

Methods and models for estimating the global circulation of selected emissions from energy conversion

Sørensen, Bent

Publication date:
1992

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Sørensen, B. (1992). *Methods and models for estimating the global circulation of selected emissions from energy conversion*. Roskilde Universitet. <http://milne.ruc.dk/lmfufaTekster/>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain.
- You may freely distribute the URL identifying the publication in the public portal.

Take down policy

If you believe that this document breaches copyright please contact rucforsk@ruc.dk providing details, and we will remove access to the work immediately and investigate your claim.

TEKST NR 226

1992

**METHODS AND MODELS FOR
ESTIMATING THE GLOBAL
CIRCULATION OF SELECTED
EMISSIONS FROM ENERGY
CONVERSION**

BENT SØRENSEN

TEKSTER fra

IMFUFA

ROSKILDE UNIVERSITETSCENTER
INSTITUT FOR STUDIET AF MATEMATIK OG FYSIK SAMT DERES
FUNKTIONER I UNDERVISNING, FORSKNING OG ANVENDELSER

ROSKILDE UNIVERSITY, P O BOX 260, DK-4000 ROSKILDE, DENMARK,
TEL: (45) 46757711, FAX: (45) 46744065, TELEX 43158.
INSTITUTE OF STUDIES IN MATHEMATICS AND PHYSICS, AND THEIR FUNCTIONS
IN EDUCATION, RESEARCH AND APPLICATION.

10. AUGUST 1992

METHODS AND MODELS FOR ESTIMATING THE GLOBAL CIRCULATION OF SELECTED EMISSIONS FROM ENERGY CONVERSION

by Bent Sørensen

IMFUFA Text No. 226

48 pages

ISSN 0106-6242

ABSTRAKT

En gennemgang af de metoder, som anvendes eller påtænkes anvendt ved undersøgelser af global spredning af forurenende stoffer fra energiproduktion, foretages. Det vises at generelle cirkulationsmodeller i princippet er det bedste redskab, omend de numeriske problemer ved gennemførelse af realistiske beregninger kan være overvældende. En række tilnærmelser omtales, inklusiv rene kasse-modeller. Rapporten er en indkaldt baggrundsrapport for et møde i FN's atomenergi-organisation IAEA, afholdt i Wien maj 1992.

Methods and Models for Estimating the Global Circulation of Selected Emissions from Energy Conversion

BENT SØRENSEN

IMFUFA, Roskilde University
Roskilde, Denmark

Draft April 1992 In final form July 1992

Review prepared for an IAEA meeting in Vienna, 11-15 May, 1992

© 1992 Bent Sørensen

Contents:

1. Introduction	3
2. Releases from energy conversion activities	5
2.1. Sources	10
2.2. Substances released	11
2.3. The physical and chemical form of release	13
2.4. Pathways	14
2.5. Removal by deposition and transformation	14
3. Brief survey of models used in the description of the dynamical behaviour of released matter	16
3.1. The need for models	16
3.2. Time scales	16
3.3. General circulation models	18
3.4. Uncoupled transport models	21
3.5. Coupled models of circulation, transport and processes	25
3.6. Compartment models	26
4. Transport of individual materials	28
4.1. Carbon dioxide and other substantial residues	28
4.2. Trace materials and minor residues from fuels of biological origin	31
4.3. Radioactive materials from nuclear fuel cycles	36
5. Discussion	41
References	43

1. Introduction

This overview aims at describing a number of models available or under consideration for the description of large-scale dispersal of releases associated with energy production and use. The ultimate purpose is to provide tools that may contribute to a life-cycle assessment of different energy sources. This is a project of truly interdisciplinary nature, and it both requires the input from experts in fields such as system dynamics, meteorology, biology, agriculture and medicine, and also the overseeing ability of scientists trained in multidisciplinary work.

The models of interest in this context certainly comprise those, where a released substance will follow the general circulation, that is the wind and current fields, before it eventually is deposited or transformed. The wind fields may be derived from measured values, in case of after-the-fact studies, or they may be obtained from meteorological models of the circulation, as they would have to be, in order to provide predictions for the dispersion and derived effects of the substance in question.

A next step may be to construct models that include both the general circulation and the substances released, in a coupled mode. This implies that the release of a given substance can alter the general circulation and *vice versa* (as for example carbon dioxide may, due to its influence on the radiation balance and due to its transfer between ocean and atmosphere compartments being influenced by e.g. temperature). Both physical and chemical processes may take part in such feed-back processes. The time-scale associated with feed-back loops turn out to be of decisive importance.

General experience with coupled models is becoming available in meteorology, e.g. through coupling of hydro cycle models and wind circulation models. Consideration of clouds, precipitation, ice formation and melting, evaporation, etc., as well as the processes associated with absorption of radiation, have brought to surface many of the issues connected with the coupling of different physical and chemical processes characterized by different time scales and different spatial behaviour.

In some cases, where neither circulation nor geographical dispersal pattern are important, one may simplify the calculations by using a compartment model. A compartment could be all tropical forest, but it could also be a particular forest on a particular location. The effort consists in identifying proper compartments, which make it meaningful to treat these compartments as single en-

tities and to consider only the time-dependent transfer between different compartments. Some dispersion models treat ocean volumes in this fashion, while maintaining a circulation model for the atmosphere. The prime consideration associated with employing a compartment model is to justify the simplification and to demonstrate the plausibility of assuming average transfer rates between compartments.

The review is structured in the following way: Section 2 describes the releases of various substances, from their source in the energy handling and conversion chain, through pathways in soil, water and the atmosphere, noting how they may undergo changes in chemical or physical form, e.g. by chemical reactions, by radioactive decay, or by physical processes such as attachment of particles to rain droplets.

In section 3, models used for the description of long-range transport of various substances through the ecosphere are described. A variety of models suited for describing dispersal on different time-scales are mentioned, including compartment models as well as models based on general circulation simulation techniques. The state of each of these model areas is discussed.

Section 4 describes, by way of examples, the knowledge pertaining to the large-scale or global circulation of individual materials, such as carbon dioxide from combustion of fossil fuels, trace gases and particulate matter from the conversion of fossil and other fuels of biological origin, as well as radioisotopes arising from nuclear power plants, either in normal operation or being released during accidents.

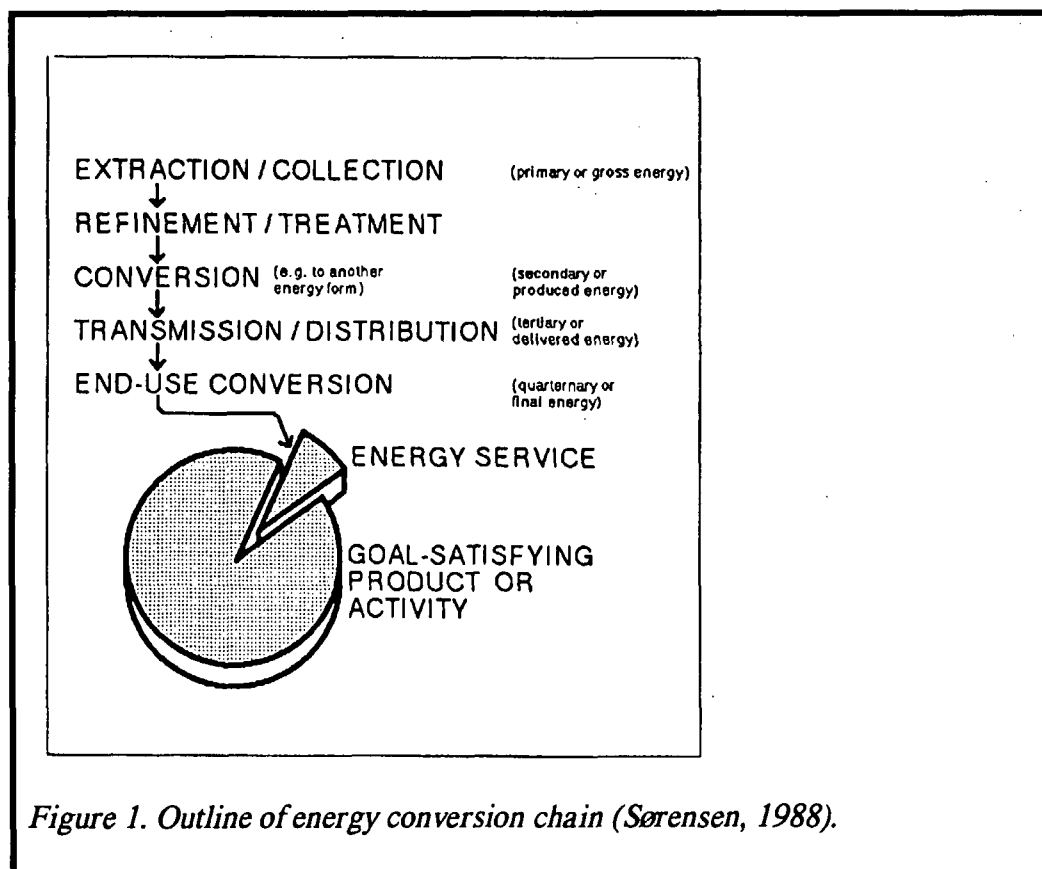
In section 5, the models are subjected to a brief discussion, aimed at establishing the limitations of each type of model, identifying the key parameters needed to perform an actual calculation, and the relationship between the nature of the questions asked, and the model appearing most appropriate for answering those questions.

One should bear in mind, that the decision-making process eventually relies on a comparative assessment of a variety of health, social and environmental impacts. Therefore, the models selected should provide outputs suitable for carrying out such evaluations.

2. Releases from energy conversion activities

The various emissions, effluents and other reject material arising from the generation and subsequent conversions of energy may differ greatly in substance and form, depending on the type of energy system being considered. Because different energy systems may have their most severe impacts in different stages of the conversion chain, it is important to include all stages of conversion in any assessment. This may be referred to as a *life-cycle assessment* (Sørensen, 1992). In the case of fuel-based energy systems, the term "fuel-cycle approach" is sometimes used (IAEA, 1992).

In this section, the sources of environmentally important substances associated with energy systems are identified, the nature of the substances is described, the form of release, the pathways through the global environment, and finally the transformations and transfers, that may take place, and in some cases may render the material less offending (deposition, decay, chemical transformation, etc.).



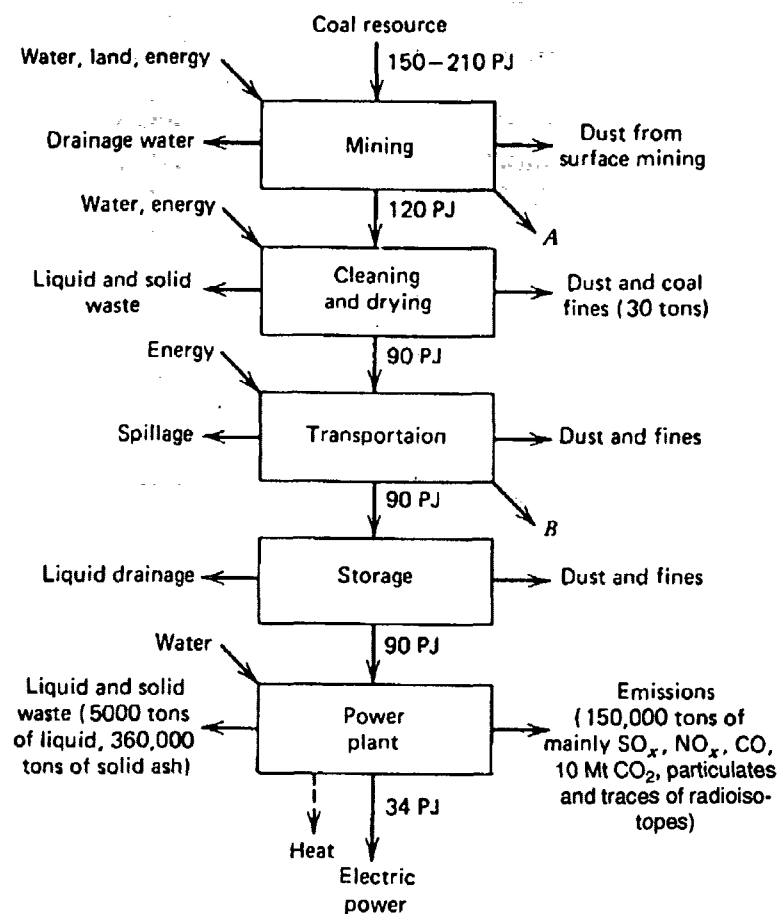


Figure 2. Coal usage chain with indication of inputs, energy losses, and outputs including environmental impacts. The quantities correspond to annual use by a 1 GW(e) power plant based on hard coal. Alternative usage paths indicated are: A. Gasification or liquefaction, B. Industrial combustion (with use of Jensen and Sørensen, 1984).

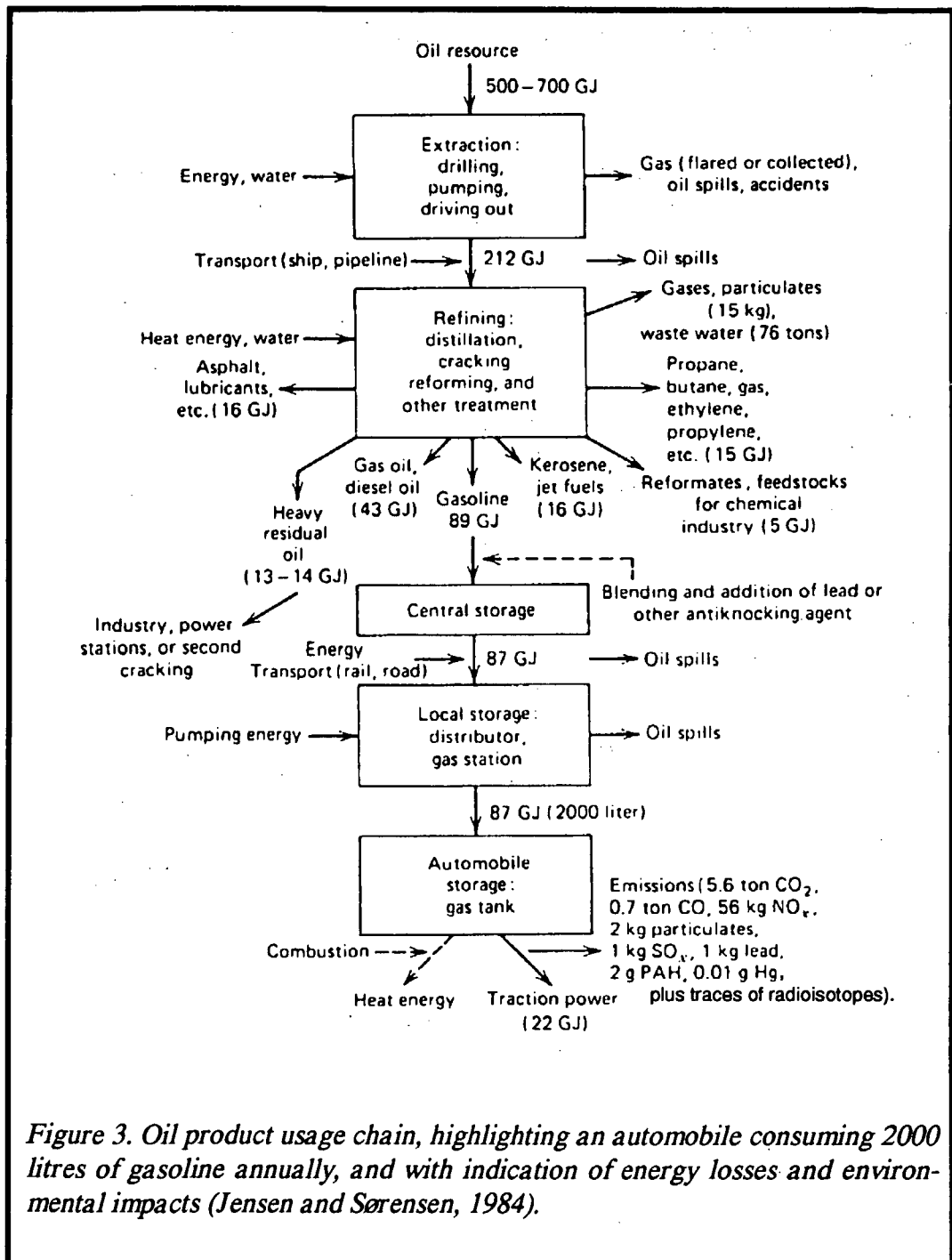


Figure 3. Oil product usage chain, highlighting an automobile consuming 2000 litres of gasoline annually, and with indication of energy losses and environmental impacts (Jensen and Sørensen, 1984).

