance of interests.
- "Pacta sunt servanda", treaties which have been concluded must be complied with. This basic norm of international law is in the interest of the vast majority of states since only in this way can vital stability and predictability be maintained in the international system. Furthermore, international interest groups emerge which have an interest in compliance by their respective nation for economic or other reasons and urge it on the national authorities.

A critical assessment of the present state of the art in international relations [Rittberger 90] must come to the conclusion that neither of two theories can claim to give plausibly and empirically reliable reasons for (non)compliance. It is difficult for realism to explain why states still comply with treaties even if the interest and correlations of power of those involved have changed whereas institutionalism has problems in explaining the by no means unique contractual violations in general and the "accumulations" of infringements with respect to countries and subjects. (Some states seem to violate treaties more often and breach of contractual obligations is more frequent in some issue areas than others.) The question of whether this is related to the (low) intensity of verification, the (low) probability of detecting the violation and thus to the (unlikely) possibility of sanctions remains

open. Corresponding evidence that reliable safeguards and credible threats of sanctions lead to increased compliance would support the explanatory power of the realistic theory.

This clash of theories which still remains to be settled, is not an academic exercise and has serious implications for the conception of verification systems since the realists expect an opportunistic defiance of treaties so that participants in the issue areas regarded as relevant must remain vigilant to obtain the highest possible degree of certainty about the behaviour of all parties. The need for verification is very high and verification would therefore have to be very dense and intrusive.⁴ Institutionalism, which bases its arguments on consistent, predictable compliance with agreements on the part of states, would in contrast be satisfied with a small degree of certainty and a low verification density and could cut back the demands made on the organizational infrastructure of the verification system on the international level.

As yet, a uniform understanding of treaty violations has been assumed. Institutionalism now mentions further causes of treaty violations which are given less weight in the theory of realism (cf. [Chayes 93]). The need for verification changes depending on which of the reasons is regarded as decisive for noncompliance:

1. In principle, the possibility of intentional treaty violations is acknowledged by all schools of thought. They may serve directly to achieve advantages or avert the disadvantages which may arise if obligations are complied with. A violation of treaty obligations is an intentional act of considered government policy. In the political discussion and in the theory of realism, treaty violations are generally regarded as the expression of such a specific policy directed towards the state's own advantage. Intrusive verification is justified and has its central field of activity here. It should detect unambiguous signs of deviant behaviour at the earliest possible time and insist on a correction of this behaviour, if necessary by means of negative or positive incentives (international enforcement, dispute settlement, cf. [Sands 93]). The percentage of all violations represented by this type of treaty violation is not clear.

⁴ Density cannot only be established from the number and type of instruments etc. employed for information gathering and verification. A quite central aspect of density is the intervention in the states' sovereignty associated with the application of such instruments. This is described by the concept of intrusiveness.

2. Capacity shortage in implementing treaties. In arms control, the traditional and most important field of verification, the obligations agreed in the treaty are addressed directly to the states. They have to reduce weapons systems, dispense with weapons tests or subject themselves to other restrictions. As a rule, only the state itself has armed forces, it alone is responsible for realizing the provisions and also has direct access to the objects to be safeguarded, which are government organs. In the majority of cases, the state is in a position to fulfil its obligations if so inclined, i.e. it has the capacities to implement the treaties or can make these capacities available fairly rapidly. Capacity problems are the exception⁵ or are rooted in specific politico-economic problems.⁶ However, in many other agreements, not least in the case of environmental protection, although the states are the contracting parties nevertheless the provisions are directed towards influencing the behaviour of social entities, e.g. the economy or individuals whose activities are responsible, for instance, for greenhouse gas emissions.⁷ In order to alter its behaviour in such a way that it corresponds to the overall result of the treaty goal, each state must undertake intermediate steps in order to reach the "lower" level of social actors: legislation, administrative regulations, implementation and control (national enforcement, cf. [Sands 93]). There are no comparable problems of various levels in arms control. Thus, for example, in implementing environmental agreements many deficits in regulative governmental capacities may be revealed, there may be a lack of scientific and technical competence to develop implementation strategies and instruments, and deficiencies in the bureaucratic implementation and controlling abilities or inadequate financial, technical and staff resources may become apparent.⁸ Such problems are by no means rare and the contracting parties often make efforts to take remedial action. Thus, for example, financial, technical and administrative support for the developing countries in fulfilling their treaty obligations is incorporated in the Montreal Protocol on Substances that Deplete the Ozone Layer and its amendments, as well as in the framework convention on climate change.

5 There are certain technical problems, e.g. in destroying chemical weapons or utilizing nuclear weapons material in nuclear reactors to make it less useful for weapons purposes.

6 Thus, for example, the collapse of the USSR reduces the ability of the successor states to fulfil their disarmament obligations.

7 Emissions of greenhouse gases for which government action is directly responsible are estimated to be in the region of a few per cent and originate to a considerable extent from the military sector (including upstream processes like the building of military hardware) and the administration.

8 See [Jänicke 93] for the debate on the possibilities and limitations of government action, particularly in the environmental sector.

3. The time delay in implementing agreements. This is closely connected to the problems discussed in the previous paragraph and may be expected at an earlier point the more time and resources required for the implementation of treaty obligations. In this case there may be latecomers whose compliance may be regarded as low at an early point after the treaty comes into force. This might simply involve difficulties during a transition period and should not be regarded as a violation of the treaty. A decision on effective compliance can therefore not simply depend on a single event but rather on a longitudinal analysis taking into consideration the dynamics of compliance.

Treaty violations may therefore also be the result of a well-meaning but incompetent policy so that it should not be assumed that the state is unwilling to comply with the treaty. If the capacity-conditioned and also the time-lag violations were dominant, and not intentional treaty violations, then on the basis of confidence in the principle readiness of the state to comply with its contractual obligations verification could be designed to be less intrusive and instead more implementation-oriented and corrective. Admittedly, this would necessarily assume that all states had a basic interest in solving the problem and would regard the treaty provisions as a fair compromise. This refers back to the two schools of thought and their explanatory power for the origin of international treaties.

It must be remembered that although both schools of thought regarding international relations recognize a general need for verification of international agreements, also in the issue area of the environment and particularly for climate protection, nevertheless in the central question of how dense this verification should be and the emphasis to be given to various models of treaty violation they represent different positions.

On the basis of the recognition of the basic need for verification concerning a climate protection convention, a specific analysis should determine the required verification density in a pragmatic manner.

2.3 Verification in the Issue Area of Climate Protection

International cooperation in safeguarding a global common is particularly difficult since all relevant participants must contribute towards the protection goal and at the same time there is an incentive to take on the position of a freerider contributing nothing towards safeguarding the global common but to profit from other countries' successful protective measures. Climate is a global common of

this type (cf. [Utsch 93]). Furthermore, countries are affected to a different extent by the measures for climate protection and some countries could even profit from climatic changes and their consequences (cf. [Fischer 92; Oberthür 93]). These special features also characterize the determination of the necessary verification density, which is the result of several factors:

1. The extent of the mutual uncertainty on the part of states concerning compliance with a convention. In the case of a climate convention, uncertainty about compliance is relatively high in comparison to other environmental treaties [Efinger 91]. The reasons: a) A large number of governmental and non-governmental actors are contracting parties or affected by the national implementation of a convention; a large number of measures must be realized and their success controlled. b) The states have different scales of preferences tending either towards climate protection or economic growth. This arouses uncertainty concerning compliance. c) Supplier countries wish to obtain evidence from recipient countries that the funds transferred for climate protection have been used appropriately. d) Programmes on the joint implementation of climate protection measures must also be verified as well as the envisaged compensation models for the optimum distribution of funds among countries where the greatest reduction in greenhouse gas emissions can be achieved. e) The states have different degrees of ability to control the implementation of agreed policies. f) There may be countries which regard themselves as winners with respect to climate change and which have been forced into the climate convention without the intention of complying with the provisions.

2. The dominant conflict type [Efinger 91]. Typologies concerning the subject of a conflict assume that the way in which countries act is determined by the nature of the issue. The climate (convention) issue area is one of the type of conflicts concerning means or interests with respect to absolutely valued resources⁹ and is therefore less competitive and comparatively open to cooperation. Consequently, distrust concerning the behaviour of other states and thus the need for verification is lower than in the issue area of (external) security and arms control where questions of power represent an important aspect (zero-sum games). Nevertheless, the drastic reduction in greenhouse gas emissions of 60 - 80 per cent required by some scientists could result in such serious impacts on the economy

9 In the case of conflicts about means, the aims are not in dispute but rather "only" the means (strategies, instruments ...) of achieving the goal. Conflicts of interest about absolutely valued resources, such as sufficient food, clean water, pure air, offer good chances of being solved since these resources - within limits - can be increased and have their own value for each actor, quite irrespective of how much the other parties possess.

and patterns of trade that conflicts about relative resources may arise (shifts in power). Within the framework of such a strict convention, the incentive to deviate from the contractual provisions would be higher and the verification density would thus increase with the regulation density of the convention.

3. The significance of the issue area. After the first oil shock, the concept of (international) security was supplemented by an economic dimension (economic security). Today the "ecological dimension of security" is emphasized, not least with a view to the consequences of the climate problem ([Sands 93]; critically to the discussion: [Daase 92]). In the case of security-relevant problems there is, as in arms control, a desire for more, and more precise, information about the actual behaviour of the other states. Only in this way can it be ensured that some contracting parties are not clandestinely evading the costs and burdens of a climate convention. This is closely related to the problem of freeriders.

4. The consequences of a violation of the convention. Relative to the individual event, these consequences would be of less objective relevance than a treaty violation in the case of arms control treaties. "Clandestine" emissions of several million tonnes of C would be of marginal significance in view of global anthropogenic releases in the order of 6 billion tonnes of C. A verification system for the climate convention therefore need not display the density regarded as necessary for arms control where every atomic warhead and every launcher system counts. From the perspective of climate policy, the individual violation is not a problem but rather the signalling effect of such an event or indeed even the suspicion that there might be substantial and permanent undetected violations. The entire climate regime might collapse (domino effect). The detection of serious, persistent violations must therefore be ensured.

As a **result** it may be established that the need for verification in the issue area of climate protection is initially low and mainly concentrated on treaty violations resulting from capacity shortage or implementation delays (time-lag). One reason for this is the low regulation depth of the framework convention on climate change which only contains a few, fuzzily formulated material obligations (cf. [Oberthür 93]; [Fischer 92]), providing hardly any starting points for "hard" verification. The verification system for the framework convention on climate change therefore displays a low verification density and concentrates on verifying the completeness of national emission declarations or on compliance with certain criteria in drawing up the declarations (e.g. consideration of emission factors). There is no independent verification of the correctness of the declared data itself. If a dynamic climate protection regime should develop and protocols with extensive precisely

timed and burdensome obligations for the reduction of greenhouse gases should be agreed then there will probably be a moderate verification need which would also pay increasing attention to elements of intentional treaty violation. Verification density will increase and also have to consider the correctness of national data on emissions etc. Verification density would then probably lie somewhere between the intrusive safeguarding of disarmament agreements and the low verification density which has characterized most environmental protection treaties to date.

3. Verification Elements

3.1 Greenhouse Gas Inventories, Verification Activities, Radiative Forcing (W. Katscher)

The regular compilation of reliable (national) emission inventories comprising all essential sources (and sinks) is of central significance for the global restriction of anthropogenic greenhouse gas emissions which is the aim of the climate convention. These inventories are the basis for assessing the effectiveness of national reduction measures for greenhouse gas releases. Transparency and reconstructability of the data and methods on which compilation of the inventories is based are essential for international comparability and verification.

In the following, the present status of international efforts towards developing uniform inventory methods is examined. Furthermore, studies of the data base in Germany will be discussed in order to provide an instance of the data quality currently to be expected in declarations with the example of the situation in a highly developed industrialized country.

IPCC/OECD Method Development

Probably the most important impetus for international method development emanates from the Intergovernmental Panel on Climate Change (IPCC) which was set up in 1988 by two United Nations organizations, the WMO (World Meteorological Organization) and the UNEP (United Nations Environmental Programme). The tasks which the IPCC first undertook in three working groups composed of experts co-operating worldwide are:

- evaluation of the scientific knowledge available on climate change;
- estimate of the socio-economic and other environmental impacts of climate change and
- formulation of prevention strategies.

The first comprehensive scientific report was published by the IPCC in 1990 [IPCC 90], the most recent is dated February 1992 [IPCC 92].

In method development and establishing guidelines for the compilation of national greenhouse gas inventories, the IPCC is supported by the Organization for Economic Cooperation and Development (OECD), which presented its first comprehen-

sive report in August 1991. This is to be regarded as the first milestone along the path towards developing an internationally agreed methodology, so-called Guidelines, which should lead to Guidelines Phase I for CO₂ and CH₄, to be adopted by the IPCC in summer 1994, as well as the draft of the Guidelines Phase II for the gases N₂O, NO_x, CO and NMVOC (non-methane volatile organic compounds) [Schwengels 1993]. All known essential greenhouse gas sources influenced by man will be covered, ranging from energy and industrial technology to the waste economy and the sectors of the food industry, forestry, utilization of biomass and the consequences of modified farming methods.

The work proceeded very dynamically and has been presented for discussion at international workshops. Experience for an applicable methodology was gathered in accompanying studies, e.g. in a survey of greenhouse gas inventories with data from 25 countries in 1991/92 [IPCC 93]. However, the latter study, which was restricted to CO₂, CH₄ and N₂O inventories, made it clear that we have a long way to go before achieving reconstructible, comparable emission data. The approach pursued by the IPCC of developing the simplest possible methods and avoiding complications if they only provide a slight reduction in result uncertainties will undoubtedly help to shorten the journey.

The methods developed by IPCC/OECD and internationally approved are to be regarded as an offer to the states; they will not be bound to apply these methods. According to the current contractual position, the states can also make use of their own methods although they must ensure the transparency and comparability of the methods, and thus of the inventories. With respect to verification, which is now also an IPCC topic, this means that it must be adapted to the respective national method of data collection, which naturally increases the effort required. An agency entrusted with the task of verification will have to collect a vast quantity of information in order to estimate the various national declarations. Such information should comprise energy statistics, demographic and economic data, as well as details about structures and trends in the industrial, transport or agricultural sector, i.e. as much data as possible which may be used as an indication of the correctness and completeness of the declared inventories.

Method Development Within the Framework of ECE/CORINAIR/UNECE

An important development in connection with the IPCC/OECD method development may be the envisaged compilation of an "Emission Inventory Guidebook" as outlined in the form of a proposal by McInnes on 7 June 1993 at the UN-ECE

(United Nations Economic Cooperation in Europe) Task Force Meeting on Emission Inventories in Delft, The Netherlands [UNECE 93]. The aim of the guidebook is to provide a comprehensive summary of methods for determining the inventory of each gas to be inventorized and all sources to be identified. This has undoubtedly also been undertaken in the knowledge that fulfilment of obligations to compile inventories undertaken within the framework of various environmental treaties must not be made more difficult by divergent methods.