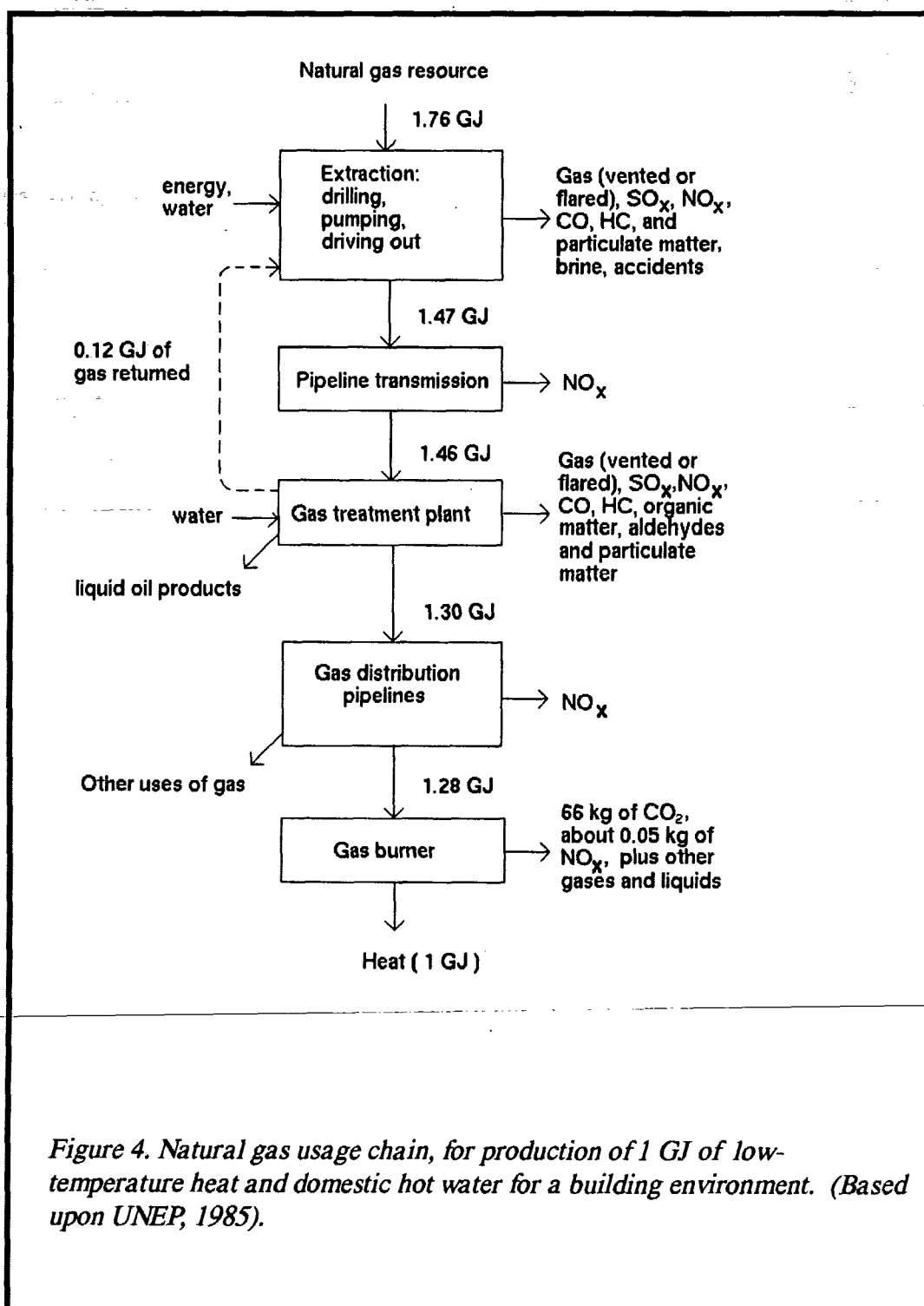
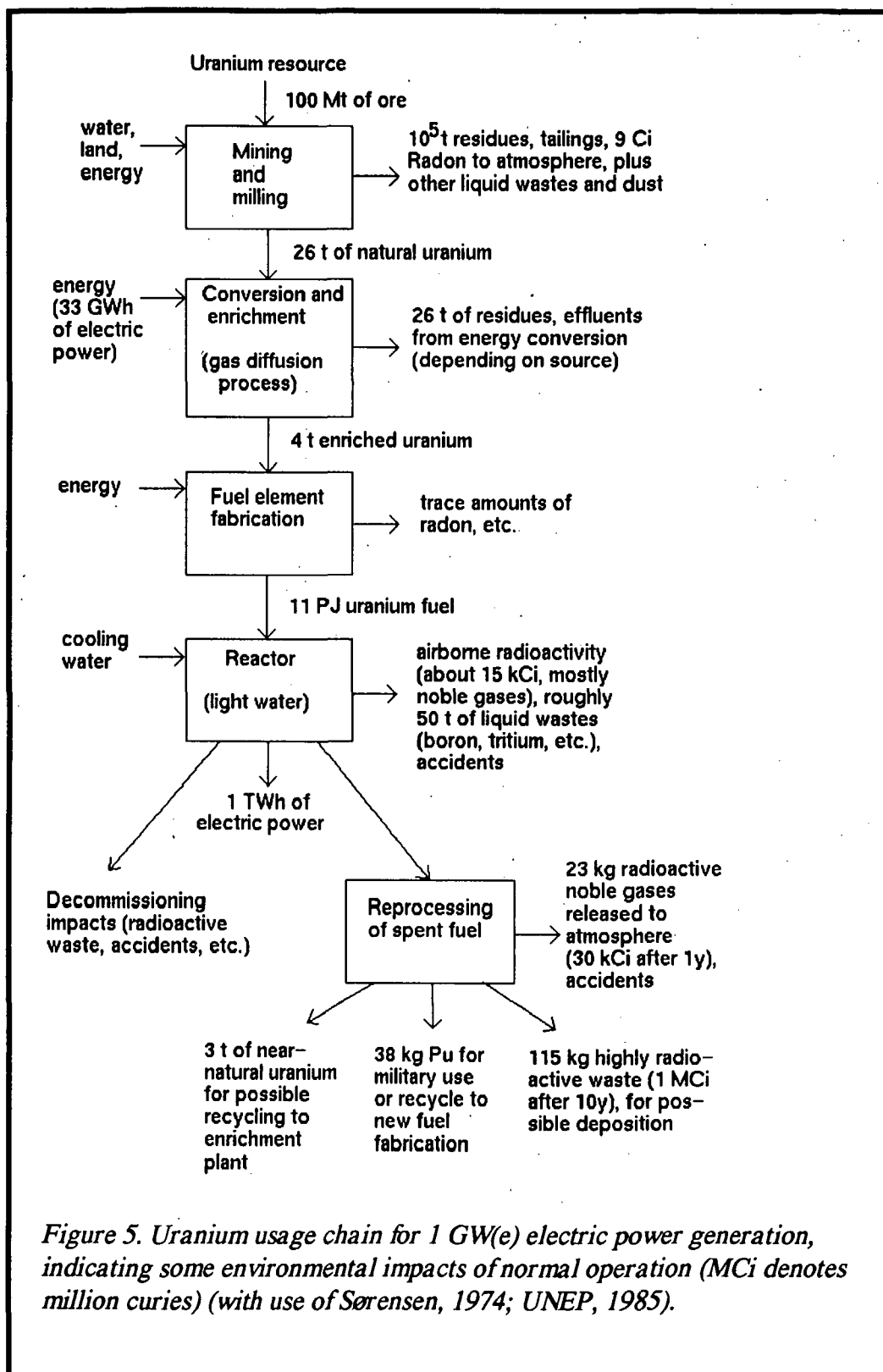
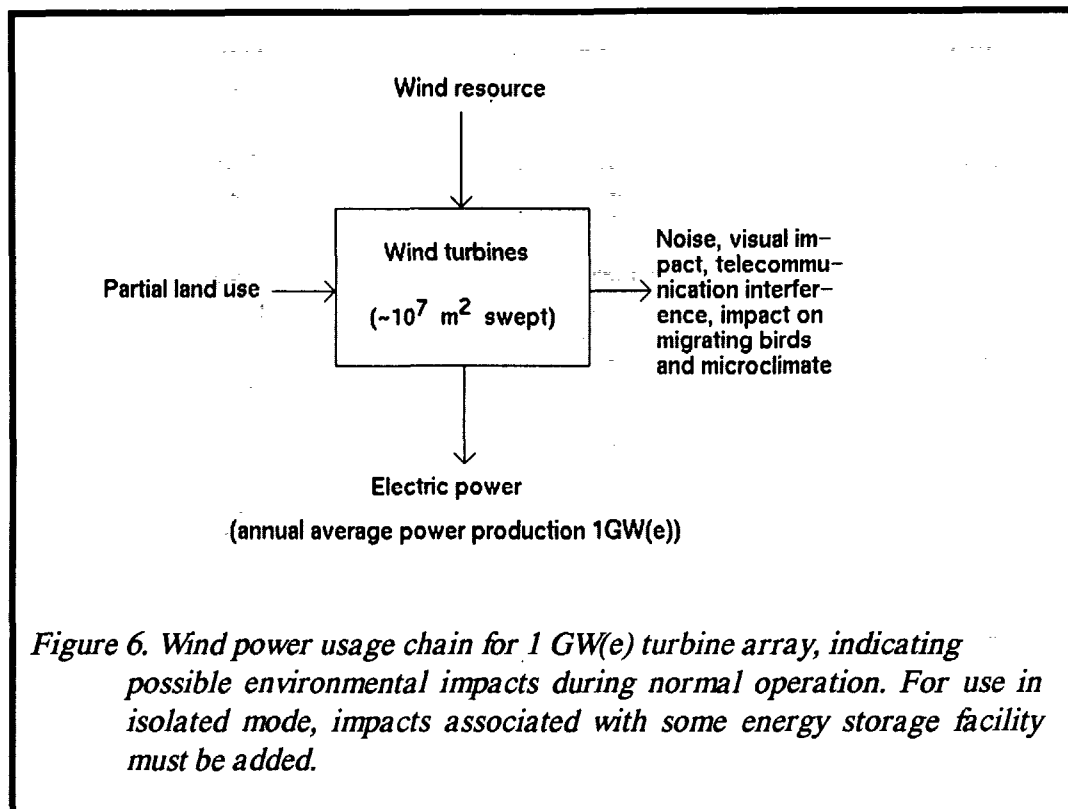


Figure 4. Natural gas usage chain, for production of 1 GJ of low-temperature heat and domestic hot water for a building environment. (Based upon UNEP, 1985).



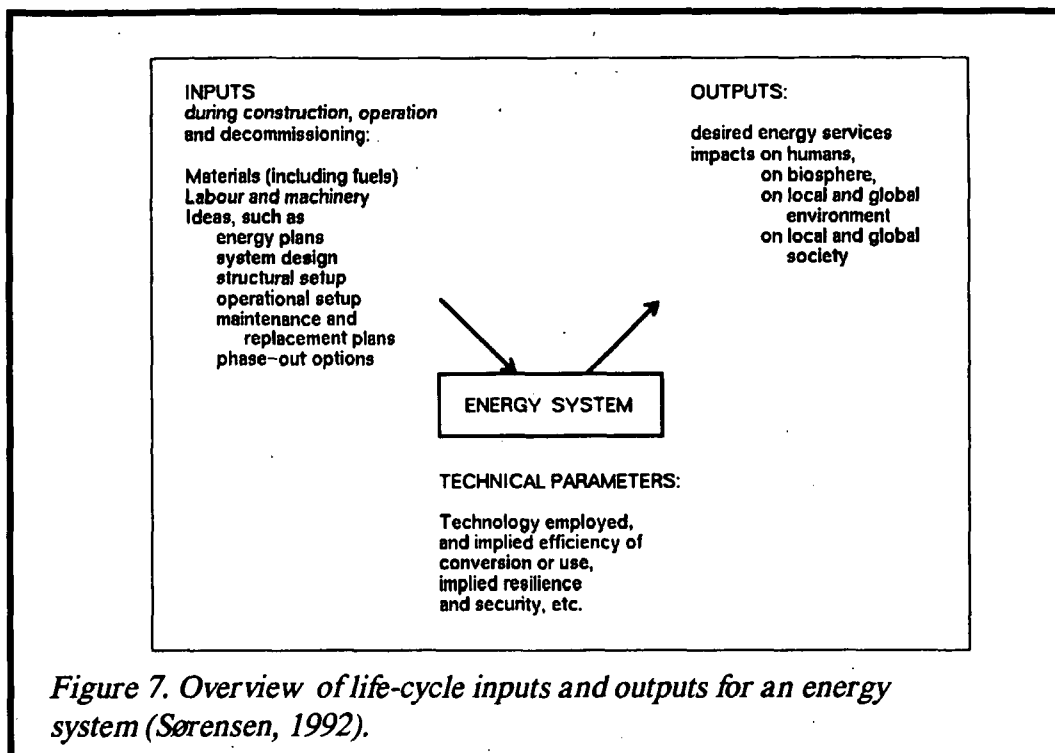


2.1. Sources

The sources of possible environmental releases are all stages of energy production and use, throughout the life-cycle stages. Examples are effluents from mining, refining, primary conversion, distribution activities such as transport or transmission, end-use conversion, waste disposal, and decommissioning. Figure 1 gives an overview of the chain of conversion, and Figures 2-6 show examples of the primary steps in the chain, for some typical energy sources, along with a number of associated impacts.

The need to consider all stages of fuel handling and energy conversion is of course, that some energy sources have major impacts in one area, while other have their main impacts in a different area.

It is clear that every time some equipment is needed, or an industrial process is required, there will be construction, operation and maintenance work with associated environmental impacts. Furthermore, equipment replacement or de-



commissioning may entail separate impacts, as indicated in the overview of Figure 7.

Figures 2-6 illustrate the normal operation of energy facilities. In all cases there is the further possibility of accidents, ranging from minor to in some cases major ones. Accident types are specific for each type of energy conversion process and involve different impacts, such as fires, release of chemicals, release of radio-nuclides, occupational hazards (physical or health-related), exposure to dangerous materials, etc. Only in some cases, normal operation or accidents lead to global circulation of undesirable substances. These will be looked closer at in the following.

2.2. Substances released

For selected types of energy chains, one may attempt to extract a list of those releases, that can contribute to global dispersal of substances of concern.

In case of fossil fuels, this includes fines and residues from mining and handling, solid and liquid residues from combustion (ashes and filter contents), as well as a number of substances released to the atmosphere. They comprise particulate matter, sulphur and nitrous oxides, carbon monoxide, heavy metal and

radioactive trace elements, and organic compounds such as poly-aromatic and unburned hydrocarbons. Furthermore, there is the main combustion product, carbon dioxide.

Measures are normally being taken to reduce the emissions. A major exception is CO₂, for which current research has not identified removal options, except at costs far above the present cost of the fuel itself. The actual amounts of controllable releases depend on filter efficiencies and other details of the conversion system.

Accidental releases are mainly of the hydrocarbons themselves (oil tanker spills, gas explosions, etc.). Additional environmental impacts along the fuel cycle conversion chain are associated with waste heat, e.g. from power plants.

Except for the larger particles, which will settle on the ground near the point of release, most of the releases mentioned are candidates for long range and sometimes global dispersal.

For nuclear fuel cycles, the main problem is radioactive substances, although waste heat is also produced at the power plants. Due to the low concentration of materials such as uranium in nature, the formation of residues, tailings and dust from mining and milling operations are of importance. In the enrichment process, during normal operation of power plants, and during reprocessing of spent fuel, most potential releases are controlled. Exceptions are tritium, ¹⁴C and noble gases, which are often released to the atmosphere.

Spent fuel and power plant decommissioning poses problems of disposal of highly radioactive material. The present philosophy is to attempt to confine these materials for a very long time, possible after extracting those materials that can be re-used (such as plutonium). Sea dumping of lower level radioactive waste materials from the operation of nuclear facilities has been a widespread practice, but the tendency is towards halting this practice, for which a de facto moratorium exists at present.

In case of accidents, core fission and activation products are released into the environment. Notable among these are ¹³¹I, ⁹⁰Sr, ¹³⁷Cs and ²³⁹Pu, plus a number of less abundant isotopes, characterized by a long half-life and thus the possibility of long-range impacts.

For renewable energy, the environmental impacts vary quite substantially among the different technologies. For photovoltaic and thermal solar panels, the impacts are practically restricted to the manufacturing process, and possi-

bly work accidents during construction and maintenance.

For wind turbines, additional impacts include land use, noise and telecommunication interference, none of which are in the global category (Sørensen, 1981; 1986).

For biofuels, the situation is closer to that of fossil fuels. Substantial air pollution and solid residues may derive from burning of wood. For biogas and liquefied biofuels such as ethanol or methanol, there is a co-production of carbon dioxide, which however should be smaller than the amount of carbon dioxide originally assimilated by the plant. Biogas has some positive side-effects, related to the waste treatment processes often associated with biogas production. If the source of biomass is not waste or residues, but energy crops, then there may be environmental side-effects similar to those of agriculture (Jensen and Sørensen, 1984).

Energy storage facilities, which are required to a larger extent in some energy systems, than in others, entail further impacts.

2.3. The physical and chemical form of release

Knowledge of the physico-chemical form of releases from energy facilities is important for modelling the behaviour of substances released into the environment. Typical forms include gases, aerosols and larger particles, soluble substances, liquid wastes and solid waste (fines, residues, complex chemical compounds, including organic material and heavy metal compounds, etc.).

Synergisms between different forms of release have been discussed (IAEA, 1975).

The effect of releases may be direct or indirect. Toxicity of a substance would imply a direct effect, while - as an example of indirect effects - one may consider the change in the radiation balance caused by aerosol releases. These changes may lead to warming or cooling, depending on the aerosol size distribution (Volz, 1983; Sørensen, 1979).

2.4. Pathways

Airborne emissions from energy-related facilities often originate from point-like sources, although there are exceptions (e.g. releases from surface mining activities). If the release is gaseous, it may be transported along with the air, but it may also move independently from the air masses, e.g. due to differences in density or diffusivity. Particulate emissions may travel independently by the rules of gravity and up-draft, or they may become adsorbed on e.g. water particles or droplets. Finally, several emitted substances would be capable of entering into chemical reactions with other substances. Temperature differences between emissions and air play a role for the dispersal. This is relevant, not only during the initial phases, in case of radioactive materials. The physical properties of the released material may change in time, and several of the mechanisms indicated may come into play during different stages of atmospheric transport.

Typical processes of depletion along the path of transport are rainout and washout, which lead to deposition on the underlying surface, as do dry deposition mechanisms.

Material released to waterways are also subject to a multitude of possible pathways, e.g. following the transport of water to a certain degree, but occasionally behaving differently.

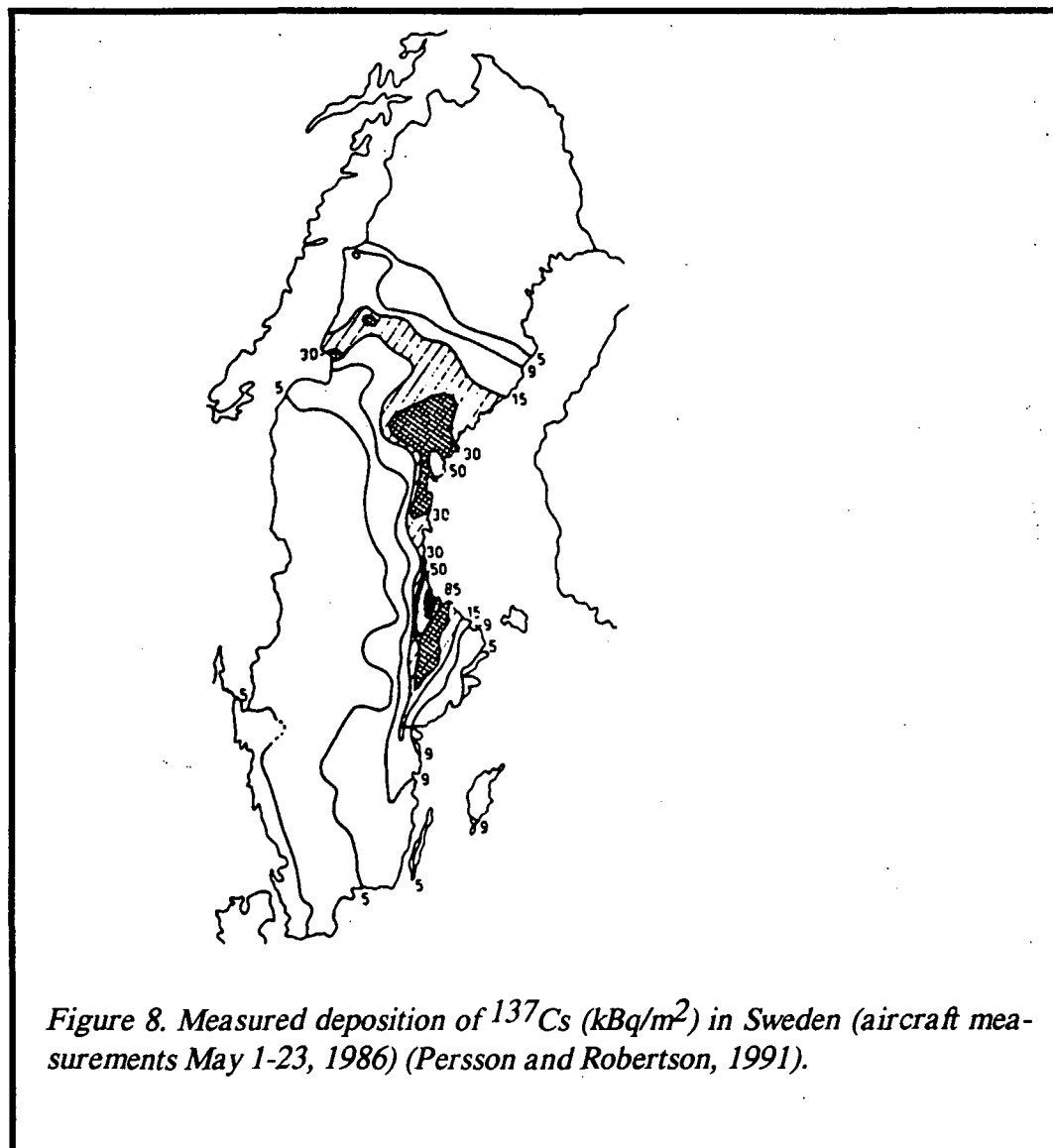
Material released to soil or other surfaces may sieve down to ground water, may adhere to soil particles, may be washed away by rain and continue travel along the sewage system. Ground water motion is usually a slow process, that eventually brings the material into streams, rivers and finally into the oceans. However, retention processes are at play all along the chain, and deposition at each stage is possible.

2.5. Removal by deposition and transformation

Processes such as deposition of airborne material on the ground remove the effluents from the pathways relevant for global dispersion. For a review of dry deposition see e.g. Davidson and Wu (1989), for aspects of wet deposition e.g. Barrie and Schemenauer (1989). Figure 8 shows an example of wet deposition (of ^{137}Cs) in Sweden following the Chernobyl nuclear accident.

Chemical processes or radioactive decay may transform the substance into other materials, with altered importance for the global environment. A review

of the sources, sinks and transformation processes for aerosols in the atmosphere may be found in Heintzenberg (1989).



3. Brief survey of models used in the description of the dynamical behaviour of released matter.

3.1. The need for models

Models are needed to bring out the messages contained in data, and for allowing evaluation also in cases where insufficient data are available, including of course any attempt to make predictions regarding the future. The final purpose of these efforts is to find mitigating strategies against negative impacts of the releases in question, and models serve to evaluate the implications associated with different strategies. As some impacts are delayed and some releases can cause impacts over very large intervals of time, a number of different models may be needed in order to arrive at a full understanding of short-term and long-term effects and options. The dispersion models generally aim at predicting the amounts of substances with potential impacts, that will be found at different times at locations of interest, whether at sea, on land or in the atmosphere.

3.2. Time scales

Important for the selection of model to use is the time scale of events on which statements need to be derived. Often, the size of the time scale translates into a length scale: short time-interval behaviour of a point release cannot be associated with global effects, but long-term behaviour may. The assumptions on the relation between length and time scales are contained in the *ergodic hypothesis* (see Sørensen, 1979).

The present survey focusses on impacts requiring large-scale or global outlook. That implies that methods such as plume models aimed at short-term, local dispersal are not of interest. Also models with only regional scope may be unsuited, but there is a smooth transition between regional and large-scale or global model capabilities, and the selection of model will depend very much on the type of release and on the questions likely to be asked.

For example, radioisotopes such as ^{85}Kr and ^3H behave very differently, since one is a noble gas and the other enters into a variety of different chemical compounds relevant both for the physical processes of the environment, and also for the biological compartments. In one case, one may be satisfied with a long-term distribution of the radionuclide in a steady state situation, while in

the other case, the dynamical behavior is needed in order to assess the range of possible impacts.

For estimating the impacts associated with radioisotopes, the half-life of the substance is clearly the basic parameter for deciding what time scale that will be appropriate. For non-radioactive substances, the impacts could persist forever, but in many cases, there is an ultimate transfer to a compartment, where little harm is expected, or a transformation of the substance into a form where impacts are considered small. As a general observation, one may say that if a substance is going to remain in the environment for a very long time and with a fairly smooth distribution of concentrations, then a detailed modelling of the dynamical behaviour may not be relevant. In such cases, compartment models may be useful. They allow the calculation of total amounts of substances as function of time, for each compartment used.

The class of models based on general circulation models may be said to be compartment models with so many compartments, that they simulate a continuum. The real difference, however, is in the way the rate of transfer between locations (infinitesimal "compartments") is derived. Real compartment models must derive the transfer rates from data, and thus, a sufficiently long time-series of data is required to be available, and one which grows with the number of compartments in the model. On the other hand, the general circulation is given by basic physical laws, and transport models based on general circulation models also have as foundation the proper physical and chemical laws for describing the substance in question.

Hence, even if the circulation-based transport model is compartmentalized for numerical reasons, it still is based on accepted theory (i.e. laws of nature) and not on *ad hoc* parametrization of some data. In practice, the distinction may be weaker, because also in general circulation models, an averaging has to be made, which again poses the question of how one can deduce the laws governing averages from the microscopic laws for whatever is inside the boxes being averaged over. More precisely, one can prove that for linear interactions, the averaging leads to meaningful laws for the averages, whereas for most non-linear systems, the averages do not behave dynamically in ways that depend only on averaged quantities. This will be discussed further below.

The question of scales is then a question of averaging, and thus is tightly connected to the problems of averaging over non-linear effects. Any calculation, which confines itself to a certain scale (rather than doing the entire calculation on a microscopic scale and averaging only the results) must address the problem of non-linear couplings to motion on scales below the selected one.

3.3. General circulation models

A model of global circulation can be formed by suitably averaging the physical equations of motion for continuous media (i.e. the motion of air or water). Additional equations may be written for each substance of interest, including sources and sinks to describe processes outside the model.

The basis is Euler's transport equation for a given substance A :

$$D_t(pA) + \text{div}(vpA) + \text{div}(o_A) = S_A$$

where t is time, p density, v the velocity field in the medium, o a vector describing the transport by molecular processes, and S a source term. Using the density weighted average q^* of a quantity q ,

$$q^* = \langle pq \rangle / p$$

one may introduce $q = q^* + q'$ into Euler's equation and obtain

$$D_t(pA^*) + \text{div}(pv^*A^* + \langle pv'A' \rangle) + \text{div}(\langle o_A \rangle) = S_A$$

It is seen, that it has not been possible to fully eliminate the deviations from the averages, v' and A' , from the equation of motion, and hence the description of the general circulation cannot be made without knowledge of the small-scale motion, called turbulence or chaotic motion. In practice, what one does is to neglect the term depending on v' and A' , or replace it by some parametrized average, and integrate the remaining terms. Also the source term S will have to be assumed to depend only on averaged quantities. The result is a solution, which will be valid only as long as the chaotic terms stay negligible. For wind fields, this may be periods of a few days to one or two weeks, depending on the conditions. This is the reason, that it is fundamentally impossible to make valid weather predictions for periods exceeding the indicated values.

If, on the other hand, diurnal weather patterns are not considered important, the same equations may be used to predict long-term behaviour. The reason is, that the forcing of the system (through solar radiation), and the boundary conditions that make oceans and atmosphere stay around the world, place some constraints on the effects of the chaotic terms, which makes it possible to extract climate statements from integrating the Euler equations. *Climate* is defined as the set of (e.g. 30 years) averages of weather parameters.

The averaged Euler equations may comprise a quite large set of coupled equations: For $A = 1$, it is the mass continuity equation, for A equal to a velocity component, σ_A is the stress tensor and S_A the external forces (gravitational and Coriolis, assuming that a coordinate system following the Earth's rotation is used). By introducing an equation of state for the fluid (ocean or atmosphere; in the latter case, the ideal gas law is often used), and the first law of thermodynamics, Euler's equation becomes an equation for temperature, with source terms representing absorption of solar radiation and heat from condensation of water.

The treatment of releases is made by increasing the number of Eulerian equations. Each substance is described by a mixing ratio A_j , and its injection or removal is described by suitable source terms S_{A_j} . Chemical processes and other transformations (cloud formation, etc.) not covered by the Euler equations must be added through auxiliary equations. In summary, a coupled set of equations of motion will have to be solved with a number of side calculations, describing physical and chemical processes taking place at a given place in the atmosphere-hydrosphere-lithosphere system (Sørensen, 1979).

The averaging time scale is typically of the order of 10 minutes to 1 hour in time for the motion of air in the atmosphere, and much more for water in the oceans. In practice, general circulation models include a number of further approximations needed for numerical purposes. Either, an integration mesh is established in physical space (typical current calculations use about 3° horizontal boxes and around 10 vertical layers in the atmosphere, and a much coarser mesh in the oceans), or a spectral transformation is performed on the horizontal part, with Fourier components up to about 30 included (IPCC, 1990). As stated, the variables describing small-scale motion are neglected, but the coupling terms between small-scale motion and large-scale motion are, as mentioned, averaged in such a way, that only the large-scale variables remain (Boussinesq approximation, cf. Sørensen, 1979). In meshed models, the finite size of each box gives rise to undesired integration effects such as pseudo-diffusion (motion from box to box faster than is physically possible). There are standard techniques for approximately getting rid of such problems.

In case of releases from energy production, they are treated just like other scalar quantities (for example temperature), by adding one more equation describing the transport of the substance (coupled to other equations through the wind velocity), and describing the sources, sinks and transformation properties for the quantity in question (with further possibility of coupling to other among the equations). Many calculations use extremely simplified versions of these relations. For instance, the effect of carbon dioxide doubling would be estimated by simply adjusting the source term describing the heat sources and

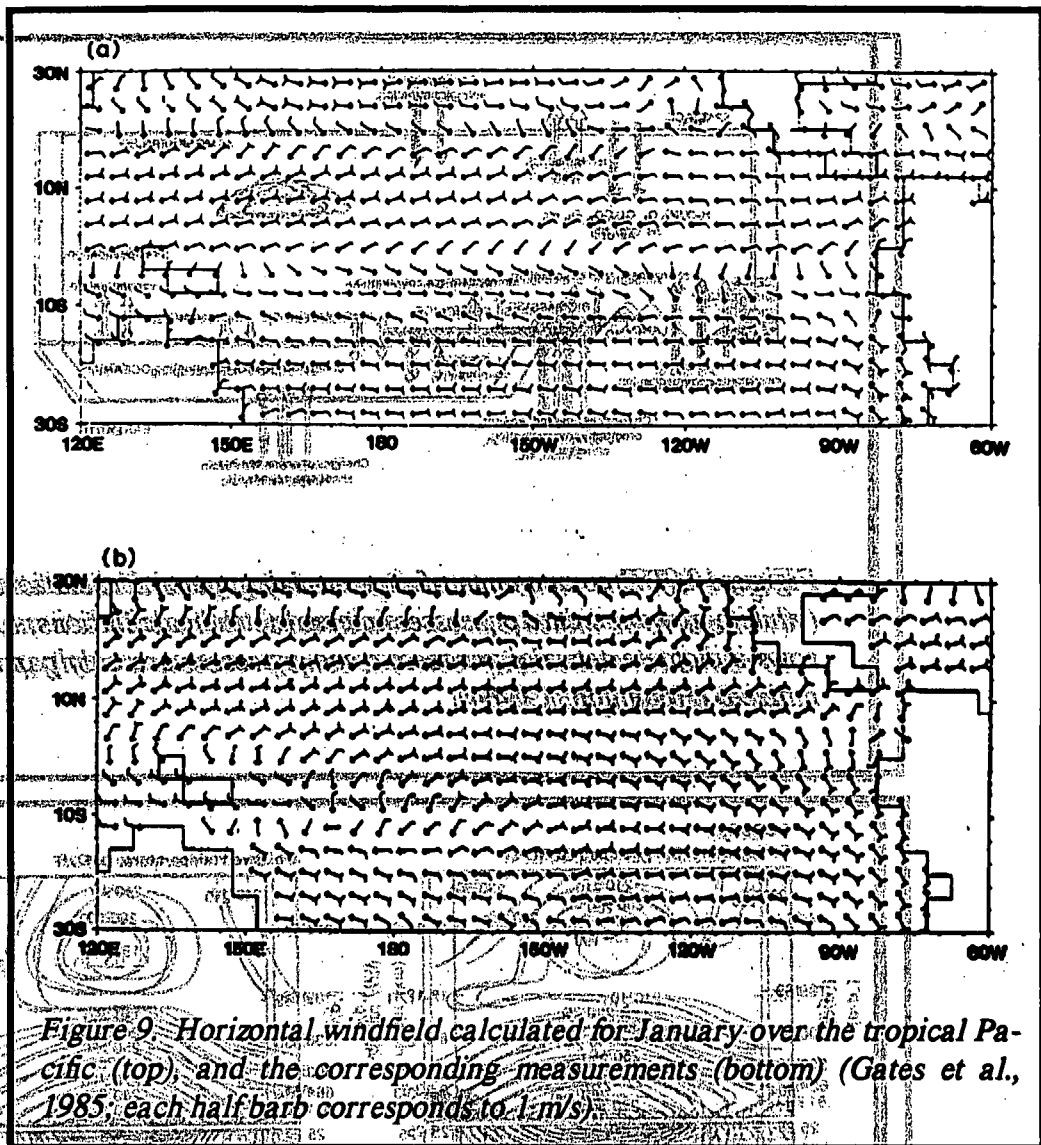
sinks in the temperature equation, and repeating the calculations for different fixed amounts of CO₂ being present globally in the atmosphere.

Most recent atmosphere-ocean coupled models have tried to incorporate the mechanisms of transfer of CO₂ between oceans and the atmosphere. This goes along with other ocean-atmosphere transfer, say of heat or of momentum. Each of these transfers have been subjected to detailed study, e.g. exploring the penetration of radiation into the oceans, and the variations in the extent of a mixed layer (Woods, 1985). The boundary conditions between the ocean and the atmosphere have been particularly difficult to reproduce, and in many cases, model fluxes have been arbitrarily adjusted, in order to get an equilibrium ocean model and an equilibrium atmosphere model to match (IPCC, 1990).

Important issues in the construction of circulation models is the modelling of cloud chemistry. This issue is reviewed e.g. by Iribarne and Cho (1989). Present efforts aim at improving the realism of the modelling regarding ocean-atmosphere coupling, cloud behaviour, role of particulate matter and ice dynamics, i.a. (IPCC, 1990). The methods used for solving the models, whether meshed or spectral, are in current implementations reaching the limit of available computer power, especially for time-dependent study of transient behaviour over time-scales of say hundred years (recall that the integration step is typically a fraction of an hour, as required due to the forcing from the diurnal radiation cycle).

Figure 9 shows the horizontal windfield calculated for January over the tropical Pacific (top), and the corresponding measurements (bottom) (Gates et al., 1985; each half barb corresponds to 1 m/s).

Figure 10 shows the key features being modelled by present generations of global circulation models, and Figure 11 shows an example of the validation against available temperature data of a 3-dimensional ocean-atmosphere model. Both validation and sensitivity analysis are important tasks for any modelling effort in this regime. Less interesting are the benchmark studies, that used to be popular some years ago. A benchmark study compares different model implementations and is useful in disclosing e.g. programming errors. However, it does not validate the models, and the mutual agreement between ten models, which do not reproduce experimental data well, may even lead to misinterpretations, if poorly communicated to decision-makers.



3.4. Uncoupled transport models

The number of coupled equations can easily become very large. It is therefore often necessary to neglect some couplings, which will make the calculation manageable. In many cases, the release considered is incapable of causing major alteration on the circulation itself. Exceptions may be substances causing processes where large releases of heat take place, e.g. by releasing significant amounts of chemically active substances, or cases where physical processes are able to modify the radiation balance, e.g. by altering absorption or by modifying cloud cover. Without couplings, the equations may be solved one after

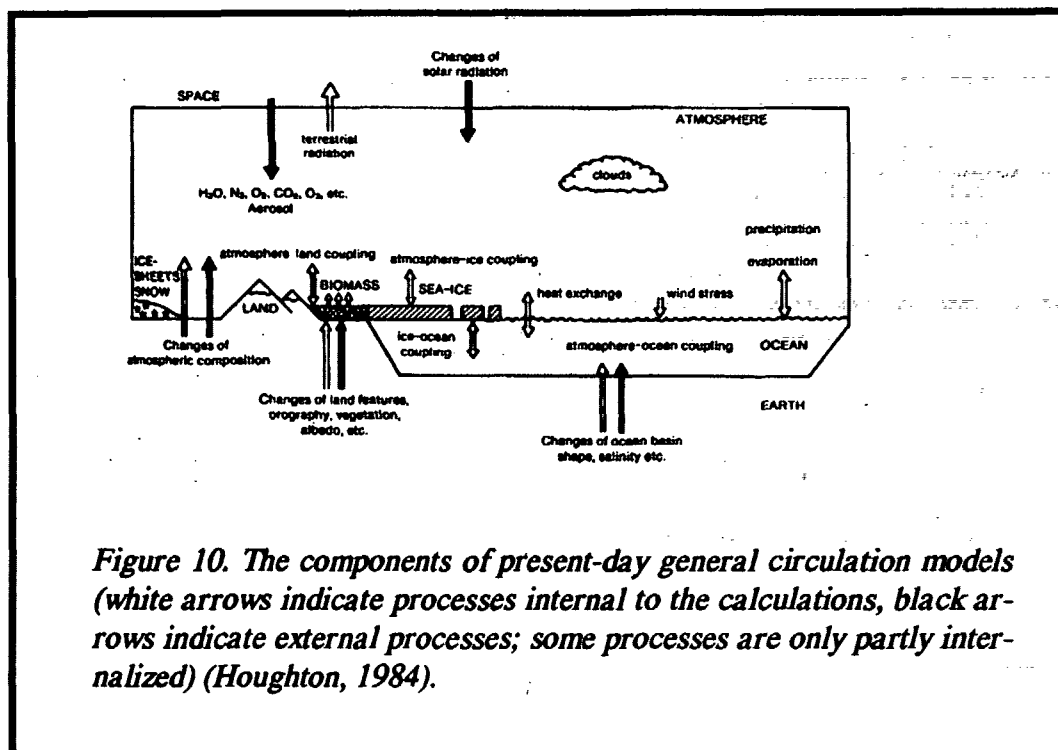


Figure 10. The components of present-day general circulation models (white arrows indicate processes internal to the calculations, black arrows indicate external processes; some processes are only partly internalized) (Houghton, 1984).