Accordingly, the guidebook should be designed in such a way that it covers the inventory requirements of the most important international activities at least such as those of the Convention on Long-Range Transboundary Air Pollution, the Fifth Environment Action Programme of the European Community, or IPCC/OECD activities. The gases covered will include SO₂, NO_x, NMVOC, CH₄, CO, CO₂, N₂O, NH₃ and possibly heavy metal and POP (persistent organics) releases. One chapter will deal with verification (see below).

The guidebook will be based on the source-oriented approach of the CORINAIR emission inventory of the EU. However, close OECD/IPCC cooperation should ensure that the approach will not only be applicable for one programme so that finally harmonization can be achieved in about 1994/95. Present work is investigating the way in which the CORINAIR data can be converted into IPCC inventories.

Data Base for Greenhouse Gas Emissions in Germany Energy-Related Emissions

In order to obtain insights into the status of the data base in a highly developed industrialized country, the Öko-Institut in Darmstadt was entrusted with a study of data bases for energy-related, climate-relevant emissions in the Federal Republic of Germany [Fritsche 92]. The aim of this study was to evaluate the available national information basis, to analyse the methods and highlight weak points.

Four data sources on greenhouse gas emissions were available for the analysis: the Federal Environmental Agency (UBA), the Research Centre Jülich, Programme Group Systems Analysis and Technology Evaluation (KFA-STE), the Öko-Institut e.V. and the Institute of Energy and Environmental Research (IFEU) in cooperation with the Technical Control Board (TÜV) Rhineland. Of these, only the data banks of the UBA and the Öko-Institut provided information about the majority of greenhouse gas emissions from different sectors, whereas KFA-STE only

considered CO₂ from the combustion of fossil energy carriers and IFEU/TÜV only the transport sector. Furthermore, the data available for Eastern Germany are often unreliable or incompatible with the data for Western Germany.

The analysis of the features and content of the four data bases showed that in general no primary information was available but rather secondary data supplied by "intermediate collectors" (e.g. from energy associations, the Energy Balances Working Group (AGEB), Federal and State ministries and authorities) or originate from the literature.

The situation with the methods used for assessing the greenhouse gas emissions often proved to be unfavourable. Frequently, only subjective estimates were available on the basis of scattered information. This is generally true of CH₄ emissions from non-energetic sources. The situation with respect to N₂O emissions was even more unfavourable. With respect to verification it seems that the lack of clear standards may lead to difficulties in assessing the reliability of declared values.

Due to these methodological inadequacies, the Öko-Institut placed major emphasis on determining emission factors and also on methods of estimating the **energy-related emissions of CO₂** from the combustion of fossil energy carriers. To this end, the characteristics of the fuels in question were described and evaluated. It became apparent here that although in many cases values from different sources were not in agreement thus leading to variations in the emission factors (i.e. in the mass per unit of converted energy of emitted greenhouse gases), nevertheless, in comparison with other greenhouse gases the quality of energy-related CO₂ emission data can be regarded as good. In determining the completeness of the combustion process it was assumed for the majority of emission processes considered that oxidation was complete. This assumption is correct for plants with typical burn-up rates of 99 % and more, and is also in accordance with the current IPCC approach of complete carbon conversion. Solely in Eastern Germany it is not possible to rule out burn-up factors of as little as 80 % due to unfavourable firing conditions when using domestic lignite - a problem which, however, is becoming increasingly less significant with the current restructuring and technological modernization taking place there.

The most important data source for calculating CO₂ emissions from the energy sector has proved to be the Energy Balances Working Group (AGEB). The AGEB provides consistent energy balances for Western Germany. Considerable efforts are currently being made in the new federal states to achieve comparable energy statistics. The Öko-Institut study shows that the present AGEB methodology is ca-

pable of improvement, particularly with respect to the completeness of data and allocation of calorific values to particular fuels. If the improvements are made then a restriction of the uncertainty for energy-related CO₂ emissions in Germany in the order of less than $\pm 5\%$ is to be expected. The working group "CO₂ Inventories", under the auspices of the Federal Environmental Agency, with representatives from ministries, the energy economy, research establishments and the IKARUS Project is concerned with this aspect. Extensive agreement has been reached on a table for energy-related CO₂ emission factors compiled by KFA-STE.

The Öko-Institut furthermore expects that the uncertainties in the overall emissions may be reduced to values of about $\pm 1\%$ by solving the delimitation problems of transboundary traffic and also definition questions involved in CO₂-relevant non-energetic consumption.

As noted above, the data uncertainties for other energy-related greenhouse gas emissions are considerably greater, above all in the transport sector, but also in the other energy sectors. Improvements may result here with data from the other IKARUS subprojects.

Non-Energy-Related Greenhouse Gas Emissions

Whereas the IKARUS project concentrates on energy-related greenhouse gas releases, the topic of the "verification of an international greenhouse gas convention" cannot be restricted to this alone but must also include the other emissions caused by man.

In order to obtain an overall view of the data situation in Germany in this respect as well, the Öko-Institut was commissioned with a further study on the data bases of non-energy-related greenhouse gas emissions, which is available in a draft form [Buchert 93].

The study is concerned with the trace gases CO₂, CH₄, N₂O, NO_x, NMVOC, SO₂ and CO, as well as CFCs and CHCs, directly or indirectly influencing the climate, from the sectors of industry, agriculture and forestry as well as waste management. Furthermore, it contains an indication of other greenhouse gases, to which little attention has been paid as yet, but which become important due to their long atmospheric life of sometimes possibly more than 1000 years, such as sulphur hexafluoride or tetra- and hexafluoromethane emissions originating from aluminium production.

As the sole German data base, the Öko-Institut identified that of the UBA. Only publications on subsectors of greenhouse gas emission were found at other institutions such as the Federal Ministry of the Environment, Agriculture and Forestry, environmental agencies of the federal states, industrial associations and research establishments.

Overall, the Öko-Institut established that uncertainties in the data base are to be estimated at about $\pm 50\%$ in the most favourable case, and that variation ranges - about an unknown average - often exceed a factor of 2.

It is considered possible that the data position for specific releases of SO_2 , NO_x and CO can be improved for strong emitters in the next few years by means of continuous measurements, whereas the Öko-Institut does not expect any significant improvement for NMVOC, CH_4 , N_2O and CO_2 . There are still methodological problems with CFCs and CHCs in converting consumption data to emission data (consideration of the banking effect, e.g. by the confinement of CFCs in foams), in considering and assigning stored transboundary quantities as well as in disposal.

A considerable need for research to improve the data situation has been identified in the sectors of agriculture, forestry and waste management. Here greenhouse gas inventories are based practically exclusively on estimates with a mainly small, often foreign data basis.

Verification of Greenhouse Gas Inventories Within the Framework of IPCC/OECD

International efforts towards establishing a climate convention will in coming years be quite essentially directed towards creating the data basis. Verification in the sense of safeguarding clear, verifiable environmental protection goals cannot yet be of relevance since the climate convention does not include any such goals. It merely includes, as a quantitative goal for reducing greenhouse gas emissions, a target for "Annex I" countries to reduce their anthropogenic release of CO_2 and other greenhouse gases not included in the Montreal Protocol, individually or jointly, to the 1990 level. Jones [Jones 93] points to the voluntary nature of the agreement between sovereign states which does not include any mechanisms for compelling compliance. He designates what the individual signatory states themselves aim at as the "real" environmental goal.

Nevertheless, verification has now become a topic in the introduction of "guidelines" for the declaration of national greenhouse gas inventories by IPCC/OECD [OECD 93a] in a cautious approach taking into consideration current problems in introducing the convention.

The declared **goal** is first of all **improving the inventory quality** although the question initially remains open of whether verification should be carried out by the IPCC or the individual states. Elements currently envisaged are

- verification of the completeness of the inventories;
- verification of the reconstructibility of the methods;
- comparison of the estimated emission values with IPCC default methods and assumptions;
- comparison of activity data and emission factors with internationally available values and
- a simple international comparison of emission factors.

An OECD project, in cooperation with the International Energy Agency (IEA) [OECD 93b], discussed at an OECD Experts Meeting on 1 and 2 July 1993 in Geneva and planned to start in autumn 1993 is clearly aimed at this goal. Amongst other aspects, six country reports from the "Annex I" countries - including the Federal Republic of Germany [BMU 93] - are to be evaluated according to the following criteria:

- 1 transparency (reconstructibility of the data, clarity of approach and conclusions, accessibility of national data, source information),
- 2 comparability (degree of detail of comparable data on policies, measures and programmes; degree to which international proposals to ensure comparability and global assessability are taken into consideration) and
- 3 completeness and quality of data (degree of coverage of the sources and sinks included in the convention, as well as of the relevant policies, programmes and measures. Completeness of relevant information; data on the reliability of quantitative estimates).

These activities, which in the above mentioned cooperation may profit extensively from the more than 15 years of experience by the IEA (International Energy Agency) in verifying country reports from the member states and also from other countries [Kemper 93], would seem to represent a pragmatic and also effective

path for developing verification mechanisms. The simplicity of organization will depend not least upon whether agreement can be reached on joint inventory methods and report formats.

Use can be made of methods as have been developed within the framework of the UN-ECE Task Force on Emission Inventories. As already mentioned above, a chapter in the Emission Inventories Guidebook of the UN-ECE will deal with methods for verifying emission inventories. A comprehensive project description was presented by D. Mobley, US EPA (United States Environmental Protection Agency), at the Task Force Meeting in Delft [UNECE 93]. In this case as well, the declared goal is an improvement of accuracy and reliability of the inventory surveys. The verification elements are:

- documentation of data quality or quality assurance activities;
- evaluation of the data with respect to the survey goal, for example, estimate of the relative significance of emissions;
- comparison of alternative estimates;
- uncertainty estimates;
- measurements using statistical methods and models.

Attention is drawn to the fact that the UN-ECE activities span a much broader spectrum of emissions, reduction goals and observation areas - ranging from local to regional and global - than is the subject of the climate convention. Although, only a section of the proposed verification methods will be correspondingly applicable to the convention they nevertheless represent a valuable supplement to the IPCC/OECD verification activities mentioned above.

Global Warming Potentials

The quantities of greenhouse gases released do not themselves give any indication of their significance for the climate; this requires a weighting with respect to their radiative forcing.

The Global Warming Potential (GWP) was developed to obtain a manageable value for political decisions and has now become accepted on an international level and, in spite of all its weaknesses, will continue in future to serve to assess the radiative forcing of the various gases [Grassl 92].

As a simple multiplier, GWP designates the radiative forcing of the released quantity of the gas under consideration as a multiple of that from CO₂; i.e. it directly provides CO₂ equivalents and thus a direct yardstick for assessing the overall radiative forcing in the optimization calculations of the determined technical measures.

[IPCC 90 and 92] include a detailed description of the concept of global warming potential and data on the best figures currently available. The most important information from these reports is summarized here.

The GWP describes the integrated contribution to radiative forcing over a period of n years (= induced radiation energy flux change at the tropopause) of the gas i for the spontaneous release of a unit of quantity (1 kg) in comparison to that for the release of 1 kg of CO₂. The following is valid:

$$GWP = \frac{\int_0^n a_i c_i dt}{\int_0^n a_{CO_2} c_{CO_2} dt}$$

a = greenhouse effect from the released unit quantity

c = concentration of trace gas at time t after release.

Attention should be drawn to the fact that as indicated by the term "**global** warming potential", the GWP is an indicator of possible impacts on climatic events **worldwide**. It can thus only refer to gases whose lifetime or residence time (generally defined as the period until degradation to the 1/e-fold) permits a global mixing in the atmosphere, i.e. is counted in years at least. In determining the GWP, a differentiation is made between direct and indirect global warming potential.

Direct GWPs refer to the direct greenhouse effect of long-lived trace gases. [IPCC 92] includes CO₂ (residence time 120 a), CH₄ (10.5 a), N₂O (132 a) and various halogenated hydrocarbons with residence times of up to more than 500 a in this category. To these are added indirect GWPs, which in the 1990 IPCC report are still quantitatively estimated due to their great uncertainties (see below), but which are only represented in the 1992 report by indicating their plus or minus sign.

Indirect GWPs result from the formation of radiative forcing daughter products during the chemical degradation of trace gases. If the "mother" trace gases are

themselves long-lived, i.e. if they are capable of mixing globally in the atmosphere, then the GWP approach is also appropriate for short-lived daughter products such as ozone (days) or (tropospheric) water vapour (8 d), as for example during methane degradation. The same is true of the formation of long-lived daughter products during the degradation of short-lived mothers, thus for example CO₂ formation during the oxidation of CO (months) or of non-methane hydrocarbons (days to months). The GWP approach cannot detect the simultaneous influence on the ozone balance by these conversions or by the short-lived nitrogen oxides (days).

The most recent **direct** GWPs from [IPCC 92] are compiled in Tab. 3.1 for the **most important long-lived trace gases** covering approx. 85 % of the anthropogenic greenhouse contribution. They have not significantly changed in comparison to data from 1990, and the deviations are based exclusively on differences in assumed lifetimes. CH₄ represents an exception: its GWPs had to be corrected considerably (up to 50 %) towards higher values due to a printing error in the 1990 report. Tab. 3.1 is kept deliberately short to cover the aspects of interest in IKARUS.

Gas	Contribution to additional greenhouse effect [%]*	Lifetime [a]	Direct GWP for integration times			Positive or negative sign for the indirect GWP
			20 a	100 a	500 a	
CO ₂	50	120	1	1	1	-
CH ₄	13	10.5	35	11	4	positive
N ₂ O	5	132	260	270	170	unknown
FCKW 11	5	55	4.500	3.400	1.400	negative
FCKW 12	12	116	7.100	7.100	4.100	negative

* From [Bundestag 1990]. The remaining 15 % is distributed between ozone (7) and others (mainly halogenated hydrocarbons). Only direct fractions are included in the CH₄ contribution.

Tab. 3.1: Direct global warming potentials (GWPs) for the most important long-lived trace gases relative to the mass (kg) of the input gas. Source: [IPCC 92].

The following remarks should be made on Tab. 3.1:

a) Due to the different lifetimes of the trace gases, the integration time (see formula on page ?) plays an essential role in evaluating their relative radiative forcing. The time horizon to be applied depends largely on the goal of the respective analysis. 100 a is usual.

b) Although the **indirect** GWPs are only qualitatively mentioned in Tab. 3.1, nevertheless they may possibly have a weight similar to the direct GWPs. This is particularly true of methane, of which it is assumed in [IPCC 92] that the indirect effect is comparable to the direct.

To date, the following **major effective factors** are known for the individual gases:

CO₂ behaves inertly in the atmosphere. However, due to its influence on temperature distribution it could influence the chemical reactions of other trace gases.

90 % of **methane** is decomposed to CO₂ and water vapour in the troposphere by reactions with OH radicals, in the course of which ozone simultaneously results. The latter and the water vapour arising during methane decomposition in the stratosphere provide the major contribution to the indirect GWP.

N₂O is decomposed by photolysis. No indirect effect is indicated.

The indirect greenhouse effect of the **CFCs** is largely based on the ozone depletion in the stratosphere caused by them. This effect is negative and could largely compensate the direct effect of the CFCs.

The **remaining gases** mentioned above which are covered in the IKARUS project (NMHCs, NO_x, CO and SO₂), have relatively short lifetimes: NMHCs days to months; NO_x days; CO months and SO₂ weeks.