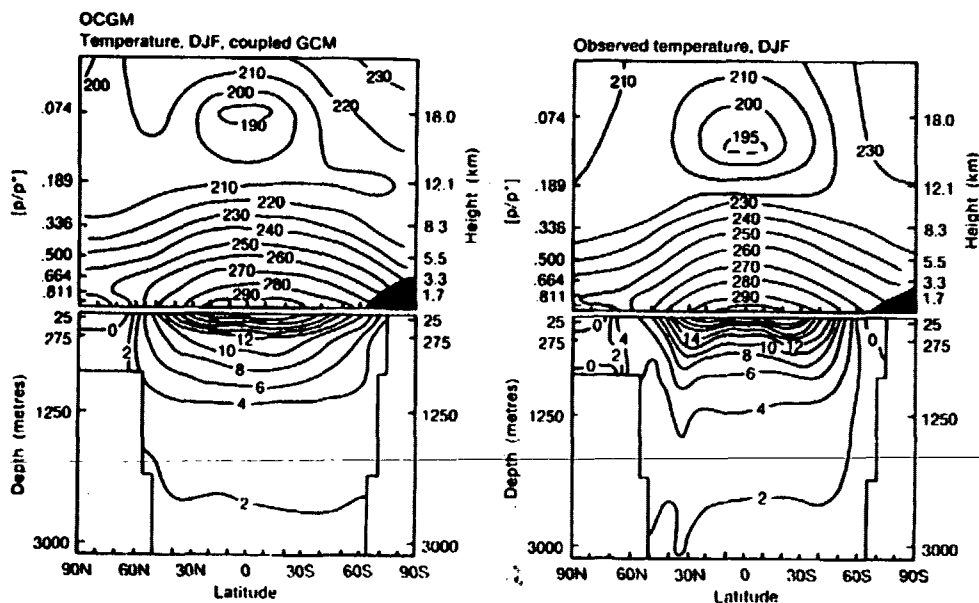


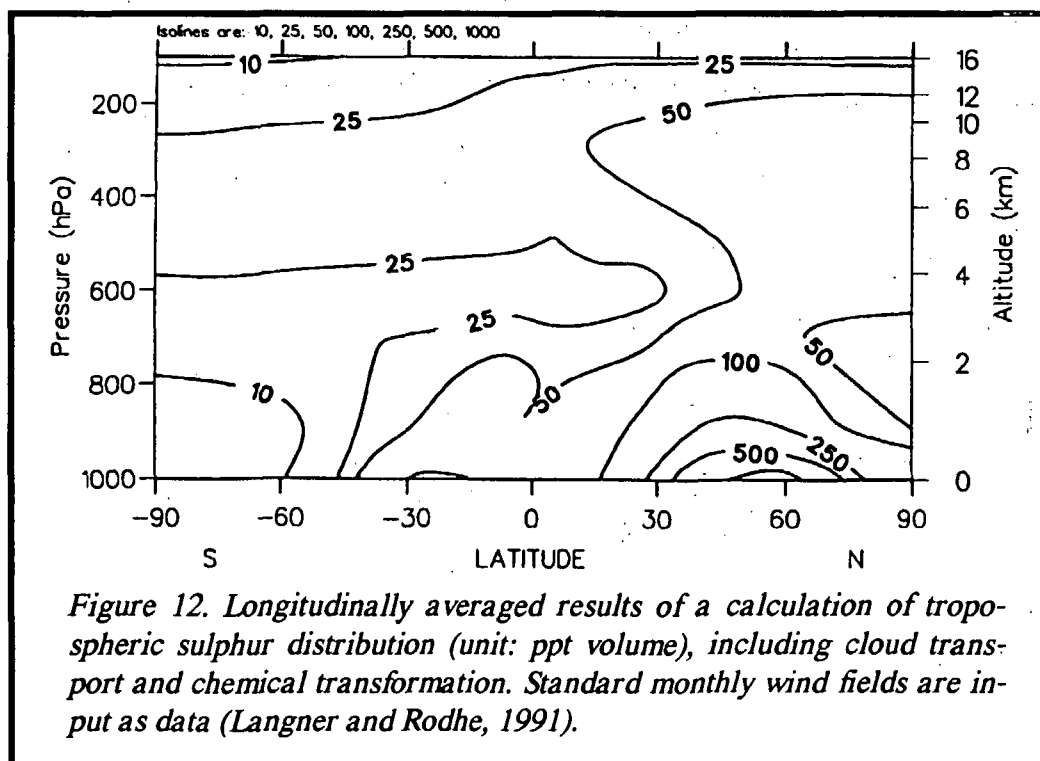
Figure 11. Comparison of observed December-January-February zonal mean temperatures (right) and values calculated by a coupled ocean-atmosphere model (IPCC, 1990; calculation from Washington and Meehl, 1989; observed atmospheric temperatures from Newell et al., 1972, observed oceanic temperatures from Levitus, 1982).

the other, starting with the wind fields, that enter in many of the subsequent transport equations.

For example, in many calculations of the effect of altered carbon dioxide levels, one has decoupled the problem by translating the new CO₂ level into a modified heat source term, with which the standard calculation of the circulation is repeated (either once, for a radical change in CO₂, or in a time-dependent way, with small annual increases in CO₂ incorporated into the radiation terms). Such calculations are still in a preliminary state, with simplified assumptions on the coupling between ocean and atmosphere models, and with *ad hoc* adjustments for discrepancies arising from mismatch between the ocean and atmosphere models (cf. IPCC, 1990).

Simplified calculations would solve only the transport equation for the substance of interest, using standard meteorological data or standard circulation model runs as input. In this approach, dispersal and deposition can easily be included. An example is provided in Figure 12, for SO₂ in the troposphere.

One further step of simplification would be not to use the mixing ratio of the substance as variable, but to consider one or more puffs released from each source. The meteorological data or circulation model (wind fields) are used to transport the pointlike puff, thus decoupling the transport from the dilution (in-



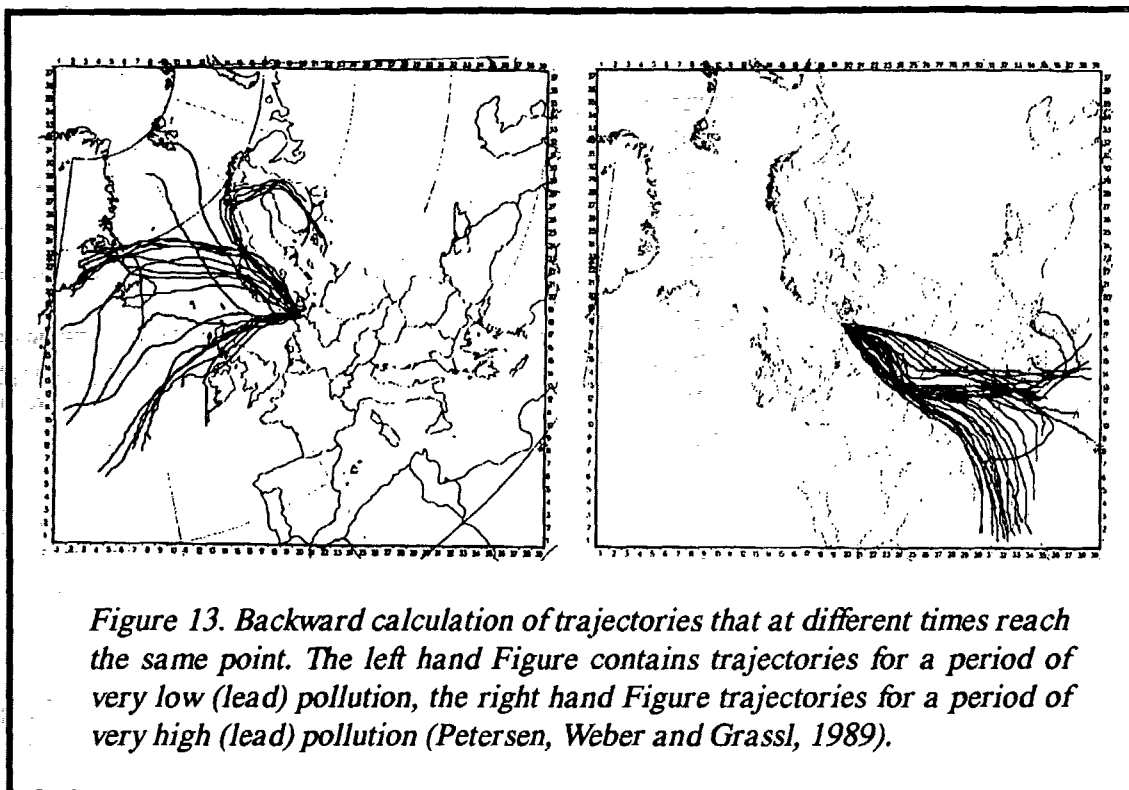


Figure 13. Backward calculation of trajectories that at different times reach the same point. The left hand Figure contains trajectories for a period of very low (lead) pollution, the right hand Figure trajectories for a period of very high (lead) pollution (Petersen, Weber and Grassl, 1989).

crease of puff dimensions). Such models, called *trajectory models*, are clearly inadequate when the puff has grown to such a size, that different parts of it will be affected differently by the wind fields. Trajectory models can be worked backwards, and they have played a role in identifying the origin of pollution observed in given locations. Trajectory models were first highlighted at the UN Environment Conference in Stockholm (Swedish Ministries for Foreign Affairs and Agriculture, 1971). Figure 13 shows a recent example of using the method to trace lead pollution.

The simplest form of trajectory model considers only the wind velocity at the point of release, and uses a uniform (e.g. Gaussian) expansion of the plume. Such *plume models*, which may be adequate for estimating pollution close to a stack, have been misused extensively for describing radioactive releases associated with nuclear reactor accidents (e.g. Rasmussen, 1975). The inadequacy of models implying monotonously decreasing concentrations as function of distance from the point of release is demonstrated by the measured activity levels in Europe following the nuclear accident in Windscale 1957 (see Figure 14).

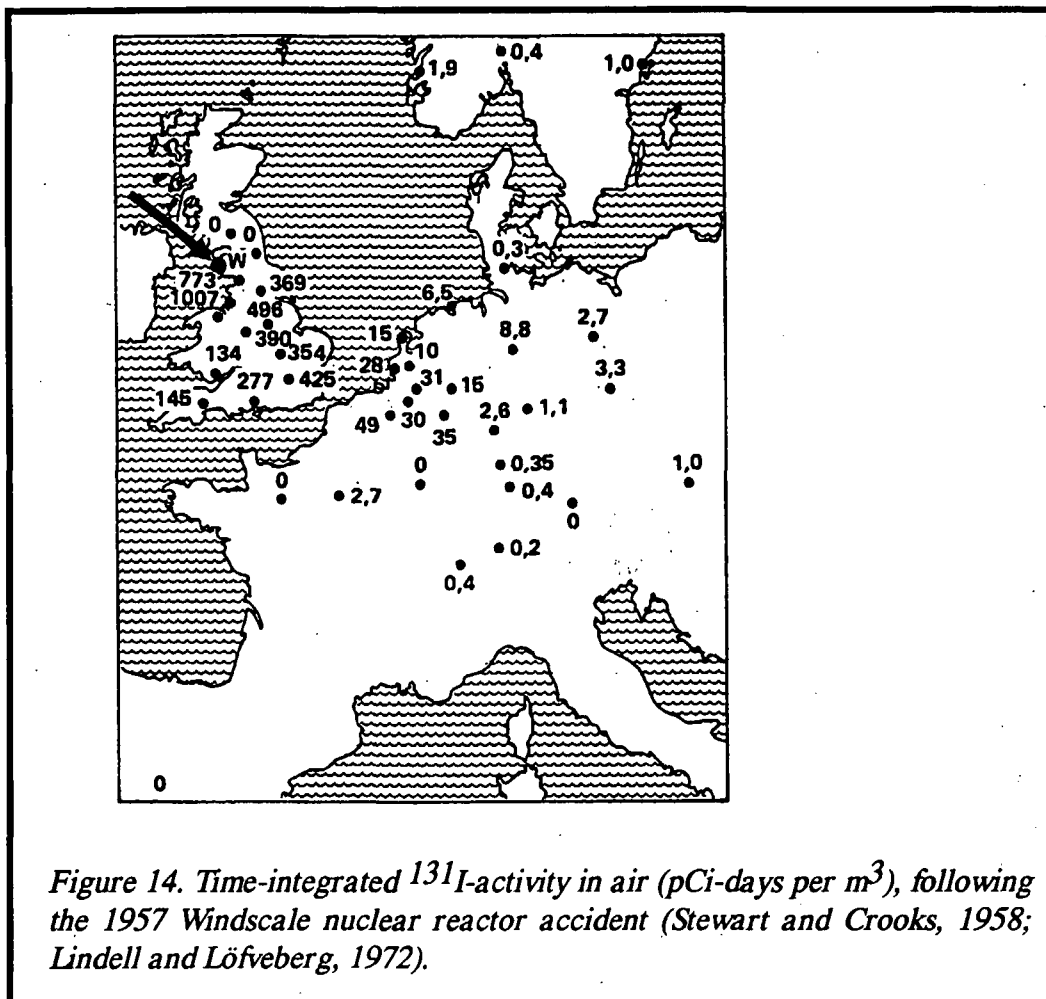


Figure 14. Time-integrated ^{131}I -activity in air (pCi-days per m^3), following the 1957 Windscale nuclear reactor accident (Stewart and Crooks, 1958; Lindell and Löfveberg, 1972).

3.5. Coupled models of circulation, transport and processes.

In the future, it is likely to become possible to run larger, realistic coupled models, in those cases, where couplings are important. There would still be processes modelled by auxiliary calculations, and transport equations decoupled from the rest.

For example, as the CO_2 models have become time-dependent models for the transition to a different climate (as distinguished from earlier steady state calculations for a fixed, higher value of CO_2), then it is no longer reasonable to neglect the geographical and temporal distribution of CO_2 releases and transfers. Rather than modelling CO_2 as an overall change in the radiation source term, one would have to include the effects on the circulation of a realistic CO_2 cycle (see section 4.1 below), and to include the influence of clouds, cir-

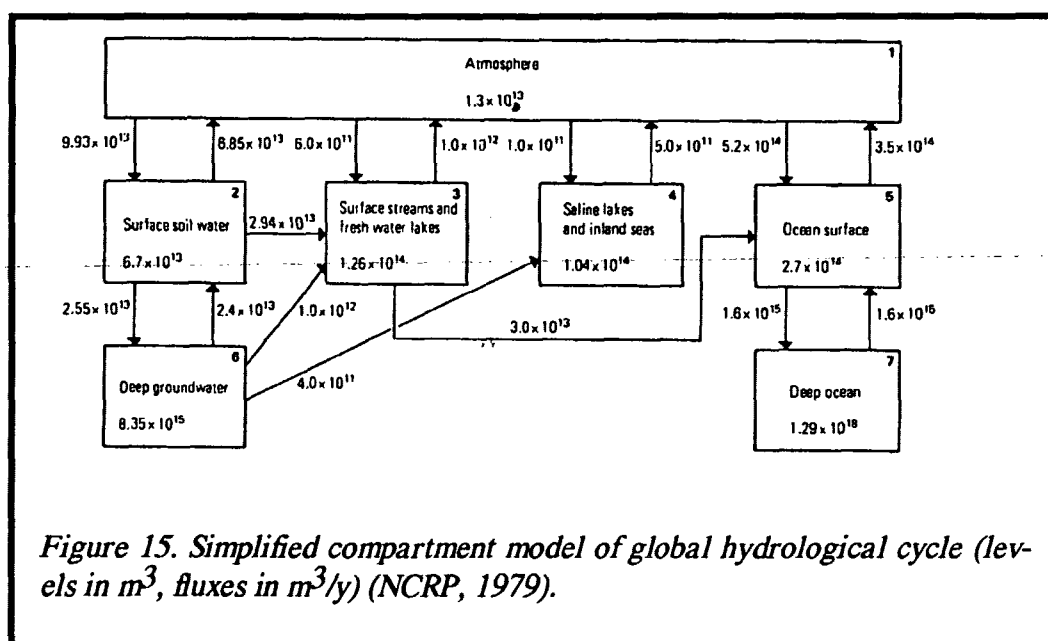
ulation and ocean-atmosphere transfers, as well as of vegetation, on the disposition of CO_2 . This is just one example of the more complex models needed at the present stage.

The ingredients of such models are largely available, and the limiting factor is computer power, or ingenuity in selecting and improving numerical methods.

In case of other greenhouse gases, e.g. CFC's, the stratospheric processes are of decisive importance, implying a need for integrating the chemical modelling with the transport of the CFC's to the stratosphere, and the geographically varying effects on the radiation source term. The same is true for modelling of ozone.

3.6. Compartment models

Compartment models are characterized by a box structure. The boxes are not necessarily small, but an assumption of homogeneous mixing and a well-defined interaction between boxes has to be made, in order to treat each of them as an entity. Examples of typical compartments are top soil, fresh water lakes, mixed layer of oceans, deep ocean, sea beds, etc. Compartment models can be used to study fairly local problems, such as the consequences for a given region of radioactive fallout (Sørensen, 1975), or entirely global problems of atmosphere, hydrosphere and lithosphere fallout (Björkström, 1983; IAEA,



1985, cf. Figure 15).

Sometimes a compartment model can capture the main behaviour of complex systems, at a very small computational effort, and these models are often used to get a first orientation in a new kind of problem.

The compartmentizing of a problem necessarily hides some levels of interaction, and granted that most interactions in systems of interest are non-linear, it is clear that models dealing only with compartment averages can be very wrong. It also implies, that the laws governing the interaction between boxes has to be determined from selected data, because the underlying physico-chemical laws generally cannot be generalized to the averaged compartments, unless they are linear. In other words, there is no way to theoretically derive the laws of transfer between compartments. There is then no guarantee, that the compartment model will be applicable to a new piece of data not used in the construction of the model, and the only type of verification possible is to withhold some fraction of the available data, and then test the model on these. There will be problems if too many data have been used in formulating the model, but also if too few are used.

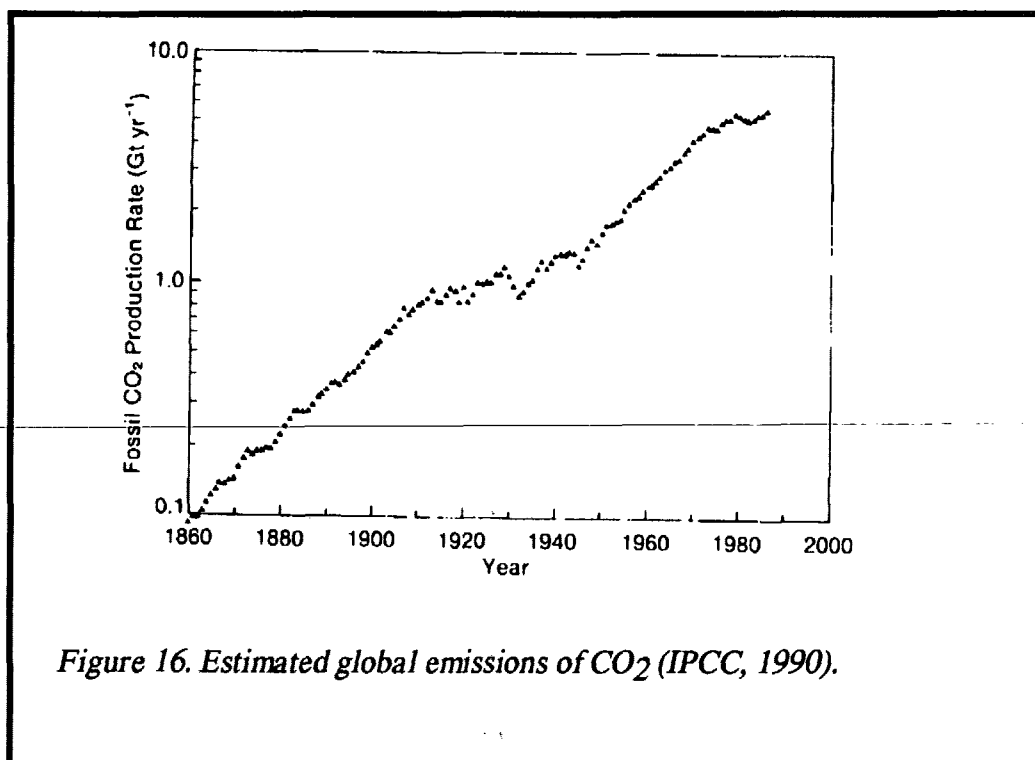
Scientifically speaking, except for linear systems, compartment models are only suitable for depicting flows and levels in a known system, not for predictive work. For linear systems or systems with small deviations from linearity, compartment models can be very useful. An example of linear behaviour is radioactive decay of given substances, but the transport of such substances may be governed by very non-linear processes.

4. Transport of individual materials

This section will exemplify the results of measurements and modelling for individual substances released from the activities associated with energy production and use. The substances are grouped as large-scale releases from fossil fuel conversion, trace-releases from fossil and renewable energy conversion, and finally releases from nuclear energy conversion.

4.1. Carbon dioxide and other substantial residues

Substantial releases from conversion of fossil fuels include carbon dioxide emitted into the atmosphere (Figure 16), and residues (mostly solid) either de-



posited or used in construction work (road beds, building materials). Also the combustion of biomass or generation of biogas produces CO_2 , but in these cases the time delay between CO_2 assimilation and re-release is much shorter. The average residence time of carbon dioxide in the atmosphere is several years, and that in oceans is orders of magnitude larger, which makes the problem a global one. CO_2 emissions as function of time have been reconstructed from a multitude of data sources, including ice core studies (Siegenthaler and Oeschger, 1987; Tans et al., 1990).

From a global dispersion point of view, CO_2 is of interest. Because the possible adverse effect is a long-range modification of the radiation disposal, the short-term distribution of CO_2 is of minor interest: CO_2 is predominantly emitted into the northern hemisphere, but after a few years, such a release has been fairly homogeneously distributed over the entire atmosphere. The time frame for effects on the greenhouse warming to reach a new equilibrium is believed to be of the order of 70-100 years (IPCC, 1990).

The short-term distribution of CO_2 is characterized by the hemisphere differences (Figure 17) and a seasonal pattern (Figure 18). The uncertainty in deriving these values is significant (Enting and Mansbridge, 1989). The main cause of the seasonal pattern is the seasonal variations in CO_2 assimilation by green plants. They explain most of the seasonal variation and some of the North-South difference (due to larger land masses on the Northern hemisphere). The rest of the differences may be explained by the difference in burning of fossil

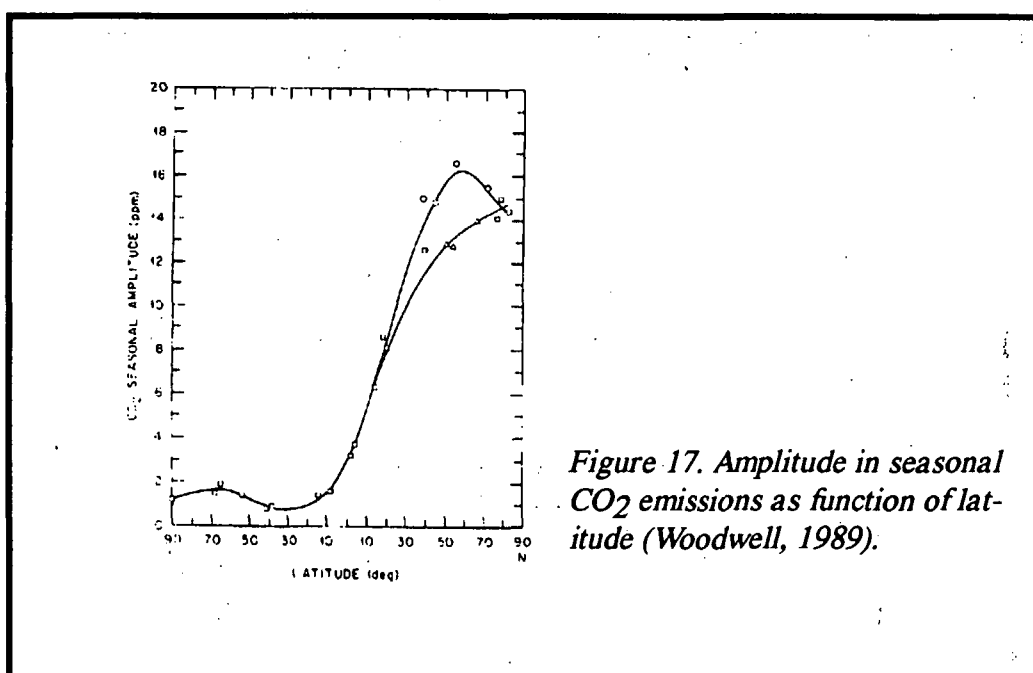


Figure 17. Amplitude in seasonal CO_2 emissions as function of latitude (Woodwell, 1989).

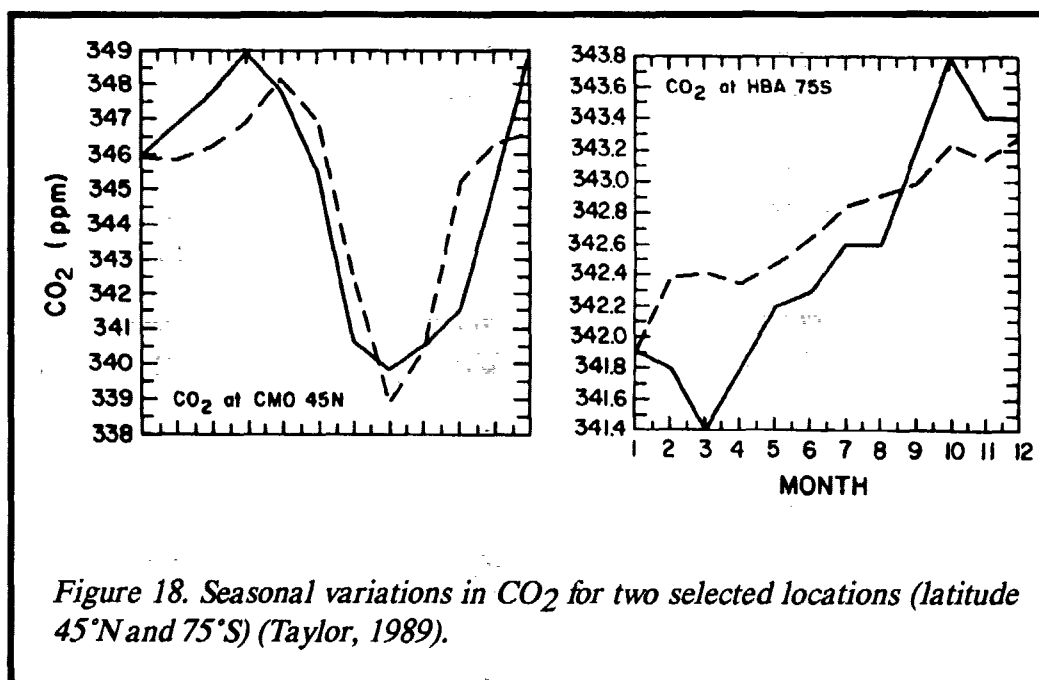


Figure 18. Seasonal variations in CO₂ for two selected locations (latitude 45°N and 75°S) (Taylor, 1989).

fuels between the hemispheres, and possibly an effect of the higher rate of fossil fuel combustion during winter is contributing, although it cannot quite compete with the spring plant growth peak.

Substantial effort has gone into trying to predict the global warming caused by the measured increase in the atmospheric content of CO₂ from all sources (fuel combustions, land use changes, etc.) (IPCC, 1990). Figure 19 gives the result

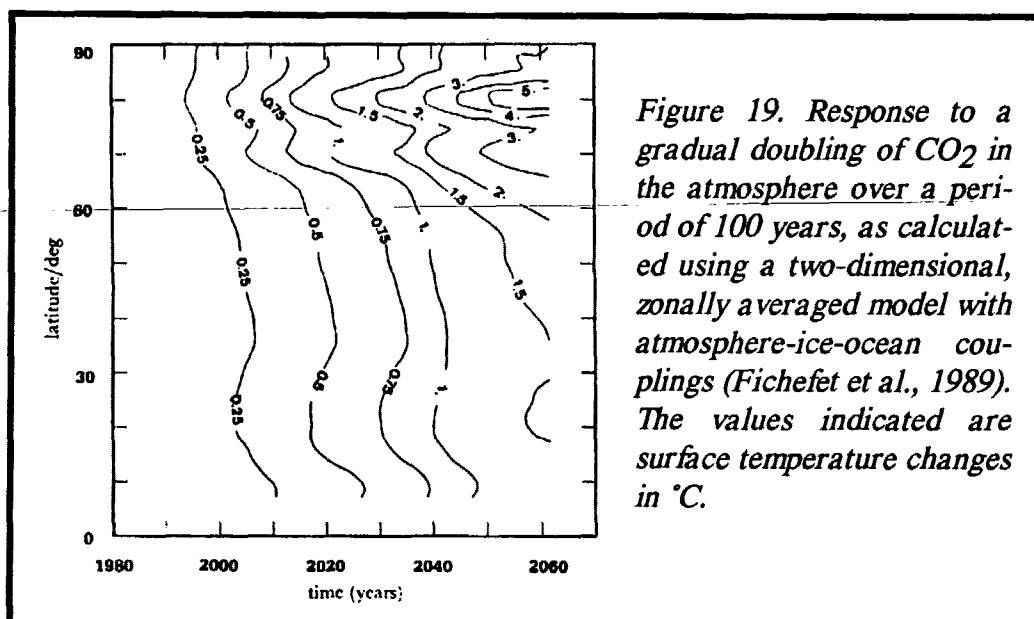


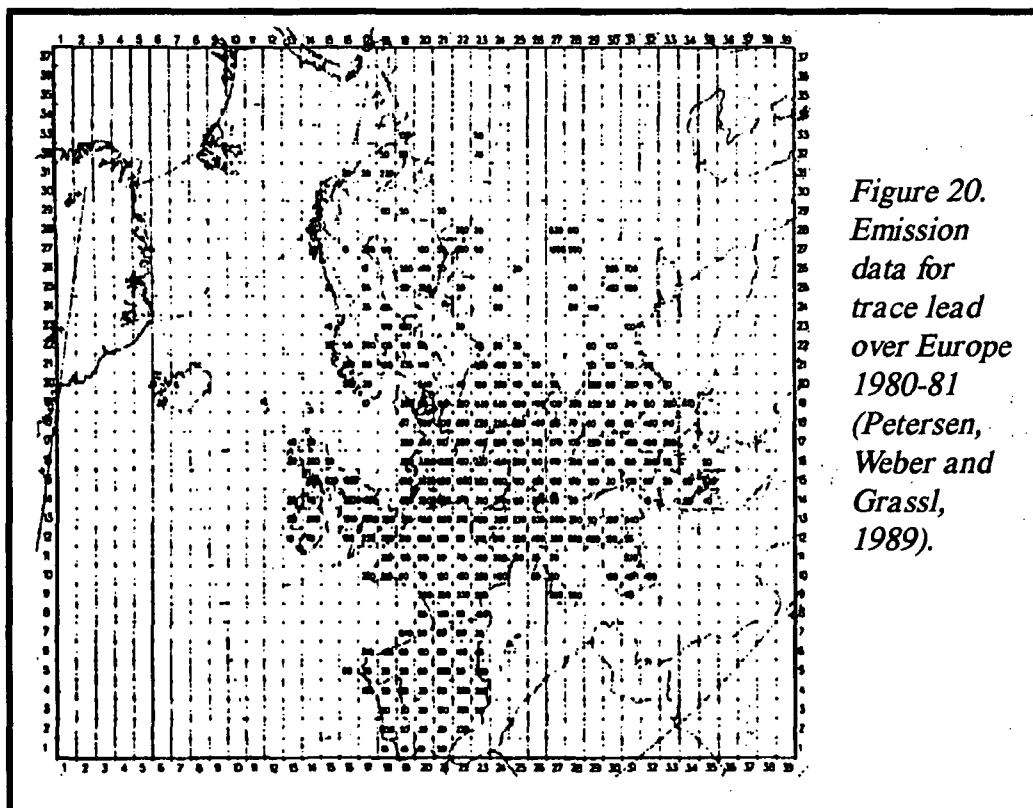
Figure 19. Response to a gradual doubling of CO₂ in the atmosphere over a period of 100 years, as calculated using a two-dimensional, zonally averaged model with atmosphere-ice-ocean couplings (Fichefet et al., 1989). The values indicated are surface temperature changes in °C.

of a global circulation calculation, assuming a gradual doubling of CO₂ over a 100 years period, and viewing the temperature variation as function of time and latitude.

4.2. Trace materials and minor residues from fuels of biological origin

Among the trace substances released from fossil energy conversion activities are SO_x, NO_x, N₂O, trace metals, PAH (Polyaromatic hydrocarbons) and unburned hydrocarbons (CH₄, oil products, etc.), plus other particulate matter with different size distributions. Burning of biomass exhibit similar releases, and other biofuel technologies may produce isolated releases, e.g. of methane).

The physical and chemical form of these releases cause them to mainly stay in the lower troposphere and to become deposited during time intervals typically in the range of days or weeks. Thus, the main environmental problem is regional rather than global. For this reason, adequate results have often been obtained with simple models such as forward or backward application of trajectory models. As an example, Figures 21-23 show lead concentration in the air



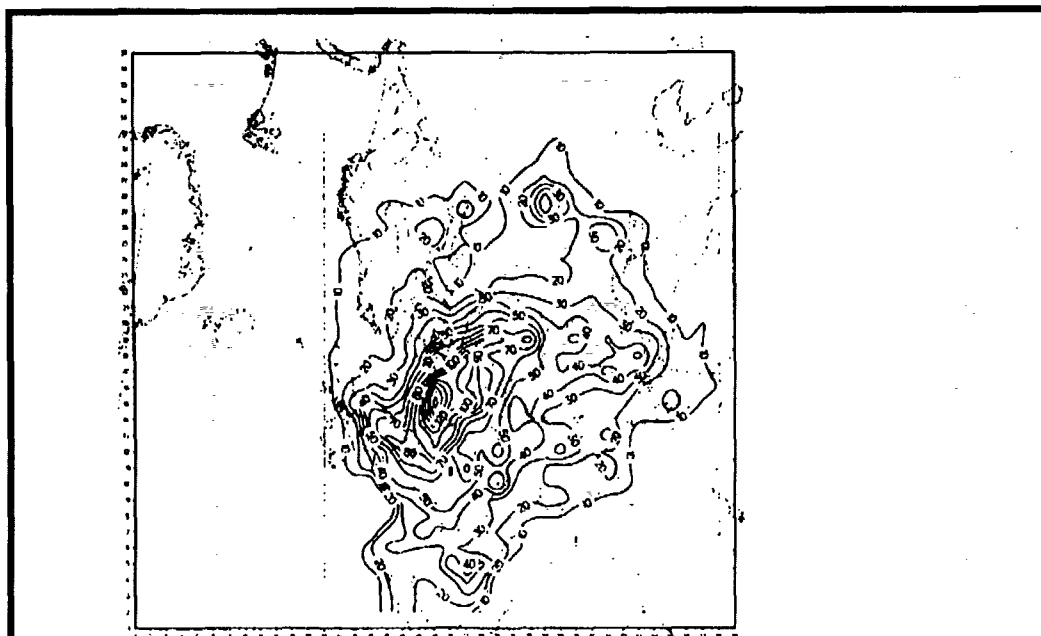


Figure 21. Lead content of surface air over Europe, January 1980, as calculated by using a trajectory model (Petersen, Weber and Grassl, 1989).