Qualitative data on direct radiative forcing are only found in [IPCC 90] for NO_x, CO and SO₂, where a low effectiveness is specified for the last two. There are no data on NMHCs.

The above-mentioned gases - with the exception of NO_x, which contributes towards additional OH radical formation - react with OH radicals; they thus influence the lifetime of trace gases, which also undergo a degradation reaction with OH radicals, such as CH₄. NMHCs and CO have CO₂ as their long-lived degradation product with a correspondingly positive indirect GWP contribution.

The above-mentioned trace gases influence the formation of the greenhouse gas ozone - largely in the troposphere - in which connection NO_x is particularly dominant. The indirect contribution of SO₂ is especially found in aerosol formation and thus also influences cloud formation. According to [WMO 91], the sulphate aerosols in the atmosphere cause a negative greenhouse effect. In any case, in the

same way as their precursors, they have a short atmospheric lifetime so that changes in emission are effective within a matter of weeks. It does not seem possible at present to quantify the radiative forcing of SO_2 .

Whereas the indirect effects for NO_x , NMHCs and CO were still quantified positively in [IPCC 90] in the ratio 150/31/7 (integration time 20 a), [IPCC 92] only contains qualitative statements about the positive or negative sign: positive for NMHCs and CO, and indeterminate for NO_x . Only the indirect GWPs originating from CO_2 formation during the degradation of NMHCs and CO_2 (irrespective of the integration period) can be estimated as 3 and 2 respectively.

In view of their nature, GWPs will defy verification within the framework of an international climate convention. However, they will have a decisive influence on quality demands in drawing up inventories of the various greenhouse gas emissions and their verification. Particular attention should therefore be given to their development.

3.2 Measuring Techniques for Radiative Forcing Gases (W.D. Lauppe)

Introduction

The question of the need for verification has already been dealt with in detail elsewhere in this report (Fischer p. 6) and will not be treated further here. For the following discussion, it is assumed that there is a basic need for verification. There are undoubtedly divergent ideas about the extent of such a verification. The demands to be made on the degree of certainty about the correctness of the contents of national reports made by other countries are to be established on a political level. The more stringent these demands are, the higher is the verification density required and the greater is the implied sacrifice of national sovereignty.

In order to assess the entire spectrum of possible verification measures with increasing density, it also appears helpful to discuss verification measures based on direct and indirect measurements. Recourse to other international treaties or agreements, e.g. the Non-Proliferation Treaty, is only of limited assistance here since the respective subjects of verification differ essentially both qualitatively and also quantitatively. Other environmental agreements only contain very "soft" verification measures or dispense with them entirely.

The present report intends to investigate the contribution which currently available measuring technology could make to an independent verification of emission inventories in a dynamically developing climate protection regime. Such measures can only be taken into consideration to a greater extent at an advanced stage of a climate protection regime. A comprehensive implementation of such measures would represent a state of high verification density.

The Object to Be Verified

An essential condition for all types of international verification is the availability of national reports or other information from the states with details both of a qualitative and also quantitative nature relevant for fulfilling the goals laid down in the convention. Only the data specified in the national reports may be the object of verification. Within the framework of the climate convention, the member states commit themselves to present such reports at regular intervals. The data in these reports concern, in the first instance, the emission inventories of radiative forcing gases and measures to reduce these inventories. Verification measures may then refer to these data.

Verification may initially be of a more qualitative nature, as for example in examining the extent to which the national measures announced in the reports have actually been implemented. If figures are given in the national reports, e.g. the emission inventories of radiative forcing gases, then in principle they could be quantitatively verified.

International verification should take place independently of the national data collection, but should not necessarily have an alternative method. The gradual reconstruction of national data collection by an international institution also represents a sufficiently independent verification.

In the case of the emission inventories, the object of verification is the mass of radiative forcing gases emitted per year, broken down according to gas type and emission sector. The corresponding data in the national reports are gathered from economic statistics, e.g. on the production and import of fossil fuels and national energy statistics. This logical chain cannot always be transparently reconstructed back to the collection of source data, i.e. the quantitative determination of the masses of fossil fuels used for combustion and the respective fuel composition. A reconstruction of these national data collection steps by an international institution is thus very complex, if it can be implemented at all. In some cases, the direct measurement of the masses of essential radiative forcing gases emitted per year would represent an alternative to this procedure.

In national emission monitoring of other atmospheric pollutants, only the pollutant concentrations in mg/m^3 are recorded. Verification is thus restricted to evidence that certain pollutant concentrations only exceed a predetermined limit in a certain fixed period with a limited frequency. However, the verification of emissions within the framework of the climate convention requires absolute quantities. In the case of CO_2 verification for fossil power stations, this also means, in addition to continuous measurements of CO_2 concentrations, recording the entire mass flow of the flue gases. Additional safeguards measures are therefore necessary in order to ensure that all the waste gas flows from a firing system are covered, that is to say the measuring point is not bypassed.

The further discussion will be restricted to CO_2 and CH_4 since according to the present state of the art a verification by measuring technology seems possible here to a limited extent due to the source characteristics.

Verification Suitability

Approximately 80 % of anthropogenic CO₂ emissions [di Primio 91] originate from the combustion of fossil fuels, i.e. in the energy sector. Together with the other radiative forcing gases arising during the utilization of fossil energies, the CO₂ emissions from the energy sector are held responsible for approx. 57 % of the additional (anthropogenic) greenhouse effect [Lashof 91]. Apart from CO₂, methane plays a decisive role amongst the greenhouse gas emissions influenced by human activities from the aspect of quantity and radiative forcing. The most important contributions arise from hard coal mining, rice cultivation, stockbreeding and domestic refuse dumps.

The wide range of source configurations becomes apparent even with this brief list. However, the possibility of making a selective quantitative record of greenhouse gases greatly depends on the nature of the respective source. The technical preconditions for verification directly at the source with the aid of measuring instruments are considerably restricted by the nature of the source configuration. From the aspect of verification suitability, it is therefore meaningful to initially consider only those sources which make a considerable contribution to the total emissions of greenhouse gases and for which it appears basically technically possible, also with respect to economic considerations, to apply quantitative measuring techniques for verification purposes. These are all point sources, i.e. sources which release the radiative forcing gases into the atmosphere in a controlled manner and in line systems. The richest point sources for CO₂ are fossil power stations and for CH₄ the waste air shafts of hard coal mines. The technical conditions for a continuous and direct measurement of radiative forcing gases are most favourable here.

Apart from the above-mentioned point sources, there are a number of other source configurations which are less accessible, or not accessible at all, by direct measurement. For instance, the private household and transport sectors consist of a large number of small point sources which cannot be individually covered by measuring technology on account of their number. Such sources become aggregated to mass sources in conurbations. The third major source category comprises agriculturally utilized areas, which are therefore termed area sources.

Although emissions from these source configurations are also measurable, nevertheless this requires the assistance of models since the boundary conditions altering over time cannot all be covered simultaneously by measurements. Measurements are restricted here to the determination of typical emission parameters and

also typical boundary conditions. Together with the models, it is then possible to make an estimate of the annual emissions.

In the case of the agricultural areas, characteristic emission features and their annual variation can be measured for specific types of use. The measured data can be correlated with other factors determining emissions, such as soil type, application of fertilizer, vegetation sequence etc. As in the case of mass sources, it is frequently possible to compile emission inventories with the aid of models. The measured data may then serve as input values for model calculations or they may be used to calibrate the models.

Apart from the strong point sources, it is probably not possible to balance the other sources by measuring technology due to their complicated characteristics. In this case, the potential of measurements is to be found in extending knowledge about the source features and based on this a source modelling with the goal of obtaining the best possible estimate for the source inventories.

Physical Principles

The attribute "radiative forcing" for some gas components of the atmosphere, whether natural or anthropogenic, is based on their special property of strongly absorbing light quanta (photons) at certain wavelengths of the electromagnetic radiation spectrum. The gas molecules are internally excited in various ways so that they briefly store the input energy and then release it into their environment by a number of different processes.

The wavelength ranges in which absorption takes place differ depending on the molecule type and are characteristic of a certain gas component. These absorption lines correspond to the fingerprint of a molecule type. In a few cases, the absorption lines of various types of molecule also overlap. However, there are several absorption regions for most types of molecules so that an isolated spectral region can almost always be found which is not, or at least only slightly, influenced by other molecular spectra, thus enabling the identification and quantification of a gas component. During irradiation with a polychromatic light source, due to their heteroatomic structure, radiative forcing gases display a pronounced absorption line structure, above all in the infrared wavelength region, which is caused by the excitation of rotational vibrations. This wavelength range is easily accessible by measuring technology and forms the basis for a selective measurement of the concentration of a gas component in the atmosphere. The absorption of the radia-

tion from a broadband light source (including also the invisible spectral ranges of infrared and ultraviolet) by an atmospheric gas component in a defined gas volume is a function of the concentration of the molecules of this gas component. The concentration measurement can thus be derived from an absorption measurement.

What is valid for absorption can correspondingly also be transferred to the emission of radiation after prior absorption. After previous absorption, the molecules in a gas volume irradiated by a broadband light source emit a spectrum characteristic of the molecule type. In this case as well, the number of emitted photons is also in a functional relation to the number of molecules of a certain gas type per volume unit and thus to the concentration.

Depending on the application, either absorption measurement or emission measurement is preferred for gas analysis. For example, the absorption method has proved to be more practicable for the measurement of pollutant concentrations in waste gases since it is possible here to divert a subflow of the waste gases and continuously feed it into a measuring cuvette to perform a transmission measurement.

If no access to the emission source is possible then the measuring problem appears in a different light. A remote analysis may then be conceivable, which permits a determination, e.g. of the flue gas fractions at the stack outlet, by means of the emitted spectral lines from distances of up to several hundred metres. Since the boundary conditions are less well defined here, they must additionally be determined by measurement (e.g. laser anemometer) and calculation which requires certain model assumptions. Accordingly, this measurement is not so direct.

Legal Basis of Existing Emission Monitoring Systems

In Germany, the Federal Immission Control Act (BImSchG) as amended on 14 May 1990 is the basis for monitoring the operation of plants which may endanger the environment. Pursuant to § 29 of the BImSchG, the competent authorities may prescribe for plants subject to licensing that instead of individual measurements certain emissions "... should be permanently determined by using measuring instruments in continuous operation". The measuring regulations are based on authorization by the legislature pursuant to § 7 par. 1 no. 3 of the BImSchG:

Furthermore, the Federal Government is authorized "... to prescribe by statutory order with the consent of the Bundesrat that plant operators must undertake or arrange for measurements of emissions ..." according to procedures to be laid down in detail in the statutory order.

Further ordinances, e.g. the Regulation on Large-Scale Firing Systems (GFAVO) and general administrative regulations, e.g. the Technical Instruction on Air Pollution Control (TA Luft), have been enacted on the basis of the BImSchG.

Pursuant to § 5 of the BImSchG, which incorporates the precautionary principle, the aim of the GFAVO is to drastically reduce the large-scale air pollution by sulphur oxides, nitrogen oxides, halogen compounds and dust, as well as the heavy metal compounds contained in it, caused by large-scale firing systems. The central feature of the statutory order is the inclusion of older facilities. In comparison to older facilities, emissions from new plants are relatively low.

The scope of the GFAVO includes plants with a thermal power output of 50 MW and above, if gaseous fuels are used 100 MW and above. The statutory order is valid both for new plants as well as for those under construction or in operation (older plants). The number of facilities affected is given in the literature as approx. 1500. In the case of plants covered by the GFAVO, the requirements of the TA Luft limiting emissions are replaced by the GFAVO, whereas for the remaining facilities subject to licensing the emission limits of the TA Luft remain in force.

In accordance with the requirements of the GFAVO, continuously operated measuring systems to record the atmospheric pollutants relevant to the facility in question have already been installed at most plants covered by the GFAVO. Since the largest operators of such plants operate several facilities coming within the scope of the GFAVO they have installed largely automated measuring systems of similar design to continuously record emissions of atmospheric pollutants. These measuring systems are of modular basic design in order to permit flexible adaptation to the partially different emission characteristics of the individual plants. Differences arise, for example, from the type of fuel used, which apart from hard coal, lignite, gas or fuel oil, may also include refuse.

Apart from dust, the pollutants carbon monoxide (CO), sulphur dioxide (SO₂) and nitrogen oxide (NO) are continuously measured for coal power stations. Furthermore, oxygen is also measured for purposes of standardization since the limits are relative to a defined oxygen content of the flue gases.

Measuring Systems Fulfilling GFAVO Requirements

As mentioned above, the measuring systems for monitoring pollutant emissions at all large-scale firing systems pursuant to the GFAVO are designed similarly according to a basic concept defined by the legislature. Samples are taken from the flue gas flow in the lower part of the stack with the aid of a point-type, corrosion-resistant probe. Dust is separated from the sampling gas flow immediately behind the probe in a heated roughing filter. The extraction line is heated up to a sampling gas cooler immediately in front of the measuring location in order to avoid condensate deposits and thus line blockages. The condensate is separated in the sampling gas cooler at a temperature of 275 K. The sampling gas is pumped by a diaphragm pump with connected flow meter through a fine filter to the gas analysers connected in series.

The gas analysers used must have a standard federal certificate. Several makes and types are authorized for each pollutant component. Almost all of them operate on the principle of *non-dispersive infrared radiation measurement* (NDIR) since most gases under consideration are infrared-active.

As the name already implies, this method dispenses with dispersive elements, i.e. optical elements, which decompose the light into spectral fractions and only use narrow frequency bands. This simplification makes these instruments much more robust for practical purposes in comparison to instruments with monochromators, such as gratings and interferometers.

The measuring principle may be briefly described as follows. Light from a broadband light source radiates through a cuvette through which sampling gas flows. The light excites substance-specific molecular vibrations in the sampling gas components and thus leads to a substance-specific absorption of light by the various sampling gas components. The light emerging from the cuvette is then attenuated in several spectral regions which are specific for one type of molecule, depending on the concentration in the sampling gas.

Instruments for determining the transmission of light through a medium are known as photometers. A large number of technical designs have been developed. Due to their relatively simple design the so-called single-beam photometers are very widespread. They modulate the radiation emerging from the measuring cuvette according to two processes, the bifrequency method or the gas filter correlation method. In the case of the bifrequency method, two interference filters positioned on a rotating filter wheel are operated through the beam path between the measuring

cuvette and detector and thus modulate the beam. The so-called measuring filter only permits a narrow spectral range covering the absorption line of the sampling gas component of interest to pass unimpeded. The other filter, also known as the reference filter, similarly only permits a narrow spectral range to pass unimpeded, in which, however, there is no absorption line of a sampling gas component. With the aid of the calibration parameters, the concentration of the gas component of interest in the sampling gas cuvette can then be calculated from the two corresponding detector signals. In the gas filter correlation method, the uninfluenced beam from the measuring cuvette is detected alternating with a beam filtered through a minicuvette filled with a high concentration of the gas to be analysed. The minicuvette completely filters out all spectral fractions characteristic of the sampling gas, and the corresponding detector signal serves as a reference signal for the detector signal only influenced by the sampling gas in the measuring cuvette.

There are also numerous technical variants of NDIR photometers designed for specific application purposes. Due to their relatively simple and robust design, high measuring accuracy and long-term stability, NDIR instruments are largely used for industrial and field applications.