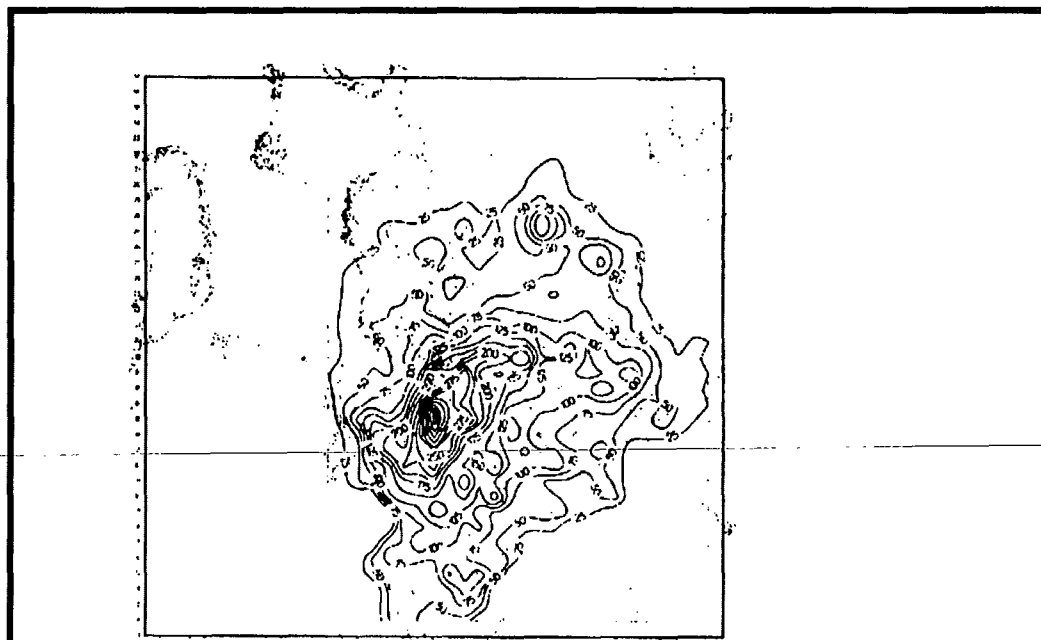
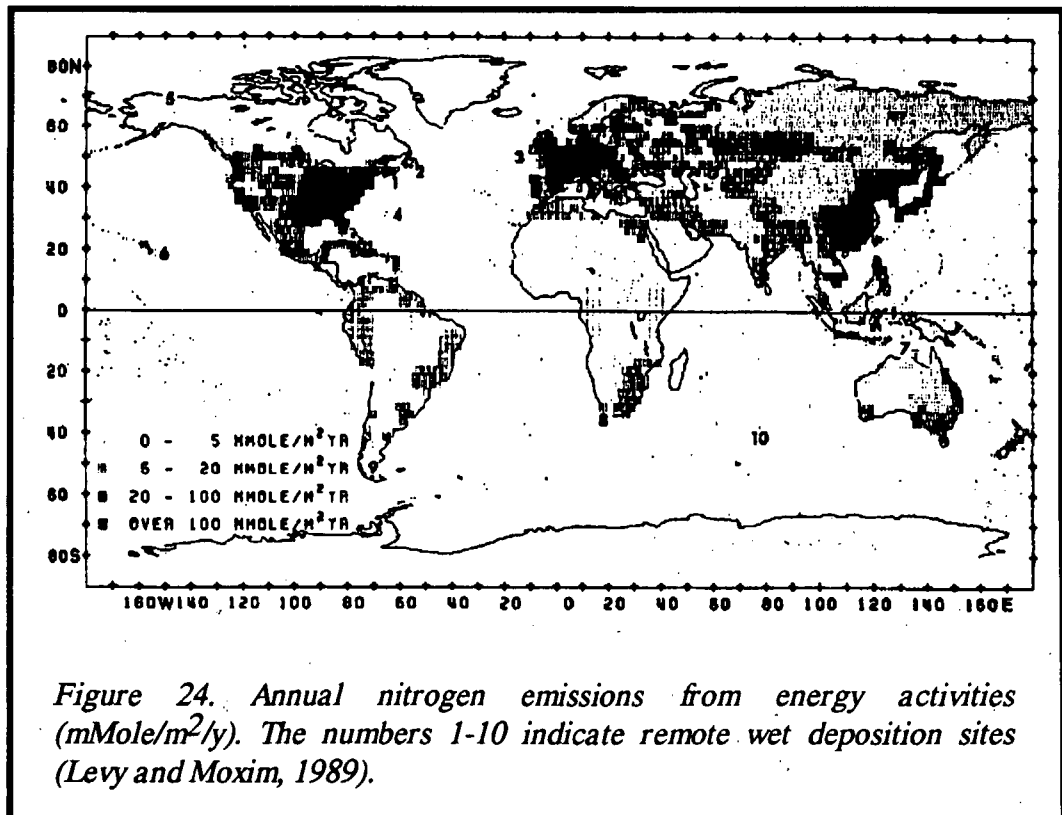
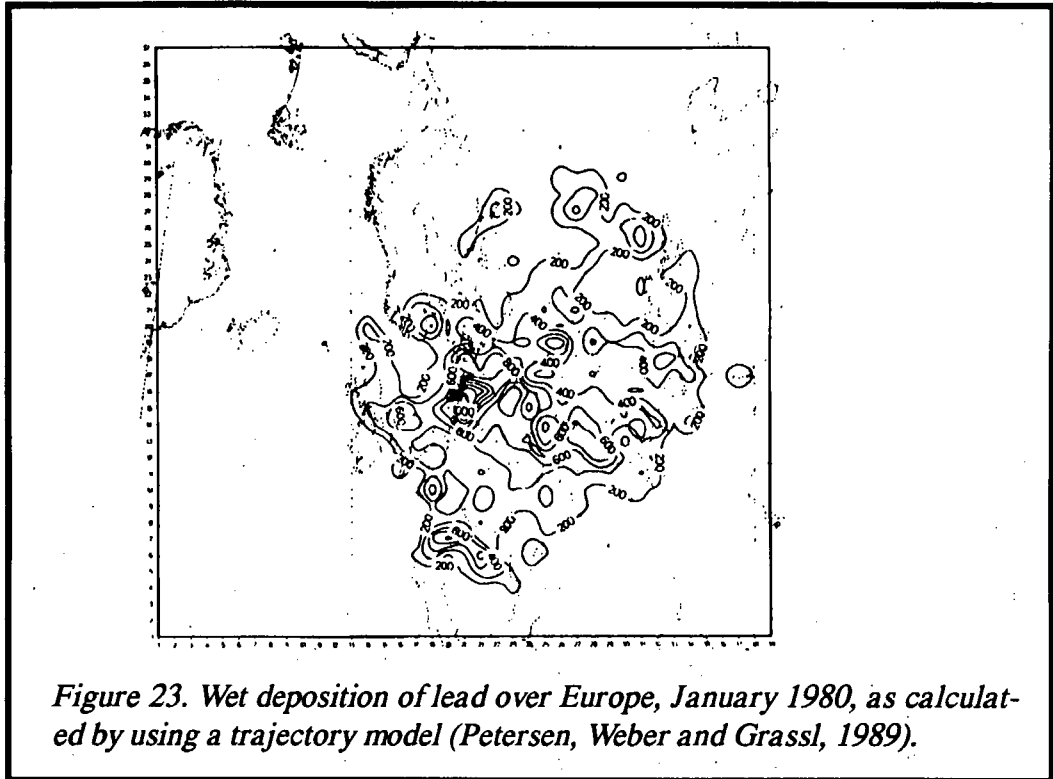
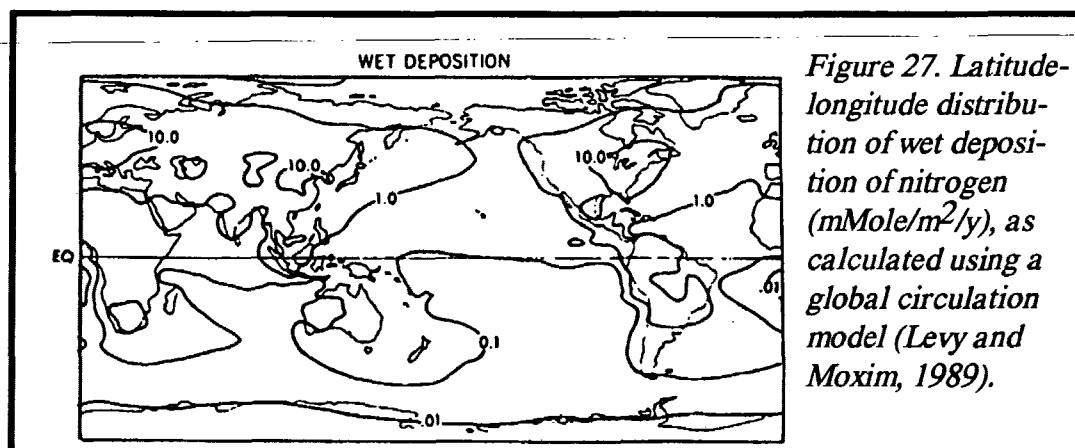
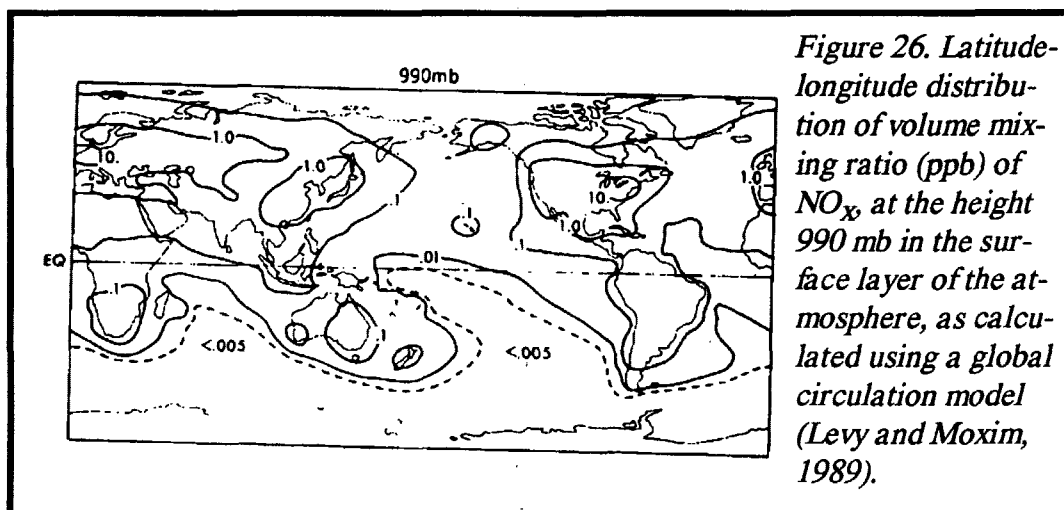
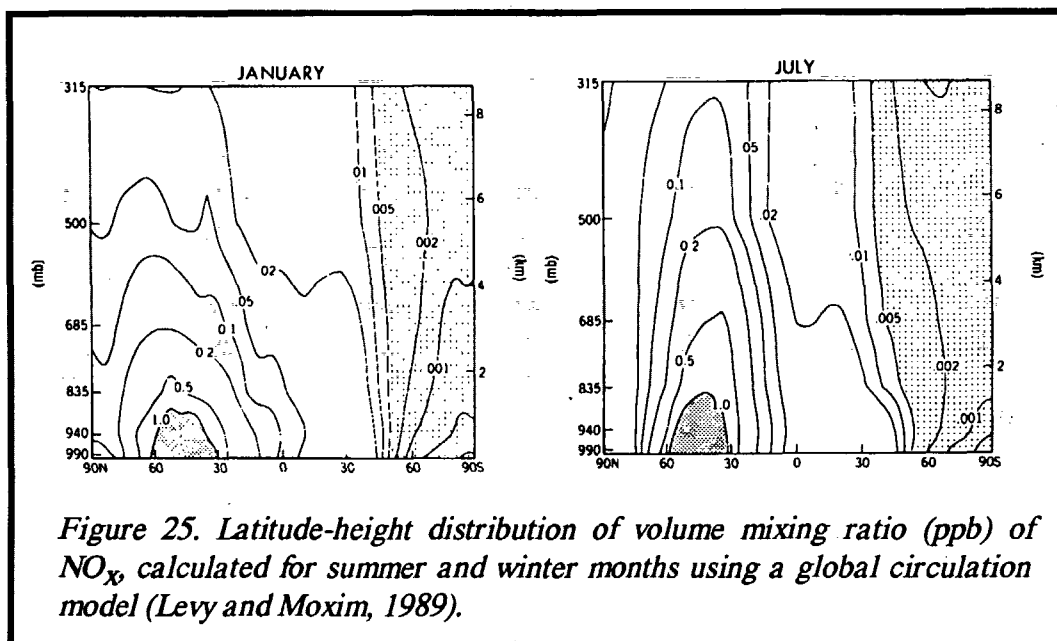
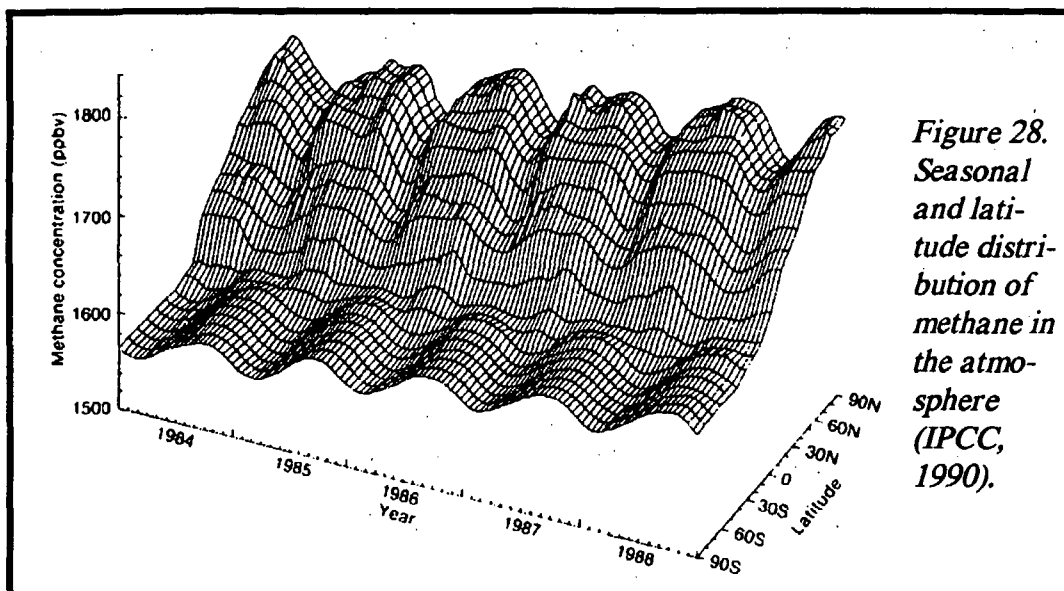


Figure 22. Dry deposition of lead over Europe, January 1980, as calculated by using a trajectory model (Petersen, Weber and Grassl, 1989).







over Europe, along with dry and wet deposition of lead, as calculated using a trajectory model and available emission data for 1980, depicted in Figure 20.

Global circulation models may give a more detailed view of the dispersal. Assuming the NO_x sources shown in Figure 24, Levy and Moxim (1989) finds the latitude-height distributions shown in Figure 25, and the latitude-longitude distribution and wet deposition given in Figures 26 and 27.

Several trace elements have natural sources, as well as originating from energy conversion. Among these are sea salt spray processes, volcanic eruptions, forest fires, biogenic emissions, and erosion followed by dust and aerosol dispersal by wind.

Some trace materials may reach the stratosphere and take part in complex chemical reactions there, including ozone depleting processes.

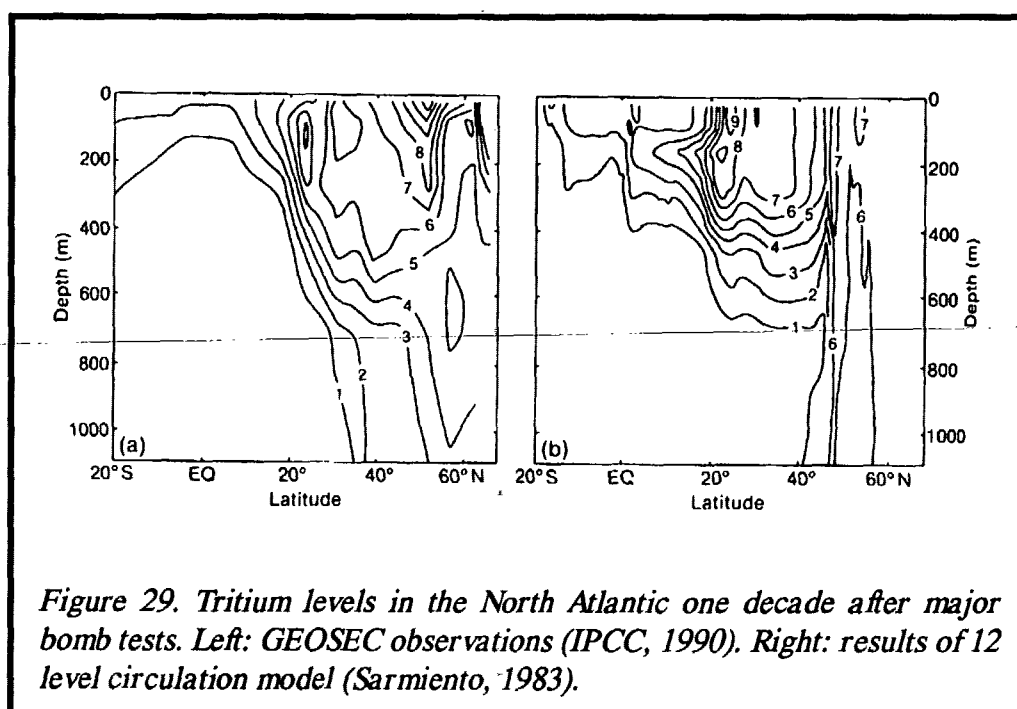
Figure 28 shows the latitude and seasonal distribution of methane in the atmosphere. Indications from radio-isotope analysis are, that about 20% derives from energy production, mainly coal mining activities and wood burning (IPCC, 1990).

4.3. Radioactive materials from nuclear fuel cycles

Among the radioisotopes released from nuclear power plants during normal operation as well as accidents are tritium, ^{14}C , isotopes of noble gases and iodine, cesium, strontium, plutonium and others. A survey of dispersion models used on a medium and long scale may e.g. be found in Reiter (1974). Estimates of emissions and dispersion of radionuclides with potential global impact, such as ^3H , ^{14}C , ^{85}Kr and ^{129}I , have been made by IAEA (1985).

Figure 29 shows the oceanic distribution of tritium in the North Atlantic, as modelled by a 3-dimensional general circulation model and compared with available data. The main source of tritium is atmospheric bomb tests. Small fractions presently derive from nuclear facilities and cosmic ray impact. However, it has been estimated, that reactor tritium may become the dominant source in the not so distant future, depending of course on the development of nuclear energy, including possible actions taken to reduce emissions (Cohen, 1975).

Trajectory models have been used to study the transport of ^{131}I following the 1957 Windscale accident, with reasonable agreement with the data (Figure 14) (ApSimon et al., 1980).



Based upon a compartment model, Figure 30 shows calculated distribution among the compartments of ^{129}I , as function of time after release into the compartment "atmosphere over land". Figure 31 gives similar results for ^3H , based on the compartment model depicted in Figure 15.

The Chernobyl accident gave rise to substantial fallout at large distances from the point of release (Figure 32 and 33). A radionuclide transport model, based upon a calculation of the general circulation and adapted to measured wind speeds, is used to simulate the time evolution of global dispersal. Figures 34-36 show examples of the calculated distribution of ^{131}I as function of time, height and location, while Figure 37 show the activity at a given location as function of time, as compared with measurements. It is seen that this kind of modelling is capable of reproducing quite closely the actual data (Pudykiewicz, 1989).

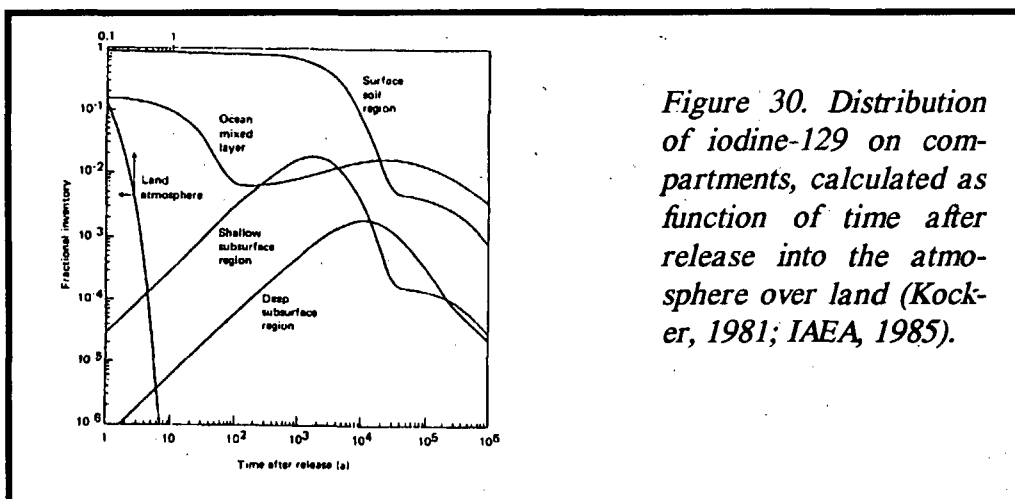


Figure 30. Distribution of iodine-129 on compartments, calculated as function of time after release into the atmosphere over land (Kocker, 1981; IAEA, 1985).

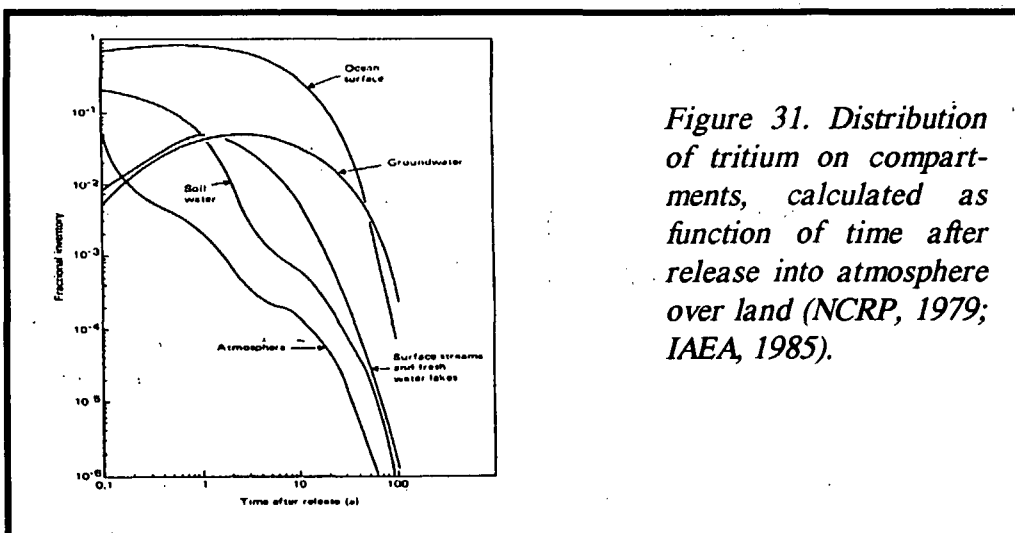
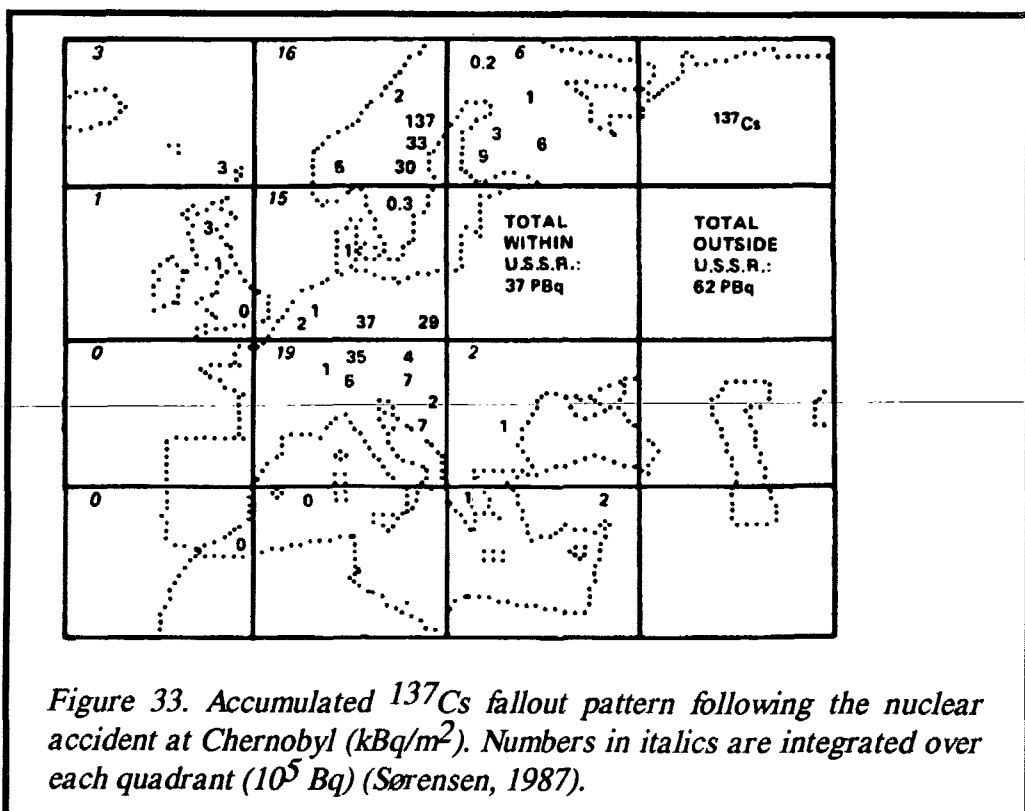
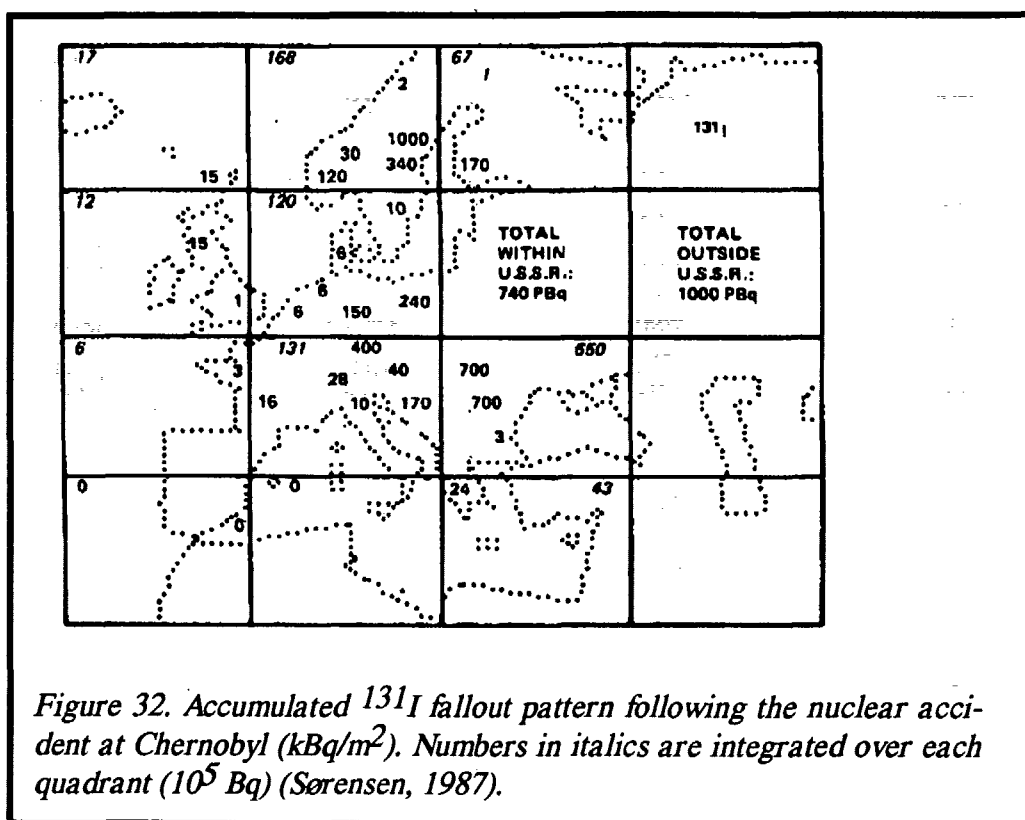


Figure 31. Distribution of tritium on compartments, calculated as function of time after release into atmosphere over land (NCRP, 1979; IAEA, 1985).



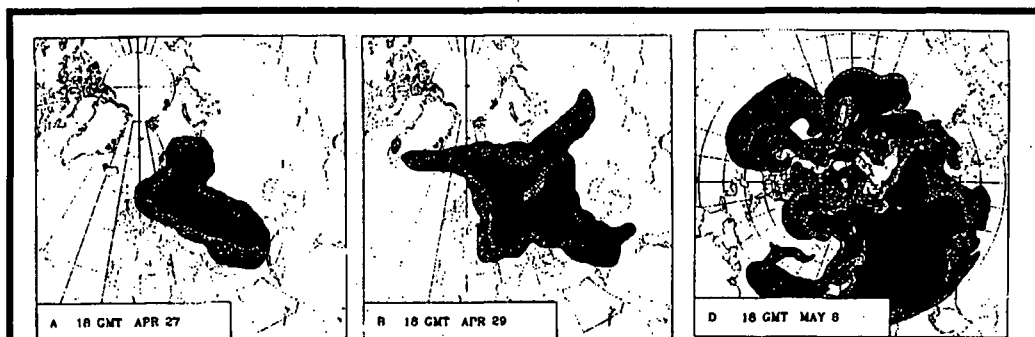


Figure 34. ^{131}I activity fields (Bq/kg) at mean sea level, A: 2d, B: 4d, D: 13d after release (Figure 35 give the values 7d after release). Dashed areas have activities between 10^{-4} and 10^{-2} , and black areas above 10^{-2} Bq/kg (Pudykiewicz, 1989).

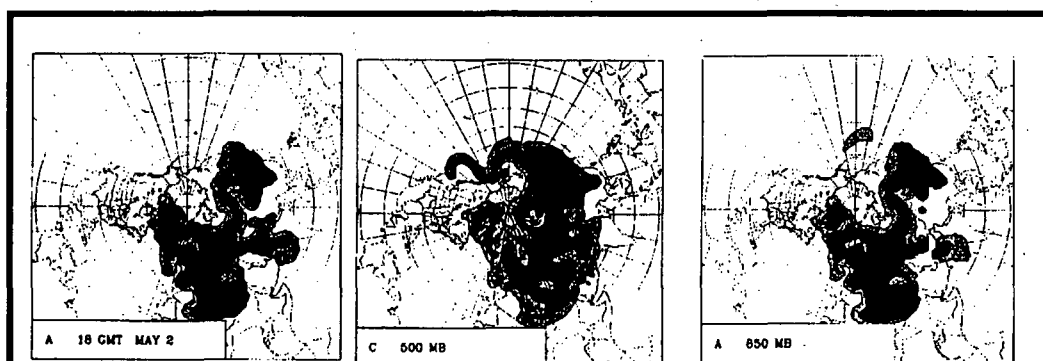


Figure 35. ^{131}I activity fields (Bq/kg) 7 days after release, at different heights. Dashed areas have activities between 10^{-4} and 10^{-2} , and black areas above 10^{-2} Bq/kg (Pudykiewicz, 1989).

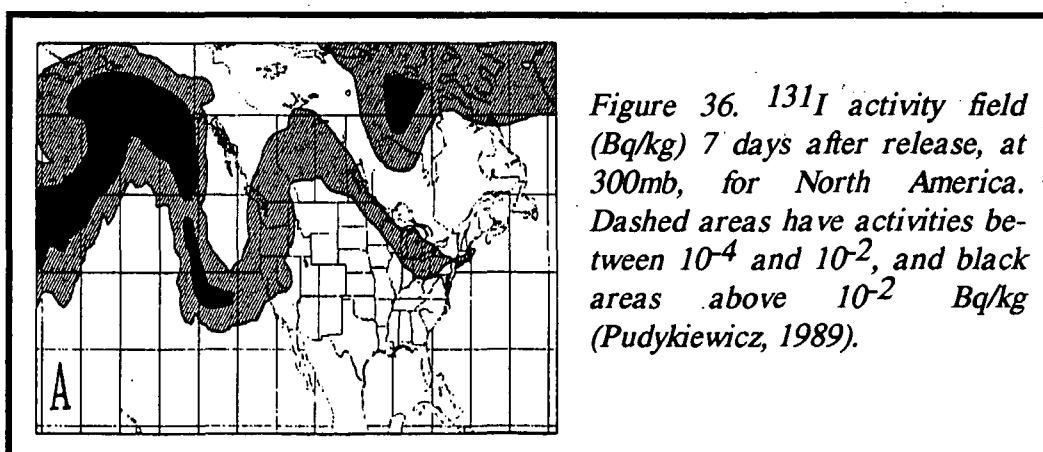


Figure 36. ^{131}I activity field (Bq/kg) 7 days after release, at 300mb, for North America. Dashed areas have activities between 10^{-4} and 10^{-2} , and black areas above 10^{-2} Bq/kg (Pudykiewicz, 1989).

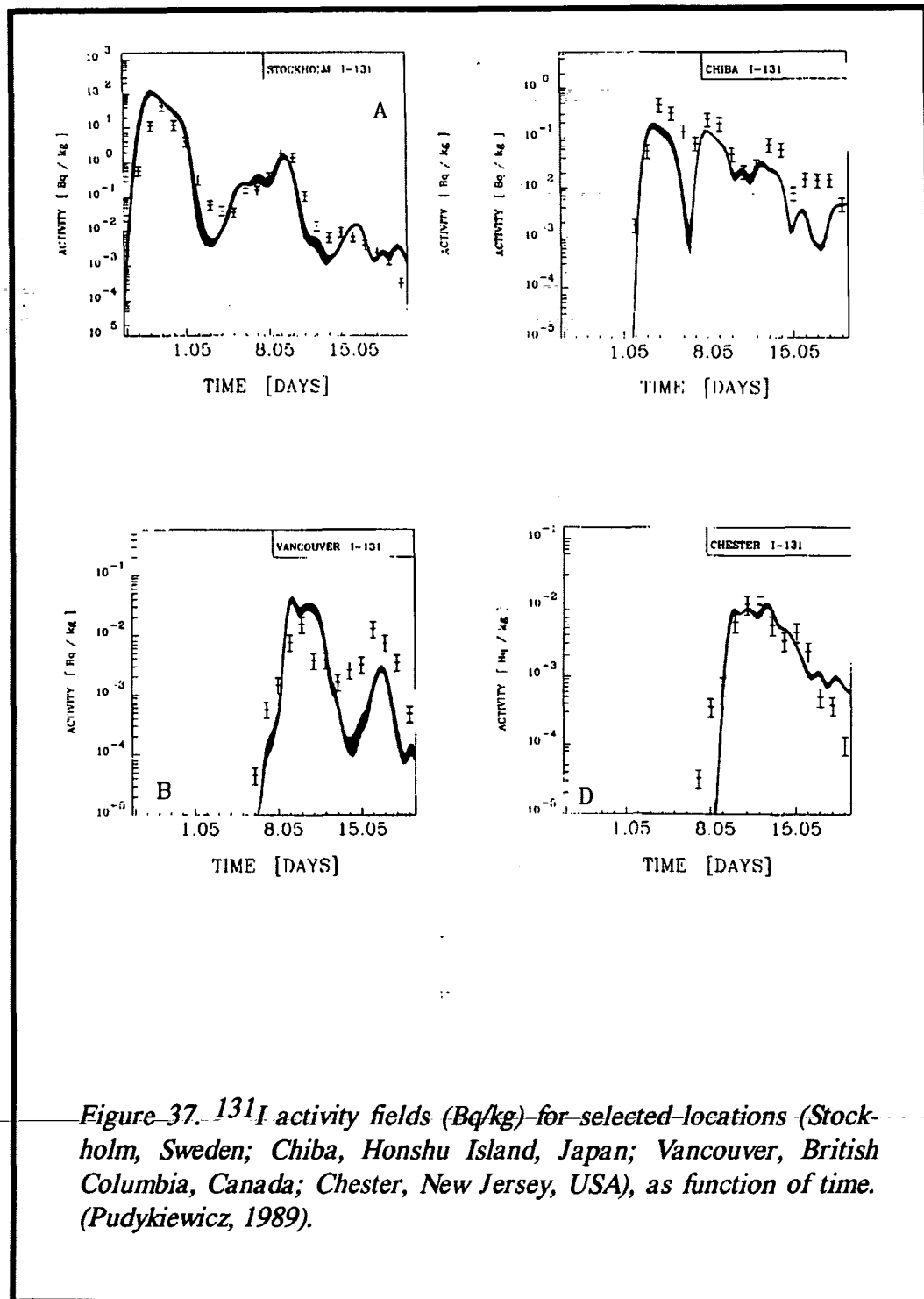


Figure 37. ^{131}I activity fields (Bq/kg) for selected locations (Stockholm, Sweden; Chiba, Honshu Island, Japan; Vancouver, British Columbia, Canada; Chester, New Jersey, USA), as function of time. (Pudykiewicz, 1989).

5. Discussion

The combination of general circulation models and transport models for individual substances of interest is in principle the most proper models for estimating global dispersal. However, these models can become extremely complex, e.g. if the substances of interest interact chemically or undergo many physical transformations. In practice, at least at the present stage of computer technology, one is thus confined to dealing with simplified models, that focus on some aspects deemed important. For instance, the effect of the substance under study on the general circulation of winds and currents is often small and may be neglected. This allows the large number of equations to be partially decoupled, so that the calculation can proceed sequentially.

Still, there may be situations, where this approach is not good enough. One case is that of dispersal depending on chaotic behaviour of winds and currents (i.e. eddies and other motion on a scale below the scale defining the averaging that is part of any actual calculation). Some help may in such cases be furnished by stochastic calculations, but this depends on the kind of questions being asked.

This is a quite general criterion for the selection of models to use. The kind of questions being addressed will to a large degree determine the type of approximations that would be useful and that are permitted. The kind of effects included in combined circulation models with transport and chemistry models of various substances depends strongly on the lengths of time during which it is desired to follow the substances. Much depends on whether the dynamical behaviour on a latitude-longitude-height basis is important for the questions being asked. If the substances of interest move from say atmosphere to soil and water on a short time scale, but lead to health or environmental effects on a much larger time-scale, then a combination of two (or more) differently structured models may be the best solution, just as the time-scales of atmospheric and oceanic motion do often warrant separate treatment, because of the difference in scale involved.

In some cases the model may be simplified to a point-like description of the release (as opposed to a three-dimensional field). This allows trajectory models to be used, for a time-series of such "puffs", eventually with the addition of a dilution estimate. The aim of such models are normally singular events on a regional scale. In special weather situations, even plume models may be used

close to the source of release. Such models predict monotonously decreasing concentrations with distance from the source.

In cases where the dispersal seems to be governed by linear processes, and where natural compartments can be defined, compartment models can serve a useful purpose.

The next years are likely to see a further development in our ability to run coupled models with more and more equations. Still, all dispersal models are approximate, and there are questions that will never become feasible to seek answers to. These are questions influenced by the non-linear couplings to chaotic motion in the atmosphere or in the oceans. An important task will be to identify useful ways of characterizing various kinds of release dispersal, which do involve such non-accessible quantities. In other words, to be able to determine the conditions for being able to answer a given question, or reversely to determine the set of questions, that may be answered in a given situation.

References

- ApSimon, H., Goddard, A. and Wrigley, J. 1980. *Long-range transport of radioisotopes in the atmosphere and the calculation of collective dose*. In "Proc. 5th Int. Congress of IRPA", paper 1067.
- Barrie, L. and Schemenauer, R. 1989. *Wet deposition of heavy metals*. pp. 203-231 in "Control and fate of atmospheric trace metals" (Pacyna and Ottar, eds.), Kluwer Academic Publ. Dordrecht.
- Björkström, A. 1983. *Modelling the oceanic CO₂ uptake and future CO₂ levels*. pp. 57-92 in "Carbon Dioxide" (Bach, Crane, Berger and Longhetto, eds.). Reidel Publ., Dordrecht.
- Bolin, B. 1985. *How much CO₂ will remain in the atmosphere?* Chapter 3 in "The greenhouse effect, climatic change, and ecosystems" (Bolin, Döös, Jäger and Warrick, eds.), Wiley, Chichester.
- CEA/NRPB 1979. *Methodology for evaluating the radiological consequences of radioactive effluents released in normal operation*. CEC Doc. No. V/3865/1/79.
- Cohen, J. 1975. *Cost effectiveness of release prevention controls for tritium and krypton-85*. pp. 285-298 in IAEA, 1975.
- Davidson, C. and Wu, Y-L. 1989. *Dry deposition of trace elements*. pp. 147-202 in "Control and fate of atmospheric trace metals" (Pacyna and Ottar, eds.), Kluwer Academic Publ. Dordrecht.
- Enting, I. and Mansbridge, J. 1989. *Seasonal sources and sinks of atmospheric CO₂: Direct inversion of filtered data*. Tellus, vol. 41B, 111-126.
- Fichefet, T., Tricot, C., Berger, A., Gallée, H. and Marsiat, I. 1989. *Climate studies with a coupled atmosphere-upper-ocean-ice-sheet model*. Philosophical Transaction of the Royal Society of London, vol. A329, 249-261 (also available in the monograph "The Dynamics of the Coupled Atmosphere and Ocean", The Royal Society, London).
- Gifford, F. 1967. *The rise of strongly radioactive plumes*. Journal of Applied Meteorology, vol. 6, 644-649.
-

-
- Heintzenberg, J. 1989. *Fine particles in the global troposphere*. Tellus, vol. 41B, 149-160.
- IAEA, 1975. *Combined effects of radioactive, chemical and thermal releases to the environment*. STI/PUB/404, Vienna. 358 pp.
- IAEA, 1985. *The radiological impact of radionuclides dispersed on a regional and global scale: Methods for assessment and their application*. Technical Report Series No. 250, Vienna, 81 pp.
- IAEA, 1992. *Format and structure of a database on health and environment effects of different energy systems for electricity generation*. TECDOC-645, Vienna, 232 pp.
- IPCC, 1990. *Climate Change* (Houghton, Jenkins and Ephraums, eds.). Cambridge University Press, Cambridge, 365 pp.
- Iribane, J. and Cho, H. 1989. *Models of cloud chemistry*. Tellus, vol. 41B, 2-23.
- Jensen, J. and Sørensen, B. 1984. *Fundamentals of Energy Storage*. Wiley, New York. 345 pp.
- Kellogg, W. 1980. *Aerosols and climate*. pp. 281-296 in "Interactions of energy and climate" (Bach, Pankrath and Williams, eds.), Reidel Publ., Dordrecht.
- Kocker, D. 1981. *A dynamic model of global iodine cycle and estimation of dose to the world population from releases of iodine-129 to the environment*. Environment International, vol. 5, 15-31.
- Langner, J. and Rodhe, H. 1991. *A global Three-Dimensional Model of the Tropospheric Sulphur Cycle*. J. Atm. Chem. vol. 13, pp. 225-263.
- Levy, H. and Moxim, W. 1989. *Simulated global distribution and deposition of reactive nitrogen emitted by fossil fuel combustion*. Tellus, 41B, 256-271.
- Levitus, S. 1982. *Climatological Atlas of the World Ocean*. Professional Paper No. 13, NOAA, Washington DC.
-