In accordance with the protective goals of the GFAVO, the absolute quantities of pollutants emitted are of secondary importance. A measurement of absolute quantities is therefore not explicitly prescribed. The quantities of flue gas emitted are assumed to be known and can be estimated by the plant operator on the basis of the technical plant characteristics and the quantities of fuel consumed.

It is in principle possible to measure the blower rating for this purpose although the problem of calibration then arises. The same is true if pressure measurements carried out at various levels in the stack are used for flow rate calculations. It may be possible to achieve a satisfactory solution with laser anemometers or ultrasonic flow meters. However, these possibilities still require further scientific investigation and technical development. According to the present state of the art, the greatest uncertainty with a measuring system for verification processes is probably the volumetric flow rate measurement of the off-gases. Table 3.2 gives a survey of measuring techniques available for measuring the volumetric flow rate.

Measurement-Method	Total Uncertainty	Continuous Measurement	Temperature-dependence	Requirements for Flue-gas	Design Features	Calibration	Qualification for the task
Fan-wheel anemometry (grid method)	$\pm 3\%^{2)}$	not possible (deposition of dust)	none	dry, free of dust	only manual measurements possible	none	not appropriate
Differential pressure measurement (Pitot tube grid measurement)	$\pm 3\%^{2)}$	not possible (deposition of dust)	yes	dry, free of dust	extensive installation work in stack	none	not appropriate
Differential pressure measurement (WILSON baffle grid)	about $\pm 4 - 5\%$	possible	yes	dry, without sticky particles	extensive installation work in stack	Pitot tube grid measurement	appropriate to some extend
Differential pressure measurement (TABAR-probe)	$> \pm 5\%$	possible	yes	none ³⁾	easy to handle in stack	Pitot tube grid measurement	appropriate ⁴⁾
Vortex frequency (VORTEX-probe)	$< \pm 10\%$	possible	to some extend (zero point)	none	easy to handle	Pitot tube grid measurement	appropriate ⁴⁾
Ultrasonic measurement	about $\pm 4\%$	possible	none	none	manageable (except dust on probe)	Pitot tube grid measurement	appropriate ⁴⁾
Laser-Doppler Anemometry, (LDA-grid measurement)	$\pm 3\%^{2)}$	possible	none	without clouds of smoke	extensive girder installation	none	appropriate
Laser Doppler Anemometry, (LDA-single test)	$< \pm 10\%$	possible	none	without clouds of smoke	manageable	none	appropriate ⁴⁾
Power measurement at exhaust fan	inaccurate	not possible (deposition of dust)	none	homogeneous, absolutely clean	-	-	not appropriate
Differential pressure at exhaust fan	about $\pm 5 - 6\%$	possible	yes	none	manageable	Pitot tube grid measurement	appropriate ⁴⁾

1) rough estimate for classification of the method; 2) grid measurement according to VDI/VDE 2640; 3) special installation for wet flue-gas; 4) does not comply with VDI/VDE 2640.

Tab. 3.2: Evaluation of different measuring techniques for large cross-sections and under flue gas conditions according to various criteria [Kolke 93]

Integration into Existing Measuring Systems

It appears meaningful in designing a measuring procedure for verification purposes with radiative forcing gases at large point sources to make use of experience gained in implementing the provisions of the GFAVO, especially since measuring instruments are used here which, with respect to their technical design, could be used to measure at least CO₂ and CH₄ concentrations after minor modifications without a great deal of effort. Furthermore, the measuring instruments used in implementing the GFAVO are licensed throughout Germany. The modular design of these measuring systems permits them to be easily extended, e.g. to determine the CO₂ concentration.

Nevertheless, it must be remembered that there is an essential difference in the measuring philosophy for fulfilling the GFAVO and that for verification purposes. On the one hand, the conditions of the GFAVO are concerned with observing concentration limits which may only be exceeded by a fixed amount on a restricted number of occasions otherwise penalties will be incurred. On the other hand, measurements for verification purposes are interested in the overall quantity of radiative forcing gases, in particular CO₂, emitted into the atmosphere during a certain time interval with the aim of setting up a balance. Furthermore, it must be remembered that the institutional target groups for the respective data are probably different institutions and that for this reason a strict division might be desirable. The collection of data required by the GFAVO is undertaken solely on the basis of national legislation. In contrast, greenhouse gas emissions are measured exclusively for the purpose of an independent verification. There is a need for regulation here in connection with anchoring international verification measures in national legislation.

These considerations should therefore only include the measuring technology in the GFAVO provisions as a model, the institutional and organizational division (interface) should be discussed in connection with a possible implementation of a verification system.

With respect to the requirements in designing a measuring system for verification purposes, i.e. from sampling up to presentation of a digitized signal for the concentration of a radiative forcing component of power station emissions, conditions are found analogous to those for a system to record GFAVO-relevant pollutants. The extent to which one or more components for determining radiative forcing gases should be modularly integrated into the existing system or installed comple-

tely independently of it depends on whether interventions in the system, i.e. for calibration, can be coordinated on an organizational basis.

Requirements Made on a Measuring System for Verification Purposes

The analogy between measurements for verification purposes and those to fulfil the GFAVO requirements is restricted to concentration determination. As already discussed above, the differences between the two tasks are to be found in the volumetric flow rate measurement necessary for verification and in the treatment of the data. The technical possibilities of implementing volumetric flow rate measurements at point sources with large emission cross-sections are restricted. Most methods are based on an extension of classical measurement procedures. In current practice, volumetric flow rate measurements are only performed in exceptional cases and then only for a limited period. The major problem is the lack of knowledge about the representativeness of a parameter, e.g. a pressure value, determining the local volumetric flow rate measured at one point in the flow cross-section. According to experience, a gas flow in a stack has a certain velocity profile over the cross-section, whose maximum is usually at the centre. This velocity profile need not generally be rotationally symmetrical. Although it is technically possible to measure this profile with the aid of network measurements, nevertheless this is very complicated and is thus out of the question for verification measurements. The currently established methods have already been described in detail [Kolke 93] and will not be discussed here.

A further, but less problematic, difference between existing emission monitoring systems and verification requirements is to be found in data evaluation. Whereas the GFAVO requirements are restricted to documenting concentration data, the aim of verification measurements is to record the quantities of a radiative forcing waste gas component emitted during a fixed period. To this end, the emitted greenhouse gas components must be calculated and incrementally cumulated with the aid of certain average concentration values determined at short time intervals (short in comparison to alterations in the operating state) and average volumetric flow rates measured in the same interval. Accordingly, the difference in the two systems only affects the evaluation algorithm and does not make any special demands.

Existing emission monitoring systems contain, to a limited extent, measures designed to prevent a falsification of the results. This is generally achieved by sealing the measuring instruments. More extensive measures may possibly be necessary

for verification measurements capable of revealing intentional interference in the entire measuring system from sampling up to the evaluating computer, at least retrospectively. The greatest possible transparency of the measuring system is of assistance here. There are numerous examples of possible safeguards in the field of IAEA safeguards.

In the same way as existing emission monitoring systems, measuring instruments envisaged for verification tasks should be subjected to a quality assurance programme. Although failure or malfunction of a measuring instrument would not have the same serious consequences as in the case of nuclear material safeguards, nevertheless frequent mismeasurements could undermine the credibility of a verification regime based on measuring technology. The implementation of a measuring system also involves considerable cost and doubt would be cast upon the necessity for this cost if the measuring system were unreliable.

A possible quality assurance programme could be based upon the following criteria:

- sufficient measuring accuracy
- adequate sensitivity
- calibration capability
- long-term stability, reproducibility
- functional reliability over considerable periods
- self-monitoring of servicability
- suitability for use in an aggressive environment
- representativeness for total emissions of the corresponding component
- low cross-sensitivity to other gas components or possibly correction of such sensitivity
- protection of the system and data against manipulation or tampering
- comparability of the data with other measuring methods or techniques.

Furthermore, it is conceivable that the functional status of the measuring system could be verified by remote interrogation. The accumulated data could be transmitted in the same way at the end of a balancing period. Measures of this kind could perceptibly reduce the effort of in-situ inspections. It might be possible to restrict inspections to random samples. Public data networks, telephone systems or satellites could be used as channels of communication.

An alternative possibility basically consists in measuring emissions at a certain distance from the source. Corresponding systems are currently being developed or

tested. These are essentially mobile systems capable of determining the pollutant concentration at a distance of several hundred metres after emerging from the source. Supplementary measurements of the gas velocity by laser anemometers could also permit a measurement of the volumetric flow rate [Tank 91].

A development project with this aim in mind was sponsored by the BMFT between 1990 and 1992 [BMFT 90]. The concentrations were measured with the aid of a modified Michelson interferometer in which the optical wavelength changes were not achieved by linearly sliding mirrors but by rotating retroreflectors. With broadband light sources, the result is an interferogram from which a wavelength-dependent spectrum can be calculated by a Fourier transformation. The measured volume is determined with the aid of the spectrometer field of vision and the geometrical position data of the measuring location determined relative to the emission location. It is also possible to measure the velocity at the gas outlet with a laser anemometer. In order to determine the volumetric flow rate it is only necessary to know the cross-section of the source opening.

Proposals for Further Development

There are a wide range of gas analysers available on the market to determine the gas concentrations. On the basis of experience in the field of emission monitoring, absorption photometers operating according to the NDIR principle also seem suitable for verification purposes. Corresponding photometers are also available for carbon dioxide and they are used for example in the global measuring network to determine the concentration of atmospheric CO₂. Since, like all other greenhouse gases, methane is infrared-active it can be detected by NDIR photometers. Corresponding gas analysers for this purpose are also commercially available.

In the past few years several designs of Fourier transform infrared spectrometers (FTIR) have been developed by way of competition and starting from the original Michelson interferometer have been modified in such a way that they are of manageable size and have also proved their worth in field applications. The advantage of this technology is its ability to cover the entire infrared spectral range with one single measurement, i.e. to determine as many infrared active gas components as required simultaneously. Furthermore, FTIR spectrometers can measure both emission and also absorption spectra. However, the evaluation requires a powerful computer and, depending on the number of components to be analysed, complex evaluation algorithms to implement the Fourier transformations. An FTIR

spectrometer has already been tested in a combined heating and power station [Wülbern 93].

Both measuring principles, NDIR and FTIR, can also be used for all other greenhouse gases. Measuring techniques based on the FTIR principle already provide information about the greenhouse gas concentrations of all greenhouse gases with each measurement. Detection of a specific greenhouse gas essentially only depends on the evaluation algorithm.

Considerable development efforts would still have to be invested in volumetric flow rate measurements. In flue gas ducts with large diameters, the classical methods provide data involving very large errors. It may be presumed that estimates of volumetric flow rates by the plant operators, with the aid of operating parameters and fuel throughput, are of much higher quality than the results of corresponding measurements. Qualitatively comparable measurements, e.g. network measurements [Kolke 93], can only be implemented with unacceptably great efforts and are not appropriate as a continuous method.

Optical methods, e.g. laser-Doppler anemometry, have a considerable development potential. It should be possible here to modify existing systems in such a way that the averaged flue gas velocity can be determined via the cross-section of a flue gas duct.

When the problem of measuring the volumetric flow rate has been satisfactorily solved, a test program should be implemented with a system developed from an existing emission monitoring system, e.g. in the form of utilizing the existing sampling system. Such a system requires its own evaluation computer with corresponding software in order to calculate the accumulated output of radiative forcing gases from the measuring signals of the concentration measurement and the volumetric flow rate measurement in incremental steps. A suitable test field for the first field experiment could be a large coal-fired power station.

3.3 Measuring Networks and Dispersion Models (W.-D. Lauppe)

Several measuring networks exist on the international level, largely on the initiative of UN suborganizations, whose members exchange information about the local quality of environmental media on the basis of voluntary cooperation or have information collected and evaluated by a central organization with the aim of compiling a universal data base. These measuring networks are essentially restricted to environmental monitoring and their institutional organs do not provide any recommendations for measures to be taken. By means of the data base, the participants are able to make a comparative classification of the status of the environmental media in their own region and undertake measures to reduce pollution. Furthermore, the data base provides insights into the effectiveness of regional measures to reduce the pollutant input. The subject of the measurements is largely pollutant concentrations at predetermined locations as well as supplementary status parameters relevant for evaluating the pollution of environmental media (air, water and soil). The aim of these initiatives by the UN suborganizations is protecting public health and ecosystems in polluted regions.

The following report examines the extent to which existing measuring networks may make a contribution to verifying the obligations entered into by the member states of the Framework Convention on Climate Change (FCCC). A precondition for this role would be an extension of the functions and tasks of the measuring networks. The study will therefore be restricted to the verification of emission inventories for radiative forcing gases. Furthermore, only the technical potential of measuring networks to support verification tasks will be considered. The institutional integration and arrangement of the measuring networks has already been discussed in detail [Comes 93].

Task of Existing Measuring Networks

The range of tasks of some measuring networks is very extensive and comprises the acquisition of data on the quality of the environmental media of air, water and soil. With a view to the verification of radiative forcing gases only the environmental medium of air, or the atmosphere, will be considered here. With this restriction, the objects of the environmental measuring network are above all the most important atmospheric pollutants: SO₂, NO_x, CO, ozone, lead and aerosols. In relation to the number of measuring stations, the essential radiative forcing gases, carbon dioxide CO₂ and methane CH₄, have only been of minor significance to date. Most of the atmospheric pollutants investigated have only a limited residence time

in the atmosphere, are precipitated out of the atmosphere at an early point, or are chemically converted and deposited, and thus only make a slight contribution towards changes in the average global atmospheric concentration. The major attention of these measuring networks is therefore largely focused on local and regional impacts. They measure the concentrations in the air and in precipitations as well as their development over time and the prevailing meteorological data.

Emission inventories of pollutant sources are not the subject of these measurements. If they are available they are based on data from local or regional institutions, or the operators of the emitting plants themselves. With the aid of dispersion and transport models, emission inventories enable the expected distribution of pollutant concentrations over time and space to be calculated, taking into consideration the prevailing meteorological conditions. Vice versa, in the case of pollutants with a limited lifetime in the atmosphere and thus also a restricted range, conclusions may be drawn about the emission inventories of a region with the aid of dispersion and transport models. If there is only a single emitter for a specific pollutant in a region then it is also possible to estimate its emission inventory.

Tasks for Verification Purposes

With respect to the verification of emission inventories of radiative forcing gases with the aid of individual measurements at the source or with measuring networks, the absolute masses of these gases emitted by the most productive sources in the time unit, e.g. per year, are of interest. In principle, this may also involve an aggregation of sources from different emission sectors if they are restricted to a defined regional area. Thus for example, the task might arise of determining the quantitative emissions of a certain radiative forcing gas, for example for a town, without any differentiation according to the contributions of the individual emission sectors. The difficulties in solving this task are immediately apparent.

First of all, the subject of verification should be clearly defined. In the present case, this is the emission inventories of radiative forcing gases as specified in national reports. In this connection, verification means making the veracity of these data credible. This may be achieved in various way as long as it takes place independently of compiling the report data. The emission inventories are generally aggregated according to economic sector in the national reports. This causes additional difficulties for verification by measurements if the measured object, as mentioned above, includes sources from different emission sectors. It is therefore desirable to specify the emission inventories in the national reports in as much de-

tail as possible for measurements, whether individual measurements or measurements carried out with the aid of measuring networks.

The Function of Measuring Networks

The essential components of measuring networks are the actual measuring stations for data acquisition and the communication channels to the other measuring stations or a central institution for evaluation and further processing of the measured data. In principle, a central collecting point for the data is not necessary although it is useful for coordinating the methods of data collection and the information derived from the data. The atmospheric measuring stations of the existing measuring networks are mainly in very polluted industrial conurbations and in order to determine the natural background pollution, if this is possible at all, in regions far removed from human activities. Their major task is compiling data bases on pollution in the regions under consideration. Depending on the density of the measuring stations, atmospheric pollutant dispersion can be traced. Statements on atmospheric pollutions, i.e. pollutant concentrations, on a regional scale can also be made with the aid of dispersion and transport models incorporating meteorological data.

Only the concentrations of individual atmospheric pollutants can be determined directly at individual measuring stations. Essential complementary data, apart from time and place, are all relevant meteorological data such as temperature, atmospheric pressure, atmospheric humidity, weather situation, solar radiation, wind velocity and wind direction. These data may be used as input parameters for dispersion models. The results of the model calculations enable rough conclusions to be drawn about the relative emission strength of a source. If several sources are present then it will probably only be possible to differentiate according to emitter in the most favourable exceptional cases, i.e. for pollutants with a short residence time in the atmosphere and correspondingly limited spatial dispersion.

The Technical Form of Measuring Networks

As already mentioned, the essential components of the measuring networks are measuring stations, channels for an exchange of information and, in most cases, a central documentation and evaluation authority. The information may be exchanged both between the measuring stations themselves and also between the measuring stations and the central collecting point. Information is exchanged by all

conventional data carriers such as direct data lines, commercial data networks, floppy disks or hard copies.

The measuring stations have the task of providing the actual data. This may be undertaken by continuous measurements directly at the measuring location or else discontinuously by collecting air samples at the measuring location with a subsequent analysis of these samples in a laboratory. The latter method is particularly applied for concentration determination whenever the entire range of possible atmospheric pollutants is to be covered. In contrast, most meteorological data must be directly determined *in situ*.

Established methods for continuous measurement are already available for a large number of atmospheric pollutants. If the most significant gases with respect to quantity and radiative forcing, carbon dioxide and methane, are to be detected by the existing measuring networks, then their concentration is largely determined by optical methods. The measuring methods (p. 28) are essentially based on *non-dispersive infrared photometry* (NDIR). Alternative methods of concentration determination are frequently also available in analytical laboratories.

The data may be transferred in a raw or processed form to a central evaluation point by means of the above-mentioned data carriers.

Models

A consideration of the prevailing meteorological conditions ensures that the data are dependent on the quantities of pollutant emitted per time unit in the vicinity of the measuring stations. Nevertheless, irrespective of the local meteorological boundary conditions, the functional relationship may be complex. The source emissions and the meteorological conditions are generally not constant but rather time-dependent variables. If the time course of these variables is determined by additional measurements then a functional relationship between the concentration data and the emissions can basically be determined, on condition that at least one measuring station is always in the region of the wind vane emanating from the source. In principle, this could be achieved by a high density of measuring stations. It would be possible to calibrate the model by making measurements in all conceivable emission and meteorological states. However, all possible states would also have to be exactly covered by measurements. Apart from the impracticability (due to the large number of measuring points in all three spatial dimen-

sions) of such a calibration, it would undoubtedly be simpler to determine the emissions of each individual source directly at the source location.

Atmospheric dispersion or transport models are developed in order to describe the spatial and temporal distribution of airborne matter emitted from a defined source, taking into consideration the respective meteorological boundary conditions. The attempt is therefore made to predict the concentration of these substances at each location within the range of these substances with the aid of models. This task is simplest when stable meteorological conditions prevail over a wide area.

The transport mechanisms in the medium of the atmosphere are essentially based on diffusion and convection, i.e. on being carried along in the air streams. Detailed knowledge of the meteorological conditions between the source and measuring location are required for reliable statements, which also includes the topological features of the earth's surface between the source and measuring location. Furthermore, consideration must be given to the atmospheric stratifications and the corresponding distribution of the pollutants both at the source and along the transport path to the measuring location, and also to exchange processes between the strata.

Conditions become more complicated if the substance in question is already present in the atmosphere as a so-called background, independently of the source, which is particularly the case for long-lived gases of natural or anthropogenic origin. The complexity is further increased if several other sources with similar emissions additionally influence the concentration at the measuring location. Increasing the number of measuring stations with a suitable distribution corresponding to the local situation can provide further relevant information in this case. Model statements about regional air pollutant distributions can be qualitatively improved with the aid of this information.

From the aspect of verification, an inverse application of the dispersion and transport models would also be desirable, permitting conclusions about the absolute source inventory of individual sources on the basis of the concentration data for radiative forcing gases determined at the individual measuring points. For example, this problem gained particular significance in connection with the Chernobyl fall-out. The conditions for estimating the source inventory were relatively favourable since it involved a pulsed release of pollutants which were largely completely washed out by precipitation and deposited at a few measuring locations. Furthermore, the meteorological data were well known and information about the maximum source strength and the distribution of releases in the atmospheric layers at

the source location was also available. It was possible to estimate the released inventories of individual radionuclides on the basis of model calculations. It has not yet been possible to independently verify the reliability of these estimated values since the complementary residual inventory is still not available in full and therefore an independent verification of the model statements has not been possible to date.

Conditions are considerably more unfavourable for the major radiative forcing emissions since the relevant gases, e.g. CO_2 and CH_4 , have comparatively long mean residence times in the atmosphere and are thus able to intermix on a global scale and thus contribute to a high background concentration. The boundary conditions for model calculations are thus much more difficult to determine. On the transport path between the source and measuring location, a volume element of the emitted gases loses a significant part of its information content with respect to the source. There are practical limits to compensating this information loss by the addition of further measuring points. The transfer of conclusions from individual measured concentration values to emission inventories with the aid of dispersion models therefore have little informative value. In this connection, an estimate of the error band-width seems to be rather unreliable.

Conclusions

Strictly speaking, a system for verifying the emission inventories of radiative forcing gases requires a continuous measurement of the quantities released into the atmosphere, specified according to gas type. This is particularly true of sources whose operating behaviour depends on human behaviour or on technical requirements, that is to say where normal operation with emissions constant over time and in quantity is not the rule. Sampling measurements for verification purposes in the vicinity of individual sources therefore have little informative value if a verification of the emitters' operating states is not undertaken simultaneously.

The transfer of conclusions drawn from atmospheric concentration values obtained from measuring networks to the emission inventories of individual sources or local source aggregations can only be of a qualitative nature even with favourable boundary conditions and the inclusion of detailed dispersion and transport models. Statements on tendencies can at best be made for a few individual substances on account of their favourable properties. The application of measuring network data and their further processing with dispersion and transport models does not seem an appropriate instrument for verifying the source inventories of the major radiative forcing gases.

3.4 Implementation Review (U. Kotte)

3.4.1 Introduction

Within the framework of the climate convention, the contracting parties are obliged to prepare reports on emission inventories determined and measures implemented at the national level. This reporting serves the purpose of determining compliance with the agreements laid down in the treaty. To this end, mechanisms and instruments must be created in order to verify in a suitable manner the correctness of the national data. The scope and details of the verification measures are based on the properties of the object to be reviewed.

3.4.2 Basic Requirements

The national obligations for the industrialized countries as contracting parties are as follows:

- development of national strategies and programmes to reduce greenhouse gases (GHG),
- compilation of inventories on nationally emitted greenhouse gases,
- submission of national reports on measures undertaken to the Conference of the Parties,
- acceptance of a verification mechanism within the convention.

Review of the implementation of measures should be undertaken within these terms of reference. The basic requirement is relevant reporting on the measures and support for the reporting system by suitable organization and task structures on a national level. Furthermore, a national/regional system should offer the opportunity of furnishing detailed proof of compliance if required on the basis of reports, production, application and operating documents.

For reasons of practicality (availability of measures for CO₂ reduction/stabilization), the following study is restricted to anthropogenically induced, energy-related CO₂ emissions. This involves a conceptional problem solution approach basically covering the information and safeguards aspects of implementing these measures. The universality of the consideration does not seem to be restricted as long as the transferability of the results to comparable emissions is evidently ensured.

3.4.3 Subject Matter

The concept of implementing national measures for CO₂ reduction/stabilization in the sense of a climate convention is still to some extent at the discussion and conceptual stage. By definition, at this point implementation is taken to mean an observable process which is implemented once or several times (e.g. cyclically). The measures officially announced by a contracting party within the framework of the climate convention form the subject matter of implementation. The goal of the safeguards consists of establishing with a certain degree of certainty on the basis of reports whether implementation has been undertaken or the implementation process performed.

Over and above determining the mere realization of measures, further proof of implementation may be required. This may refer to whether a measure has been implemented adequately and/or efficiently in the sense of the declared intention. In the following, however, monitoring of the implementation of measures will be regarded as the subject of safeguards without restricting its universality.

3.4.4 Measures

Measures aimed at altering technological/procedural structures and/or human patterns of behaviour seem to be an appropriate means of CO₂ reduction/stabilization. The nature, introduction and realization of measures expected to achieve specific effects or consequences will be oriented towards country-specific boundary conditions and reduction potentials. In order to achieve the postulated goals, measures of a fiscal, legal, regulatory, financial and administrative nature are proposed in the highly developed industrialized countries.

The measures may be constituent parts of political programmes and strategies as required within the climate convention. A general overview of the nature, direction and contribution of the available opportunities for action forms one of the basic conditions for developing strategies. Furthermore, the introduction of the necessary package of measures for individual economic sectors, energy carriers and plants should be accompanied by detailed conceptions of their practicability and efficiency.

As far as the Federal Republic of Germany is concerned, the application of economic, fiscal and regulatory instruments has been put forward. The following subdivision can be made for a general classification of the envisaged measures:

- free-market,
- regulatory,
- and other measures.

3.4.5 Catalogue of Measures

A complete and comprehensive collection of proposed and conceivable measures can be used as a catalogue permitting an overview of the entirety of measures. Such a compilation may furthermore serve as a starting point and reference for obligations and declarations (official statements) if they are recognized and updated in an international framework. The necessary ordering frame may be provided by developing a taxonomy permitting the classification of concrete measures according to determinable properties.

The catalogue of measures thus represents a directory of measures/instruments which can be used for CO₂ reduction/stabilization. The list may serve as a clear basis for selecting measures under country-specific boundary conditions. By way of example, in the following a few measures will be listed from a specific compilation [BMU 93a] for the Federal Republic of Germany:

Thermal Insulation

Ordinance

Within the framework of the Act on Energy Saving, an amendment of the Ordinance on heat protection (thermal insulation); in future, this ordinance will apply a low-energy-house standard to new buildings and major modifications in the building stock (heating requirements 54 to 100 kWh per m² and year, depending on the building type) [example 1]

Energy Management Act The following basic points are to be taken into account in the planned amendment of this Act:

1. Expansion of the Act's catalogue of aims to include environmental protection and conservation of resources,
2. equal priority for these goals in all decisions of the energy-sector supervisory authorities,

3. specification, with regard to the catalogue of aims, of the authorization principles for the issuance of ordinances,
4. introduction of a standard federal certification procedure for outdoor power lines of at least 110 kV rated voltage, [example 2],
5. the greatest possible exploitation of deregulation potential in order to expand the entrepreneurial latitude of energy supply companies,
6. definitions of special circumstances requiring action by energy-sector supervisory authorities should be retained for power and gas only where absolutely necessary,
7. in cases where supervisory authority must be retained, it is to be linked to criteria in a manner that ensures the predictability of legal decisions by supervisory authorities.

The proposed legislation's contents and time of submission also depend mainly on the further course of consultations concerning drafts of the EU Commission directives on the realization of the Single Market in the gas and power sectors.

Levy on Traffic

First stage: autobahn vignette (use tax) [example 3]

These three examples show that the measures envisage an indirect effect which is difficult to prove before their application to the individual emission process. Only a more detailed impact analysis concerning the application of measures can provide reliable statements about the impacts.

3.4.6 Taxonomy

An attempt at classifying measures going beyond the general aspects mentioned above (see **Measures**) may be based on perceptible differences in the mode of

action. A pattern arises from further subdivision and breakdown into which the envisaged measures may be suitably fitted. An approach of this kind towards the transparent compilation and systematic ordering of measures can be termed a taxonomy.

The following overview gives an impression of the aspects according to which known and published measures can be classified:

- free-market cost incentives/burdens
 - taxes on
 - fuel
 - carbon (content)
 - CO₂ emission
 - corresponding facilities/equipment/activities
 - tax benefits (e.g. allocation of losses) for corresponding facilities/equipment/investments/activities
 - price/cost relation
 - subsidy
 - allowance
 - progressive additional charge for large quantities
 - variably tradable certificates
 - CO₂ emission permits
 - efficiency certificates
- regulations
 - user fee (e.g. motorway vignette)
 - quota system (e.g. vouchers)
 - tariff structure
 - market intervention (pricing)
 - integrated planning of funds (LCP - Least Cost Planning)
 - supply-side policy tailored to suit market needs
 - demand side management (DSM)
 - technical specifications/standards for
 - efficiency
 - state of the art (technology)
 - choice of technique
 - specific limits for
 - CO₂ emission
 - fuel consumption
 - maximum speed (e.g. tachograph)
- other measures

- behaviour patterns
 - public information/influence
 - mode of use (e.g. electronic use records).

The following classification possibilities can be selected for the examples mentioned:

[**Example 1**] regulation: ordinance, specific technical standards, efficiency (low-energy house).

[**Example 2**] regulation: certification procedure, specific technical standards, state of the art.

[**Example 3**] regulation: tax, user fee.

3.4.7 Review Approaches

Review on the implementation of measures makes use of the information generated on a national level and subsequently transmitted by reporting. The reports must contain corresponding statements on national intents within the framework of the obligations and indications of their realization. These data should be subjected to regular verification. A consideration of the conformity of these statements on national procedure, particularly the implementation process, can be used as a methodological verification approach.

The extent of certainty about the implementation of measures may be derived from the number and detail of the corresponding information in the national reports. The assessment of compliance is based on the evidence and indications required for an adequate appraisal of the proof provided. Depending on the type and scope of the safeguards approach further information may be required over and above the announcement of concrete measures and the final declaration of their application.

To this end, three different conceptional stages will be dealt with differing in the extent of safeguards, i.e. in the type of information used. Firstly, national reporting on the application of a measure in some form or another may be sufficient. Secondly, a report would have to be made on the progress of implementation at successive points in time in a structured/formalized manner. Thirdly, statements on the verifiable effects of a measure on certain impact fields should be transmitted using qualitative/quantitative indicators on defined/agreed scales. These three stages each involving a greater communication effort for a system

safeguarding the application of instruments/measures for the reduction/stabilization of CO₂ emissions may be characterized as follows:

- unstructured concept - obligation and final declaration
- time-structured concept - phase method
- content-structured concept - cellular method.

In these methodological considerations on safeguards for the implementation of measures it should be remembered that a consensus-oriented cooperation between all those involved is necessary for the further definition of the approaches and possibilities discussed.

3.4.8 Obligation and Final Declaration

This concept establishes in a simple manner and with little effort the connection between national measures and international safeguards. On the one hand, a report is made on the measure envisaged to achieve the goal. On the other hand, the actual introduction/application of the measure on the national level is declared. The basic data on the implementation process are thus available without further details being required.

3.4.9 Phase Method

This conceptional stage envisages the transmission of data on the progress of the process of implementing the measures at certain intervals. The duration of the entire procedure may be subdivided into individual phases in order to structure the sequence. The phases are formed by task-oriented sections terminated by so-called milestones and their completion characterized by certain results. Reports on modifications and revisions of the procedure must be made in the course of time.

The phase method can be used for implementation review in order to take the time-dependence of the process of implementing a measure into consideration and to increase the amount of information available for safeguards. Examples will be given in the following describing the possibilities of subdividing the implementation process into sections:

**Impact-oriented
definition**

Section/Phase

1. source-specific problem definition
2. analysis of possible solutions (and anticipated effects)
3. design of the measure/element/package
4. compiling concrete measures
5. introduction
6. implementation/enforcement
7. impact analysis, verification, evaluation
8. feedback with context/environment
9. retention/modification/abolition
10. further development

Procedural definition

Section/Phase

1. consideration
2. planning
3. draft
4. submission
5. consultation
6. processing
7. formalization
8. resolution
9. adoption
10. legal enactment
11. introduction
12. implementation
13. application
14. verification of application
15. amendment

The following phases have already been completed for the examples mentioned:

- [Example 1]** Consideration, planning, draft, submission, consultation, processing, formalization, resolution (19.05.93).
- [Example 2]** Consideration, planning, draft.
- [Example 3]** Consideration.

3.4.10 Cellular Method

A further conceptional step consists in deriving support from the observation of suitably selected impact fields. It is assumed that the general impact area of the measure contains identifiable fields on which information is available. Furthermore, it is expected that the effects with respect to various cells/fields/matrix elements of the impact area can be recognized, attributed clearly and exclusively to the measure, and determined by means of existing/to be established indicators. The concept of the cellular method is selected on the basis of grids, networks and tables in which a subdivision into cells is undertaken.

Application of the cellular method includes the determination of corresponding cells/impact fields of the environment/impact area of the concrete measure within the framework of the agreed reports, which can be observed, investigated and verified on the basis of suitable indicators/parameters/attributes. In practice, the determination of significant impact fields is based on the information available about the mode of operation, effect and the consequences of the measure. The impact of the measures with respect to other levels/fields/cells or populations requires further detailed analysis and evaluation.

The cellular method can be used for implementation review in order to make use of the impact orientation of the process of implementing the measure and to enlarge the quantity of information for safeguards. Some of the proposed measures with examples of impact fields and possible indicators will be presented in the following to roughly illustrate the approach:

[Example 1] Impact field: Indicator

1. Building type, new buildings: number/year
2. Building type, modifications: number/year
3. Building type, enclosed space: m^3/year
4. Building type, floor space: m^2/year

[Example 2] Impact field: Indicator

1. Certification procedure: number/year
2. Certification procedure, power line: km/year

[Example 3] Impact field: Indicator

1. Vignette: number/year
2. Vignette, revenue: DM/year

3.4.11 Information Structures

On the basis of the safeguards approaches discussed, corresponding structures are to be envisaged for information to be agreed and exchanged between the national level and international review for purposes of reporting (communication). A largely standardized form of report contents and scope of reporting obligations seems appropriate for reasons of comparability and transparency. The relevant information elements of significance in the organization, realization and implementation of measures must be selected and defined according to the conceptional approaches for implementation safeguards.

The forms and instructions for reporting must be developed in detail in order to obtain the required information in a uniform and unambiguous manner. If the initial scope, contents and periodicity of the reports are not sufficient for detailed and comprehensive application of the phase or cellular method then agreements must be made on progressively concretizing any supplements and improvements. In order to take the different characteristics of the measures into consideration, the reports will probably be composed of standardized and measure-specific parts. The determination of corresponding data structures with their attributes, characteristic features and value ranges should be based on the possibilities and limits of data systems engineering.

A suitable information management system for the totality of transmitted information is to be envisaged on an international level ensuring the acquisition, management and evaluation of the information. Such a system can also be used to map and survey the emission situation (monitoring system) as already practiced by international organizations for other subject areas. This would enable different problem areas to be considered which are governed by specific perspectives and interests.

3.4.12 Verification Instruments

The possibilities listed above of defining and structuring information for the purposes of reporting on the implementation of measures should be correspondingly agreed in the protocols and annexes to the framework convention on climate change. It will then be possible to assess the implementation process by means of defined information elements taking typical properties into consideration. The described methodological approaches are used in order to obtain the necessary degree of certainty that a measure has been implemented in the sense of the obligation/convention.

The verification instruments/techniques refer to statements on the determination, structuring, classification and realization of emission-related measures. They aim at verifying conformity with the voluntarily chosen/agreed standards/stipulations within the scope of the convention. According to definition, conformity verification may make use of the following instruments/techniques:

- catalogue of measures
- taxonomy
- obligation and final declaration
- phase method
- cellular method.

This type of standards control can be supported by verifying the validity of the information presented. Reflections on plausibility, considerations of consistency and conclusions by analogy, as well as knowledge of the known consequences, can be employed to assess the implementation data. Integration and evaluation of information as part of international safeguards should then permit an assessment of the implementation process and enable statements to be made on the execution and impact of reduction/stabilization measures.

The following consideration is based on the assumption that the agreed information should be made available to the international authority in a proper and truthful manner corresponding to the obligations of the contracting parties. In contrast or as a supplement to this assumed procedure, the approach could also be selected on the part of the international safeguards agency of independently gathering information. In accordance with the possibilities of obtaining information, this information is to be sought in an extension of the national reports as well as in additional independent information gathering. Further data sources (observers, measuring networks, satellites etc.) capable of contributing suitable information

are then to be taken into consideration based on the availability of information and the definition of information elements.

3.4.13 Concluding Remarks

The topic of implementation review is addressed in this study particularly from the information and safeguards aspects. Conceptual approaches are discussed which can be applied to safeguard the implementation of measures with respect to greenhouse gas emissions and also for the international monitoring of these measures. Furthermore, a description of the problem area is given, which may serve as a starting point for further studies. This basis should permit the acceptability and range of the discussed conceptual approaches to be tested as a function of the treatment of concrete measures and the empirical know-how thus obtained.

3.5 Satellite Remote Sensing (W. Fischer)

After the energy sector, the most important sources of anthropogenic greenhouse gas emissions are changes in land use, destruction of forests (land clearing, burning off), agriculture (fertilization, rice paddies, stock breeding), and, to a minor extent, landfill sites. If an agreement on specific goals for the reduction of GHG emissions from these emission sectors were to be reached by the states then the problem of verifying the compliance would arise here. This would apply equally to an agreed expansion of GHG sinks, for example by afforestation programmes. A study on behalf of TFF, whose results form the basis for this section, investigated the contribution which could be made by remote sensing using satellites to the verification of such agreements [Lanchbery 93].

Direct methods of determining emissions from the above-mentioned sectors (by means of techniques for measuring mass flow) cannot be applied in practice since the emission sources are characterized by large area, great number of emitters, in part by their intermittent character and mobility. The quantities of emissions released from these dominant diffuse or area emission sources must be calculated, i.e. indirectly determined. Nevertheless, measuring programmes on determining emissions from small, definable areas could provide first indications of plausible estimates on which the calculations are based.

Such indirect methods of determining emissions are widespread and ideally based on two data sets: directly measured parameters and emission factors. These indirect methods will be outlined very roughly with the example of determining CO₂ emissions released in deforestation. The destroyed areas are determined (in the ideal case) with the aid of measurements on the ground, from the air and/or from space.¹ The composition and quantity of vegetation per comparable unit area is then estimated. Depending on the age, density, species variety etc. of the vegetation, an estimated content of carbon stored in the biomass is allocated to the areas. If an oxidation factor (completeness of combustion) is taken into consideration, multiplication of these values indicates the released gross quantity of carbon, above all in the form of CO₂ and CO.

In the case of such procedures, the uncertainty margins for emissions are rather large simply because the often very specific emission factors are not easy to

¹ In practice, the data are not obtained area-wide for all forested areas in a country or indeed in the world since the efforts required would be extremely great. Instead, the data are obtained from representative samples and extrapolated. For supporting institutions and methods of forest industry cf. the succinct representation in [Bundestag 90a].

determine and the effort required for their determination is considerable and continues to grow the more precise and specific the factors should be. This problem can be reduced by specifying emission factors upon which the states have reached mutual agreement, even if they only approximate to reality. This permits some transparency and comparability of the emission calculations. However, this process also involves conflict and is not easily brought to a conclusion in view of the specific interests pursued by the states in specifying such factors. The calculation of emissions by a country is further complicated if the states declare their net emissions, that is to say if sinks are considered. Areas must be determined and factors specified for them as well defining the removal of GHGs from the atmosphere per unit of time (e.g. year). These topics have been touched upon in connection with the framework convention on climate change and the IPCC is currently working on compiling such agreed emission factors.

From the perspective of verification, the determination of direct parameters is the decisive point in the process of verifying compliance. Great efforts must be expended here to verify the correctness of the national data. In contrast, if the emission factors are specified by mutual agreement, verification is restricted to merely reveal the actual application of these factors in calculating the national declarations. Whether they are factually correct, i.e. whether the emissions factors indicate the actual quantity, for example, of carbon stored per unit (e.g. hectare) on a certain area is admittedly of significance with respect to the material regulatory goal of the convention², but is irrelevant for verification purposes. Emission factors are arrangements, laid down by mutual agreement, and as such are to be regarded as valid for the verification process.

Studies of global environmental change would be unthinkable without remote sensing satellites (cf. [CEOS 92]) and satellites may also make an important contribution to the verification process by providing direct parameters. They already do this to a certain extent: their sensors provide, e.g., data on the forestry sector (area and structural surveys, deforestation and afforestation, forest decline), land use (area structure), agriculture (agricultural structure, set-aside schemes, harvest estimates), nature conservation (identification and observation of protected areas), regional planning (infrastructure, planning of transport routes) and they are capable of identifying landfill sites. Their application for the verification of a climate convention (and of protocols), particularly in the forestry and agricultural sectors, would not be a basically novel task from the technical

² Such factors should be as precise as possible so that emission reduction strategies may be optimized.

perspective (cf. [Hönsch 92]; [Gastellu 91]). Nevertheless, this would require the solution of general problems of remote sensing and the fulfilment of specific demands on satellite systems and the politico-institutional boundary conditions for their application, and on the use of information thus obtained [Lanchbery 93].

A country's emissions cannot be balanced by satellite sensors. Sensors can at best determine the chemical composition of the atmosphere in a column of air without methods being currently available by means of which conclusions could be directly drawn about the total quantity of GHG released by a country. The major strength of satellites is (amongst other aspects) the identification of areas and, up to a certain extent, the discrimination of the features of specific, small-area objects or structures in these areas. Naturally, there are also inadequacies in the practical application of satellites for specific tasks, as shown by the lack of agreement about the size of the destroyed forest area in Brazil and other regions (cf. [Myers 91]) and Climate 1991). For the satellite sensors are neither optimally designed for this task nor are the definitions of "forest", the survey methods or the methods of evaluating satellite pictures standardized (cf. [Kenneweg 92]).

Even if the basic feasibility of monitoring forests by means of satellites for verification purposes has been demonstrated [Lanchbery 92]; [Hönsch 92]), the general problems encountered by all users of satellite data with the data gathered by remote sensing systems and which need to be solved on a national and international basis should not be ignored: - The data do not satisfy requirements with respect to spatial, temporal and spectral resolution, or only in part; - the continuity of remote sensing is not guaranteed (primarily for cost reasons); - methods of data interpretation and classification are in need of improvement; - information on existing data sets and access to these data must be improved. In general terms, the interaction between the manufacturers and operators of satellites and the various user groups is still inadequate. Nevertheless, the necessity of paying greater attention to the user interests in designing satellites has already been recognized.

In spite of these problems, satellites offer good opportunities of determining relatively reliable parameters, particularly for the emission sectors of forestry, land use and aspects of agriculture, for example about the area of destroyed forest. This ability has impacts on the conception of a verification system.

The framework convention on climate change stipulates that states should determine their emissions of GHG and declare them, if possible according to sectors, i.e. to disclose them to the international community of nations. Even if

this is not yet a constituent part of contractual obligations, nevertheless from the aspect of verification the states should not just declare these (net) emissions but rather also the directly measured parameters on which they are based, i.e. the size of the deforested or afforested areas, tree species, size of the paddy fields, number and location of landfill sites. This information can basically be confirmed or falsified by satellite remote sensing (admittedly in combination with air- and ground-based activities if one looks for an optimal result). If there is a lack of this basic information then verification has no real starting point.

The critical variable in emission declarations is therefore the land areas and their change, and in determining land and changes lies the advantage of satellite remote sensing in comparison to other observation procedures. All verification systems for identifying changes on the earth's surface depend on the accuracy and reliability of the baseline (e.g. forest area, tree species), from which changes are determined. Such data are in part already available for the sectors of forestry and agriculture compiled above all by the United Nations Food and Agriculture Organization (FAO) (cf. [Myers 91]). This is particularly true of the forest areas and in part of their status.

If one turns to the technical side of verification capability then fulfilment of the verification task and solution of specific remote sensing problems require a space-based verification system which should comprise at least two categories of satellites [Lanchbery 93]. The first category continuously observes the earth's surface with low resolution, whereas the second provides discontinuous pictures of greater resolution to identify small-area changes. All satellites should be equipped with both radar sensors and also sensors to detect visible light and near infrared. There are currently some operating satellites which fulfil these conditions in part (IRS, LANDSAT, Spot, ERS, with high resolution, and EOS, Meteosat, TIROS-N/NOAA with low resolution). An increase in the number of available satellites is in preparation within the framework of "Mission to Planet Earth" activities. The launch of Earth Remote Sensing Satellite (ERS) 2, serving amongst other aspects for global vegetation observation, planned for 1995 could also represent a building block in such a verification system. Tab. 3.3 summarizes the minimum requirements for a satellite system.

The flow of information required to fulfil the verification task can be broken down into the phases of data collection, data processing and data evaluation. In the Vertic study [Lanchbery 93], the problems to be expected in these three stages are discussed.

Task	Sensor Types	Number of Satellites Needed	Types of Satellite
Infrequent high resolution monitoring	Visible/near i.r.	One	IRS, JERS, LANDSAT, MOS, SPOT
	Radar	One	ERS, JERS, Radarsat
Frequent lower resolution monitoring	Visible/near i.r.	One	EOS, FY-B, METEOSAT, TIROS-N/NOAA
	Radar	One	ERS?

Tab. 3.3: Minimum requirements for a satellite system

Data Collection Problems

The identification of areal forest destruction is relatively unproblematic. However, this is not the case for the observation of changes in forests due to selective deforestation. The specific removal of individual trees is difficult or impossible to observe by means of satellite sensors since the sensor resolution is not high enough. A further problem is the differentiation between selective removal and the natural dying of trees. In both cases, a specific assessment by air- or ground-based activities may be necessary. Furthermore, cloud cover particularly in tropical regions, prevents continuous observation. It might be necessary to make increased use of radar satellites here. In the agricultural sector, it would require too much effort to count cattle etc. by satellite so that other procedures, such as statistical recording, should be preferred here. Radar sensors, in particular, are suitable for determining the area of rice paddies but they should be supplemented by measurements in the range of visible and infrared light.

Data Processing Problems

These problems are not of a basically novel character but the cost of installing a system to process large data quantities is very high. Even today the quantities of data provided by scientific, non-military satellites exceed that which can be used. As both operators and users of satellites have recognized there are already considerable "data graveyards", which threaten to continue growing since the

information supply from satellites continues to increase. There are estimates according to which at the start of the 21st century such satellites will provide one terabyte of information per day. In order to be able to utilize the information at all, the specific data processing, evaluation and provision of user-specific information should be given the greatest priority.

Data Evaluation

In order to determine changes an exact definition must be given of what is to be designated as such. For this reason, the input data about areas and their utilization must be precise. It is also necessary to determine the frequency with which changes are measured. If the intervals are too long then a small, correctable alteration may turn into an unacceptable change. On the whole, a data evaluation system based on digitized, three-dimensional information about forests and agricultural land use seems particularly suitable to compare data obtained at different times and draw reliable conclusions.

This type of space-based system for verifying the compliance of states displays a number of features with important political and economic implications. First of all, it must be clarified whether it is necessary to entrust an international organization with the task³ of implementing verification with their own satellites or whether in view of the growing number of national satellites it would not be more appropriate to make use of their information. Practical considerations and the minimization of cost are points in favour of the utilization of satellites already installed even if they are not optimally tailored to verification purposes. The necessary information could conceivably be purchased from the satellite operators if required. One can imagine that the evaluation of pictures and information takes place at an international safeguards organization in order to ensure independence of image interpretation and comparability of interpretation methods. Such a verification system should also include agreements between an international organization entrusted with this task and the states granting the organization the right, if required, to itself gather further clarifying information in the country concerned. This requires close cooperation with the competent national implementation agencies. It seems imperative to achieve a fair distribution of costs between the states who must fund the construction and operation of the satellite monitoring system, and

3 Whether the establishment of a comprehensive verification organization is necessary at all will be discussed elsewhere. It would be conceivable that essential work on procuring the information necessary for verification could be delegated to existing organizations engaged in collecting similar information (for example the FAO but also other organizations and research institutes with remote sensing programmes).

existing systems should be integrated as cost-effectively as possible. On average, these satellites only remain operational for a few years so that there is always a danger that the design and operation of a new satellite monitoring system specifically constructed for verification purposes would come to grief due to high costs. It cannot be expected that complete global surveys of the forests and their changes could be implemented frequently and regularly. Observation will have to be restricted to hot spots of forest destruction and selected regions in other emission sectors.

Since, as discussions in the run-up to the Rio Conference (UNCED) have shown, a number of states have considerable reservations both about obligations on the protection of forests and also concerning satellite remote sensing by an international body, it seems meaningful to develop an evolutionary concept based on existing activities to determine the status of the global forests (e.g. compilation of inventories by the FAO), to first implement individual projects in order to break down scepticism about monitoring and develop incentive systems encouraging countries to participate in agreements and verification measures. Such incentive systems could not only include programmes on the protection and sustainable utilization, e.g. of forests (cf. [BML 93]), but also the more extensive transmission of such information arising from remote sensing to the cooperating countries. This would not only provide them with assistance in implementing their national climate protection policies⁴, but also their economic development projects, such as exploitation of raw materials, could be implemented more efficiently and in an environmentally friendly manner. In this connection, it would also be meaningful to reinforce the capacities of national space institutions in order to identify and enlist new user groups for satellite information [Lanchbery 93a].

4 This does not only refer to countries of the "South", which experience considerable problems in the internal enforcement of their policies, for instance on the protection of national parks or areas of indigenous population. Satellites could also help to monitor, for example, compliance with the limit envisaged by the Canadian government of restricting clear-felling areas to 60 hectares (currently several thousand hectares).

3.6 Simulation Models (H.-J. Hoffmann, J.C. di Primio)

The attempt can be made to verify data individually by tracing their evolution. If a number of related data are to be verified then one can attempt to mathematically reproduce these relations in a simulation model. If it is possible to substitute declared values from the greenhouse gas inventory, the catalogue of implemented measures or the country reports (see Introduction) for the model variables, or some of them, then the fulfilment of the above-mentioned model relationships provides an indication of the veracity of the declaration. In such a plausibility check, particularly a consistency check, the relations between declared values and measures as well as to independently determined information can be verified.

In the case of verification with the aid of models, it is envisaged that the international verification institution should have a simulation model adaptable to country-specific conditions. It may be the case that the safeguarded country compiles its declaration from source data with the same or a similar model. If this is permitted under the convention and if the country is furthermore obliged to specify the origin of the data and the model used then verification is restricted to making random checks on these data. A continuation of this concept would be to stipulate the utilization of a certain model for compiling the declaration. The international verification institution would then have to ensure that this model was further developed according to the latest state of the art so that the declarations should be as realistic as possible.

In contrast, verification making use of models is not trivial if the declared values are derived from sources of different origin, type (apart from calculations also measurements, estimates etc.) and reliability (representativeness etc.). The following consideration will be restricted to this case. Both errors in the declared data as well as errors of the verifying model are reflected in the detected discrepancies.

As mentioned above, verification with models can only provide an indication of veracity and not proof. There are two reasons for this: 1) the incomplete reflection of reality in all models, 2) the possibility of compensating errors. An unfavourable verification result need not necessarily be due to a false declaration. A more extensive examination is then required, particularly the utilization of other verification methods as a control.

Models only provide an imperfect picture of reality since simplifications are necessary for reasons of limited computer, storage or programming capacity,

manageability of the models or restrictions of the investigated area, or because there is a lack of knowledge about relationships (shown in the model as equations/inequations and parameters), or because many influences cannot be quantified. Linearity and time-independence (statics) are frequent simplifications (as in the IKARUS optimization model). In the case of causal relationships between variables requiring time the static model leads to greater errors in the model statement the greater the actual development diverges from a steady state.

Errors can largely be prevented from remaining concealed by compensation if interim results are verified or different models used etc.

A differentiation should be made in the model variables between input, interim results and output. The values specified in the declaration can in principle be distributed between all three categories. A residue of variables generally remains, to which, if they are not calculated results, values must also be allocated in order to permit computer runs. The verifying institutions would have to supplement these values from statistics available to the public, their own surveys, estimates etc. They would then expand their data, as is desirable, beyond the scope currently envisaged by INC/IPCC, since these only envisage a consistency check between declared data.

The capability of a model to undertake the verification task is the greater the more completely the declared values are included in it and the more easily accessible and reliable the above-mentioned residual variables are. The scope of this sketch does not permit existing models to be exhaustively examined with respect to their verification ability, amongst other reasons, because the information to be declared has not yet been defined. (However, according to the above opening remarks, this could also be oriented to the possibilities of a prescribed standard model.) By way of example, two models from the energy sector will be briefly mentioned in the following since energetically related emissions account for the by far the greatest proportion of greenhouse gas emissions to be declared. The older model MEDEE comes from EJE, Grenoble, and was further developed at IIASA, Laxenburg near Vienna, into MEDEE 2 [Lapillonne 78]. The newer model is actually a whole group of related models currently (1991 - 1994) being developed at the KFA Jülich on behalf of the BMFT. In the sense of an expansion of the verification task, graduated according to effort and based on growing verification need, the MEDEE model is to be ranked below the IKARUS set of instruments.

The MEDEE model was originally developed and extensively used for the purpose of long-term energy demand predictions. The demand for final energy (model

output) was linked with a hierarchy of demand-determining factors, e.g. levels of activity in industrial sectors as interim values and finally with general data such as population development and development of the gross national product (model input). Correlated with the emission factors tailored to their degree of detail, the activity levels provide the required greenhouse gas emissions. The analytic capability depends on the degree of detail being correctly selected and the description being sufficiently technology-specific. Econometric models are therefore of little use in this case. In contrast to its originally intended purpose, the generation of time series for future development, the MEDEE model would merely be used for verification purposes to provide comparative calculations for a point in the recent past. For example, the sectoral final energy consumption derived from economic statistics with the aid of the model could be compared with corresponding data from the energy balance. The efforts otherwise required in using the model for creating trend extrapolations and scenarios would not be necessary.

The IKARUS model instrument was developed with the intention of analysing the impact of measures to reduce greenhouse gases. Since both these measures and also some of the impacts are included in the declaration to be verified the statistically functioning tools can be applied for a fictitious steady state of the economy for verification purposes. The entire energy supply system of the Federal Republic of Germany is modelled so that all obtainable energy information (possibly after a certain amount of preprocessing) can be used for control purposes. Sector-specific technology models for electricity/district heating, space heat, industry/small consumers and transport provide the necessary technology-specific degree of detail. A linear optimization model of the entire energy supply system, which must, however, be operated here as a simulation model with correspondingly narrowly set bounds, ensures the interlinkage of the subsectors at a higher level of aggregation. The demand for energy services is generated in special "demand generators". The latter derive their data from an economic input/output model "MIS" with 15 economic sectors and furthermore 9 special energy sectors. Modules for demand according to goods, services and investments, as well as for the capital stock, are "flanged" on. The number and structure of the population must be predefined. International consistency is ensured by the adapted Manne-Richels model "Global 2100". This comprehensive instrument permits the inclusion of all important variables influencing greenhouse gas emissions directly or indirectly. To this end, as described above, they are assigned to the input, output or interim results of the model run carried out for the reference time of the declaration.

In particular, the task for which the IKARUS instrument was designed, namely analysing the impacts of greenhouse gas reduction strategies, takes effect if the declared measures and declared impacts are to be examined with respect to consistency. However, this is only successful (see above) for steady states. The "measures" must, in particular, be represented as components of alternative steady states. Once again, these are not optimization but simulation runs with correspondingly narrowly set bounds since verification always refers to a real state in the past.

4. Institutions (W. Fischer)

It is by no means a compelling necessity that the regulation of international problems by norm- and rule-governed, contractually supported behaviour on the part of states (governance) has to be accompanied by the establishment of organizations on an international level undertaking steering functions similar to those of national administrations (government). [Young 92] thus emphasizes that although regulation is based on norms and rules (institutions¹), their implementation does not depend on the existence of such organizations (organization²). He thus rejects the idea that the lack of an organizational structure functionally equivalent to the nation state on an international level (for example the lack of a "world government") would in itself be responsible for the failure or inadequacies of a solution to global problems: "At the most general level, governance is a matter of establishing social institutions (...) capable of resolving conflicts, facilitating cooperation, and, more generally, alleviating collective-action problems in a world of independent actors. Nothing in this way of framing the issue presupposes a need to create material entities or organizations (...)" [Young 92, p. 247].

It therefore does not appear absolutely necessary that the (by no means certain, cf. [Lang 93]) emergence of a dynamic climate protection regime should also entail the establishment of a central international verification organization with extensive competences to verify compliance, nor would the nonexistence of such an organization indicate a lack of control or verification. This would be a similarly false conclusion as the equation of compliance and effectiveness of a treaty (see the section on verification need and density).

Nevertheless, organizations on the international level do play a part in the emergence of steering processes and also in the day-to-day management and monitoring of these processes for they simplify and stabilize the information flows and set up a network of relationships in which the actors involved can learn how to deal with each other and handle divergent interests [Sandford 94]. However, international organizations, irrespective of whether they have broad (United Nations, UNO) or sectoral tasks (United Nations Environmental Programme, UNEP) or are intended to contribute to solving specific tasks (International Atomic Energy

1 Defined as "the rules of the game that give rise to and define social practices" [Young 92, p. 256].

2 Defined as "material entities possessing offices, personnel, equipment, budgets, legal personality" [Young 92, p. 256]

Agency, IAEA) they always remain under the control of states which - for example, by pulling out of the agreement or institution - can generally withdraw again from the organization's sphere of influence³. An international verification organization for a climate convention would also be dependent on the competence granted to it by the states. It would only be an international and not a supranational organization like the European Union (EU), which takes over some sovereign rights from the states with its own legislative competence.

Organizations for Verification of a Climate Convention

A verification system basically comprises two stages: the national declaration (country report) about what the states has done (or will do) to realize the agreed measures, and on the international level the (more or less accurate) verification of these reports and if necessary further steps to verify compliance. The framework convention on climate change displays the same basic structure, although the obligations on the part of the states to make declarations are different according to the provisions of the treaty.

If one ignores the possibility of the states themselves reciprocally verifying compliance (a predominate procedure) then a verification system is organized in two stages:

Within the participating states, arrangements must be made to provide information, to process it in the form of a country report and to pass it on. Almost all environmental protection treaties envisaged the drafting of such reports [Sandford 94; Ausubel 92]. In order to compile the report, a national "organization" (infrastructure) is required, whose concrete structure may, however, be determined by the states themselves as a rule. The agency responsible for compiling the declaration in the states was not defined in the climate convention and cannot be generally stipulated for all states. Differences in the political system (federative versus centralistic states), in the traditions of gathering and processing statistics, the importance of government and private sectors, the administrative responsibility for issue areas have led to the emergence of different systems of gathering, processing and transmitting the national information required for evaluating compliance. This is not only the case in a

3 An exception is the UN Security Council, which if the peace is threatened or violated or in case of aggression may impose sanctions, including military measures, against any state. However, the Security Council must act unanimously, i.e. needs the support or at least the tacit connivance of the standing member states, and in accordance with the goals and principles of the UN which have been agreed by the states.

comparison between OECD countries [Weidner 92], but also for developing countries, transition economies and the remaining planned economies. With respect to the latter three groups, the level of knowledge about national environmental information systems and their quality on which reports concerning climate protection measures and emissions are based is still poor.

On the international level, the contact must be identified who accepts the reports and passes them on to the contracting parties. Almost all environmental protection treaties designate secretariats which have either been specifically established - which is seldom the case - or which are identical to existing international organizations [for details cf. Sandford 94]. As a rule, these secretariats have neither the duty nor the competence with respect to staff and resources to undertake verification. Only in cases where they operate, finance or support independent information systems, such as within the framework of the Convention on Long-Range Transboundary Air Pollution or the Convention on Endangered Species, do rudimentary independent abilities emerge for assessing compliance [Ausubel 92]. The decision to dispense with strong, independent international verification organizations in a system of sovereign states is not surprising and has only been overcome in two cases both concerned with the issue area of security: in safeguarding the prohibition of the production of nuclear weapons in non-nuclear weapons states (IAEA) and the prohibition of the manufacture and possession of chemical weapons (Organization for the Prohibition of Chemical Weapons - OPCW). However, in its provisions the climate convention does not go as far and remains within the limits drawn by other environmental treaties [Fischer 92, 91]: the topic of verification as such is not addressed, there is only a veiled reference to verification of the national reports and no intrusive measures are envisaged. However, at least a "corporate body" has been established on the basis of the treaty in the form of a "Subsidiary Body for Implementation" (Art. 10), which should concern itself with questions of realizing the convention. This ruled out from the very beginning a mistake characterizing the Montreal Protocol on Substances Destroying the Ozone Layer, namely the lack of a treaty organ to assess the implementation of the protocol provisions. This deficiency was first remedied with the London Additional Agreement to the Montreal Protocol after the inadequacy of the information basis on the production and application of ozone-destroying substances had been recognized [Greene 92]. Even if details of its duties still remain to be stipulated (there is a lack of agreement in the discussions of the Framework Conventions'negotiation body), as an independent treaty organ the subsidiary body is according to its composition ("government representatives who are experts on matters of climate change") an instrument of the states participating in the treaty with relatively limited autonomy and little competence

for independent information acquisition.⁴ Political evaluation of treaty implementation remains - in accordance with the system of international agreements - under the control of the contracting states: responsibility lies with the state party conference meeting annually. This rapid conference rhythm, corresponding to that of the Montreal Protocol, would be able to create an effective, fast-response steering instrument relieving somewhat the demands made on the permanent organizational infrastructure.

The organization of verification cannot be separated from the verification need and density. The institutional infrastructure agreed in the framework convention on climate change seems to be adequate for the present level of obligations. However, it seems doubtful that this will still be the case if the reduction goals are tightened up by a state party conference or extended to more countries, or if specific rules for emission sectors or gases or emission limitation strategies and their instruments are laid down in protocols. The more, starting from that defined as verification according to the contracting parties' present understanding, namely an estimate of the completeness and comparability of national reports, verification proceeds towards a critical analysis of the transmitted information itself, requiring access to the national information acquisition and processing systems, and which may even contain elements of observation and measurement,⁵ the more exacting would demands be on the national organizations and the organization entrusted with verification. One example: in order to facilitate verification activities, the states' declarations should also contain information on the paths of information gathering and processing so that inspectors entrusted on the international level with verifying the declarations could undertake specific inquiries about the origin of the information if required in order to obtain a starting point for estimating the reliability of the information. This would require a well structured organizational infrastructure with precisely defined duties on both sides.⁶ The framework

4 The IAEA and OPCW are characterized by a relatively high autonomy on the working level in acquiring relevant information. In contrast, the decisive political evaluation of working results with respect to (non)compliance remains a domaine of the states and thus reflects the limited political autonomy of any international organization.

5 Such intrusive verification systems would require new international agreements and corresponding implementing legislation in the states, in which access by an international authority to information etc. located in the respective country would be regulated.

6 It is, however, fairly improbable that a single organization is responsible for procuring the information incorporated in the respective national declaration. In view of the scope of the task, the process of information gathering in the states must be carried out on a decentralized basis and then coordinated by a responsible body which prepares the synthesis. This body need not be a "national authority" but may be composed of parts of the administration under the aegis of a department ("national authority") which passes on the report and is then also the liaison office for the international verification organization.

convention on climate change does not make any statement on this issue and the methodology for compiling national greenhouse gas balances developed by the Organization for Economic Cooperation and Development (OECD) and the Intergovernmental Panel on Climate Change (IPCC) does not touch upon this aspect of disclosing the information gathering process.

An alternative to establishing an international organization would only be the delegation of the verification task to the states themselves. Although it is not uncommon for the states to undertake reciprocal verification (mostly informally) of their compliance even today, supported in part by nongovernmental organizations (NGO) [Ausubel 92], a formal responsibility by all states for verifying the national reports of all other countries would entail inacceptably great efforts. This type of national verification therefore does not appear adequate and, if there were a need for such verification, should be replaced by a verification concept in which an international organization has to undertake the task.

However, there is as yet no indication of a widespread interest in establishing a verification organization on the IAEA or OPCW model. In fact the contrary seems to be the case (cf. [Comes 92]): during discussions at the INC, massive resistance became apparent on the part of some states to any verification at all beyond that currently understood by the OECD and IPCC with respect to the term.

If this attitude should change it a dynamic climate protection regime could emerge, then two typical extreme forms of a verification organization would be conceivable [Comes 92]: a decentralized, emission-sector-specific or a centralized-hierarchical organization model responsible for all GHGs (Figures 4.1 and 4.2). The difference between the two organization models consists in the fact that in the one case state compliance is verified both with respect to the framework convention and the protocols in one organizational structure, whereas in the other case the respective protocol provisions are verified in their special verification organizations and only the political evaluation of their results is carried out on the level of the framework convention. Both models would have repercussions on the national level. In the same way as in the Chemical Weapons Convention or the Non-Proliferation Treaty, the basic obligation to establish a permanent national authority forming the link between the respective state and the international verification authority should be laid down in order to ensure smooth, continuous cooperation. In accordance with the logic of the framework convention on climate change, a regional organization, for example within the framework of the EU, may take the place of national authorities.

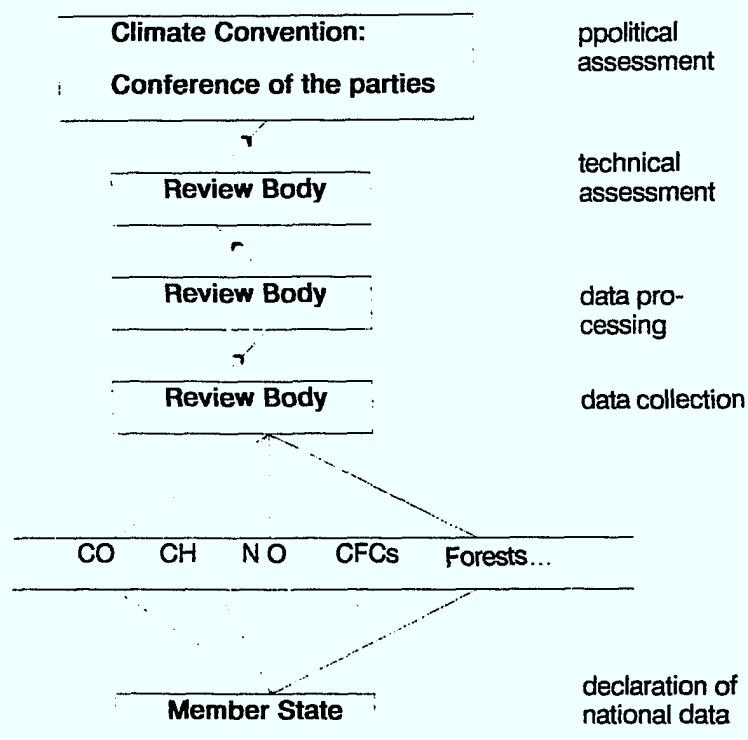


Fig. 4.1: Centralistic one-dimensional structure of a verification system
(Source: [Comes 92, p. 51])

However, as Comes's study has shown [Comes 92], a realization of neither basic model seems internationally enforceable in the foreseeable future since political acceptance is not apparent. Nevertheless, the strengths and weaknesses of these models should continue to be examined as targets for this policy.

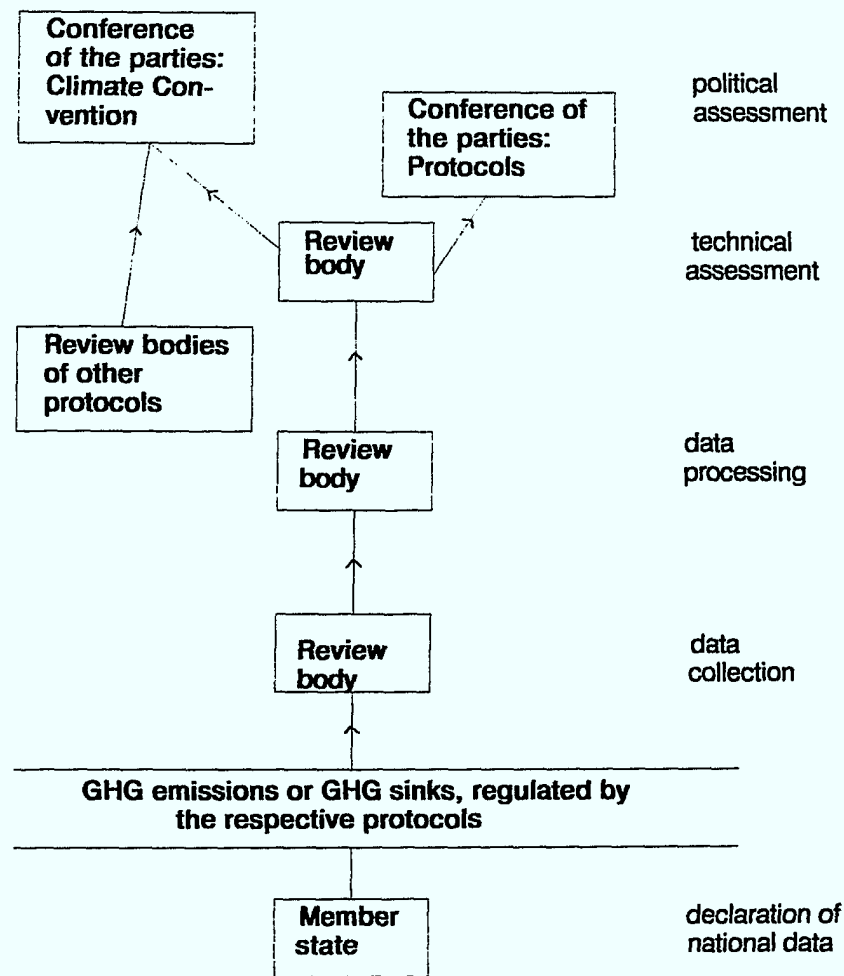


Fig. 4.2.: Decentralized structure of a verification system (Source: [Comes 92, p. 55])

An evolutionary verification system was proposed by Comes as a precursor with chances of being realized in practice, which would link current concepts with considerations on the utilization of existing measuring networks as an additional information source and the organizational basis for future verification, whose institutional infrastructure would grow with the tasks and extent of verification [Comes 92]. The question of the institutional form of the verification system is thus referred back to the material regulations on climate protection which have to be set up in a more or less dynamic climate regime. Once again, the dynamics arise out of the (inter)-national perception of the hazards emanating from climate change and the cost of climate protection.

5. Summary (G. Stein)

Subproject 9 of IKARUS investigates techniques and processes for verifying compliance by states party to the framework convention on climate change and its (future) protocols. They are obliged to limit their GHG emissions and take other climate protection measures and must make (regular) reports on the fulfilment of their obligations. In TP 9 verification is understood to be the independent monitoring of the completeness and correctness of these national reports (declarations) by a specially established organization, although only initial considerations are currently available concerning its form.

With the inclusion of the international level, the consideration of all relevant anthropogenic emission sectors and the anticipation of future protocols (e.g. forest protection, agriculture), TP 9 goes beyond the national working field of IKARUS relative to GHG emissions from the energy sector, although it remains closely linked to the overall project since the greatest attention is paid in TP 9 to verifying the declarations via the energy-related GHG emissions.

A verification of reports is also required within the framework of efforts by the IPCC and OECD to achieve a standardization of methods for the system of reporting on national GHG emissions (inventories) to be established worldwide. At least as yet the verification concepts of TP 9 and IPCC/OECD differ since they (implicitly) assume different state behaviour: IPCC/OECD concentrate on treaty violations by false or incomplete national declarations which express the states' capacity shortage. It is assumed that in spite of the states' willingness such deficiencies will hamper or delay proper balancing of their emissions. In this sense, verification intends to reveal weaknesses and assist willing but incompetent states to overcome these difficulties with help and advice. This approach is implementation-oriented and corrective. - *Over and above this*, TP 9 does not exclude the possibility that states or actors in the states deliberately (intentionally) falsify their emission data. Verification measures must therefore be more intensive and capable of disclosing these intentional treaty violations. For this reason, the feasibility and usefulness of intrusive verification instruments are also examined in TP 9.

Evaluation of the instruments, procedures and methods cover two large areas: firstly the (direct) determination of the quantities of GHG released by the respective states by means of measuring techniques and also with the aid of measuring networks and dispersion models; secondly the indirect estimate of the completeness, consistency and accuracy of the emission declarations or the

verification of climate protection measures by remote sensing, simulation models and implementation safeguards. Analyses were undertaken to discover whether emissions of GHGs from large point sources can be independently verified by the measuring technology currently available. Such a measuring system is based on the interaction of two components: gas analysers and volumetric flow meters. Commercial gas analysers are basically also suitable for monitoring GHGs. In contrast, considerable development efforts would still have to be invested in volumetric flow measurement without which it would not be possible to quantify the emissions. Optical methods have a considerable development potential, e.g. laser-Doppler anemometry. If the problem of volumetric flow measurement were satisfactorily solved then a test, for example, in a large power station facility would be meaningful in order to compare the results thus obtained with the calculated results of GHG emissions by means of computational methods (estimate). A systems analysis shows that such an area-wide measuring system would not be practically feasible for reasons of cost and administrative effort. Only strong point sources of GHGs, for example large power stations, may be the target of such balancing measuring techniques.

There are measuring networks on an international level, with the aid of which data can be measured concerning the status of environmental media, e.g. the development of the concentration of atmospheric pollutants at the local level or as part of a large measuring campaign. Since the inclusion of GHGs in such measurements does not present a basic problem, the question thus arises of whether these measurements would not be useful for verification purposes combined with dispersion models simulating a spatial and temporal distribution of the substances. The idea is to identify the polluter (states) and calculate their total releases of GHGs from the concentrations measured for a large area, in order to thus verify the national declarations of GHG emissions. The analyses reveal that conclusions from atmospheric concentration values determined by measuring networks cannot be drawn with respect to emission quantities from individual sources or to national emission quantities even under favourable conditions and if detailed dispersion and transport models are included.

The framework convention on climate change does not only oblige the states to reduce GHG emissions but also to formulate national strategies and policies on climate protection and to initiate corresponding measures. Such obligations are also subject to international verification which is, however, restricted to the question of whether the contracting states have actually undertaken these steps (implementation safeguards). To this end, information is gathered about the actual

implementation of the corresponding legislation, ordinances etc. in the states, their impacts observed and effectiveness assessed.

The potential usefulness of models for the simulation and optimization of national energy systems for verification purposes was investigated with the result that, given various boundary conditions, models such as MEDEE or IKARUS (or its submodels) appear suitable for verifying the consistency of national emission declarations.

Satellite remote sensing is also applied for verifying environmentally relevant activities and agreements. Its application for verifying protocols on sector-specific emission reductions would only be the extended application of an existing practice. However, since direct balancing of the GHGs released is not possible by means of satellites, whereas their strong point is the observation of area (changes), protocols should stipulate specific area-related protective measures for the states, e.g. the maintenance of a certain percentage area of forest relative to the area of the country, spatially precisely defined afforestation measures or practices of agricultural land use. Compliance with such obligations can be relatively easily verified. Nevertheless, the greatest obstacle to application is the cost, and above all the political acceptance of such a space-based verification system.

All in all, the study shows quite clearly that, in contrast to important fields of international arms control from which the verification concept originates, verification of the plausibility and consistency of national declarations must play the central part in GHG verification. For reasons of cost and acceptance, measuring techniques for balancing do not seem applicable on a large scale, and certainly not in determining CO₂ emissions from the states. Satellite remote sensing has a sectoral verification potential and it seems possible to make tentative use in future.

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