-
- Lindell, B. and Löfveberg, S. 1972. *Kärnkraften, människan och säkerheten*. Almänna Forlaget, Stockholm.
- Newell, R. Kidson, J., Vincent, D. and Boer, G. 1972. *The general circulation of the tropical atmosphere and interactions with extra-tropical latitudes*. Vol. 1. MIT Press, Cambridge. 258 pp.
- NCRP, 1979. *Tritium in the Environment*. Report No. 62, Washington.
- Persson, C. and Robertson, L. 1991. *An operational regional air pollution model applied to different scales*. Paper presented at "Conference on Chemistry and the Environment, Salzburg, September", 8 pp.
- Petersen, G., Weber, H., and Grassl, H. 1989. *Modelling the atmospheric transport of trace metals from Europe to the North Sea and the Baltic Sea*. pp. 57-83 in "Control and fate of atmospheric trace metals" (Pacyna and Ottar, eds.). Kluwer Academic, Dordrecht.
- Pudykiewicz, J. 1989. *Simulation of the Chernobyl dispersion with a 3-D hemispherical tracer model*. Tellus, vol. 41B, 391-412.
- Rasmussen, E. 1980. *Dispersion conditions during an adverse meteorological situation in the Øresund region*. Paper # 15, EEC Symposium, Risø, Denmark.
- Rasmussen, N. (principal investigator) 1975. *Reactor Safety Study*. US Nuclear Regulatory Commission, WASH-1400/NUREG 75/014.
- Reiter, E. 1974. *Dispersion of radioactive material on small, meso- and global scales*. pp. 35-64 in "Physical behaviour of radioactive contaminants in the atmosphere", IAEA, STI/PUB/354, Vienna.
- Sarmiento, J. 1983. *A simulation of bomb-tritium entry into the Atlantic Ocean*. Journal of Physical Oceanography, vol. 13, 1924-1939.
- Siegenthaler, U. and Oeschger, H. 1987. *Biospheric CO₂ emissions during the past 200 years reconstructed by deconvolution of ice core data*. Tellus, vol. 39B, 140-154.
- Stewart, N. and Crooks, R., 1958. *Long-range travel of the radioactive cloud from the accident at Windscale*. Nature, vol. 182, 627-628.
-

-
- Swedish Ministries for Foreign Affairs and Agriculture. 1971. *Air Pollution across National Boundaries*. Sweden's case study to the UN Conference of the Human Environment, Stockholm.
- Sørensen, B. 1974. pp. 352-360 in *Atomernes hvem, hvad, hvor* (Petersen, ed.). Politikens Forlag, Copenhagen.
- Sørensen, B. 1975. *Computer simulation of ¹³¹I transfer from fallout to man*. *Water, Air, and Soil Pollution*, vol. 4, 65-87.
- Sørensen, B. 1979. *Renewable Energy* (especially chapter 2). Academic Press, London. 683 pp.
- Sørensen, B. 1981. Chapter 4 in *Renewable sources of energy and the environment* (El-Hinnawi and Biswas, eds.). Tycooly International, Dublin.
- Sørensen, B. 1986. *The status of wind generators in Europe*. Energy Authority of New South Wales EA86/18. Government Printing, Sydney.
- Sørensen, B. 1987. *Chernobyl accident: assessing the data*. *Nuclear Safety*, vol. 28, 443-447.
- Sørensen, B. 1988. *Renewable Energy and Development*. pp. 35-74 in "Renewable Energy and local production, a vehicle for development", vol. 1. Proc. UN Conference, Thy Danish Centre for Renewable Energy, Hurup.
- Sørensen, B. 1992. *Life-cycle assessment of energy systems*. OECD, Paris. 49 pp.
- Tans, P., Fung, I. and Takahashi, T. 1990. *Observational constraints on the global CO₂ budget*. *Nature*, vol. 247, 1431-1438.
- Taylor, J. 1989. *A stochastic Lagrangian atmospheric transport model to determine global CO₂ sources and sinks - a preliminary discussion*. *Tellus*, vol. 41B, 272-285.
- UNEP, 1985. *The environmental impact of production and use of energy*, vol. IV,1. Energy Report Series 14-85, Nairobi.
- van der Hoven, I., et al. 1974. *Recent Analytical and experimental efforts on single-source effluent dispersion to distances of 100km*. pp. 427-442 in
-

"Physical behaviour of radioactive contaminants in the atmosphere", IAEA, STI/PUB/354, Vienna.

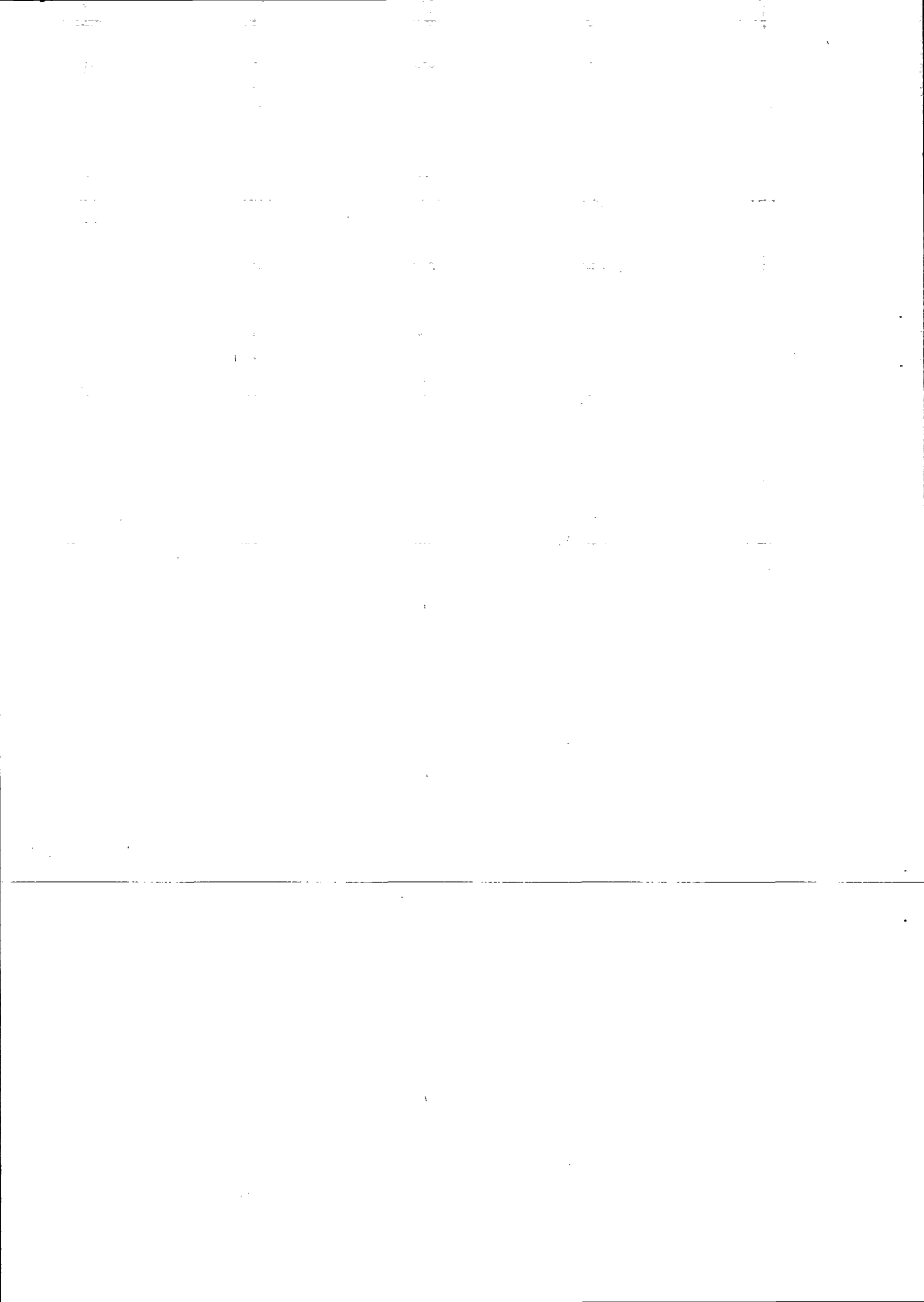
Vogt, K. 1974. *Dispersion of airborne radioactivity released from nuclear installations*. pp. 3-34 in "Physical behaviour of radioactive contaminants in the atmosphere", IAEA, STI/PUB/354, Vienna.

Volz, A. 1983. *Climatic Impact of trace gases, aerosols, land-use changes, and waste heat release*. pp. 353-376 in "Carbon Dioxide" (Bach, Crane, Berger and Longhetto, eds.), Reidel Publ., Dordrecht.

Washington, W. and Meehl, G. 1989. *Climate sensitivity due to increased CO₂. Experiments with a coupled atmosphere and ocean general circulation model*. Climate Dynamics, vol. 4, 1-38.

Woodwell, G. 1989. *The warming of the industrialized middle latitudes 1985-2050: causes and consequences*. Climate Change, vol. 15, 31-50.

Woods, 1985. *The Physics of Thermocline Ventilation*. pp. 543-590 in "Coupled Ocean-Atmosphere Models" (Nihoul, ed.), Elsevier, Amsterdam.



- 1/78 "TANKER OM EN PRAKSIS" - et matematikprojekt. Projekt rapport af: Anne Jensen, Lena Lindenskov, Marianne Kesselhahn og Nicolai Lomholt. Vejleder: Anders Madsen
- 2/78 "OPTIMERING" - Menneskets forøgede beherskelsesmuligheder af natur og samfund. Projekt rapport af: Tom J. Andersen, Tommy R. Andersen, Gert Krenøe og Peter H. Lassen. Vejleder: Bernhelm Boss.
- 3/78 "OPCAVESAMLING", breddekursus i fysik. Af: Lasse Rasmussen, Aage Bonde Kræmmer og Jens Højgaard Jensen.
- 4/78 "TRE ESSAYS" - om matematikundervisning, matematiklæreruddannelsen og videnskabsrindalismen. Af: Mogens Niss. Nr. 4 er p.t. udgået.
- 5/78 "BIBLIOGRAFISK VEJLEDNING til studiet af DEN MODERNE FYSIKS HISTORIE". Af: Helge Kragh. Nr. 5 er p.t. udgået.
- 6/78 "NOGLE ARTIKLER OG DEBATINDLÆG OM - læreruddannelse og undervisning i fysik, og - de naturvidenskabelige fags situation efter studenteroprøret". Af: Karin Beyer, Jens Højgaard Jensen og Bent C. Jørgensen.
- 7/78 "MATEMATIKKENS FORHOLD TIL SAMFUNDSØKONOMIEN". Af: B.V. Gnedenko. Nr. 7 er udgået.
- 8/78 "DYNAMIK OG DIAGRAMMER". Introduktion til energy-bond-graph formalismen. Af: Peder Voetmann Christiansen.
- 9/78 "OM PRAKSIS' INDFLYDELSE PÅ MATEMATIKKENS UDVIKLING". - Motiver til Kepler's: "Nova Stereometria Doliorum Vinariorum". Projekt rapport af: Lasse Rasmussen. Vejleder: Anders Madsen.
-
- 10/79 "TERMODYNAMIK I GYMNASIET". Projekt rapport af: Jan Christensen og Jeanne Mortensen. Vejledere: Karin Beyer og Peder Voetmann Christiansen.
- 11/79 "STATISTISKE MATERIALER". Af: Jørgen Larsen.
- 12/79 "LINEÆRE DIFFERENTIALLIGNINGER OG DIFFERENTIALLIGNINGSSYSTEMER". Af: Mogens Brun Heefelt. Nr. 12 er udgået.
- 13/79 "CAVENDISH'S FORSØG I GYMNASIET". Projekt rapport af: Gert Kreinøe. Vejleder: Albert Chr. Paulsen.
- 14/79 "BOOKS ABOUT MATHEMATICS: History, Philosophy, Education, Models, System Theory, and Works of". Af: Else Høyrup. Nr. 14 er p.t. udgået.
- 15/79 "STRUKTUREL STABILITET OG KATASTROFER i systemer i og udenfor termodynamisk ligevægt". Specialeopgave af: Leif S. Striegler. Vejleder: Peder Voetmann Christiansen.
- 16/79 "STATISTIK I KREFTFORSKNINGEN". Projekt rapport af: Michael Olsen og Jørn Jensen. Vejleder: Jørgen Larsen.
- 17/79 "AT SPØRGE OG AT SVARE i fysikundervisningen". Af: Albert Christian Paulsen.
- 18/79 "MATHEMATICS AND THE REAL WORLD", Proceedings af an International Workshop, Roskilde University Centre, Denmark, 1978. Preprint. Af: Bernhelm Booss og Mogens Niss (eds.)
- 19/79 "GEOMETRI, SKOLE OG VIRKELIGHED". Projekt rapport af: Tom J. Andersen, Tommy R. Andersen og Per H.H. Larsen. Vejleder: Mogens Niss.
- 20/79 "STATISTISKE MODELLER TIL BESTEMMELSE AF SIKRE DOSER FOR CARCINOGENE STOFFER". Projekt rapport af: Michael Olsen og Jørn Jensen. Vejleder: Jørgen Larsen
- 21/79 "KONTROL I GYMNASIET-FORMÅL OG KONSEKVENSER". Projekt rapport af: Crilles Bacher, Per S.Jensen, Preben Jensen og Torben Nysteen.
- 22/79 "SEMIOTIK OG SYSTEMEGENSKABER (1)". I-port lineært response og støj i fysikken. Af: Peder Voetmann Christiansen.
- 23/79 "ON THE HISTORY OF EARLY WAVE MECHANICS - with special emphasis on the role of reality". Af: Helge Kragh.
-
- 24/80 "MATEMATIKOPFATTELSE HOS 2.G'ERE". a+b 1. En analyse. 2. Interviewmateriale. Projekt rapport af: Jan Christensen og Knud Lindhardt Rasmussen. Vejleder: Mogens Niss.
- 25/80 "EKSAMENSOPGAVER", Dybdemodulet/fysik 1974-79.
- 26/80 "OM MATEMATISKE MODELLER". En projekt rapport og to artikler. Af: Jens Højgaard Jensen m.fl.
- 27/80 "METHODOLOGY AND PHILOSOPHY OF SCIENCE IN PAUL DIRAC'S PHYSICS". Af: Helge Kragh.
- 28/80 "DILENTRISK RELAXATION - et forslag til en ny model bygget på væskemes viscoelastiske egenskaber". Projekt rapport af: Gert Kreinøe. Vejleder: Niels Boye Olsen.
- 29/80 "ODIN - undervisningsmateriale til et kursus i differentiaalligningsmodeller". Projekt rapport af: Tommy R. Andersen, Per H.H. Larsen og Peter H. Lassen. Vejleder: Mogens Brun Heefelt.
- 30/80 "FUSIONSENERGIEN - - - ATOMSAMFUNDETS ENDESTATION". Af: Oluf Danielsen. Nr. 30 er udgået.
- 31/80 "VIDENSKABSTEORETISKE PROBLEMER VED UNDERVISNINGSSYSTEMER BASERET PÅ MÆNGDELÆRE". Projekt rapport af: Troels Lange og Jørgen Karrebæk. Vejleder: Stig Andur Pedersen. Nr. 31 er p.t. udgået.
- 32/80 "POLYMERE STOFFERS VISCOELASTISKE EGENSKABER - BELYST VED HJÆLP AF MEKANISKE IMPEDANSMÅLINGER MØSSBAUEREFFEKT MÅLINGER". Projekt rapport af: Crilles Bacher og Preben Jensen. Vejledere: Niels Boye Olsen og Peder Voetmann Christiansen.
- 33/80 "KONSTITUERING AF FAG INDEN FOR TEKNISK - NATURVIDENSKABELIGE UDDANNELSER. I-II". Af: Arne Jakobsen.
- 34/80 "ENVIRONMENTAL IMPACT OF WIND ENERGY UTILIZATION". ENERGY SERIES NO. I. Af: Bent Sørensen. Nr. 34 er udgået.

- 35/80 "HISTORISKE STUDIER I DEN NYERE ATOMFYSIKS UDVIKLING".
Af: Helge Kragh.
- 36/80 "HVAD ER MENINGEN MED MATEMATIKUNDERVISNINGEN?".
Fire artikler.
Af: Mogens Niss.
- 37/80 "RENEWABLE ENERGY AND ENERGY STORAGE".
ENERGY SERIES NO. 2.
Af: Bent Sørensen.
-
- 38/81 "TIL EN HISTORIETEBORI OM NATURERKENDELSE, TEKNOLOGI OG SAMFUND".
Projektrapport af: Erik Gade, Håns Hedal, Henrik Lau og Finn Physant.
Vejledere: Stig Andur Pedersen, Helge Kragh og Ib Thiersen.
Nr. 38 er p.t. udgået.
- 39/81 "TIL KRITIKKEN AF VÆKSTØKONOMIEN".
Af: Jens Højgaard Jensen.
- 40/81 "TELEKOMMUNIKATION I DANMARK - oplæg til en teknologivurdering".
Projektrapport af: Arne Jørgensen, Bruno Petersen og Jan Vedde.
Vejleder: Per Nørgaard.
- 41/81 "PLANNING AND POLICY CONSIDERATIONS RELATED TO THE INTRODUCTION OF RENEWABLE ENERGY SOURCES INTO ENERGY SUPPLY SYSTEMS".
ENERGY SERIES NO. 3.
Af: Bent Sørensen.
- 42/81 "VIDENSKAB TEORI SAMFUND - En introduktion til materialistiske videnskabsopfattelser".
Af: Helge Kragh og Stig Andur Pedersen.
- 43/81 1. "COMPARATIVE RISK ASSESSMENT OF TOTAL ENERGY SYSTEMS".
2. "ADVANTAGES AND DISADVANTAGES OF DECENTRALIZATION".
ENERGY SERIES NO. 4.
Af: Bent Sørensen.
- 44/81 "HISTORISKE UNDERSØGELSER AF DE EKSPERIMENTELLE FORUDSÆTNINGER FOR RUTHERFORDS ATOMMODEL".
Projektrapport af: Niels Thor Nielsen.
Vejleder: Bent C. Jørgensen.
-
- 45/82 Er aldrig udkommet.
- 46/82 "EKSEMPLARISK UNDERVISNING OG FYSISK ERKENDELSE-
1+1 ILLUSTRERET VED TO EKSEMPLER".
Projektrapport af: Torben O. Olsen, Lasse Rasmussen og Niels Dreyer Sørensen.
Vejleder: Bent C. Jørgensen.
- 47/82 "BARBERÄCK OG DET VÆRST OFFICIELT-TÆNKELIGE UHELD".
ENERGY SERIES NO. 5.
Af: Bent Sørensen.
-
- 48/82 "EN UNDERSØGELSE AF MATEMATIKUNDERVISNINGEN PÅ ADGANGSKURSUS TIL KØBENHAVNS TEKNIKUM".
Projektrapport af: Lis Eilertzen, Jørnen Karrebæk, Troels Lange, Preben Nørregaard, Lissi Pedesen, Laust Rishøj, Lill Røn og Isac Showiki.
Vejleder: Mogens Niss.
- 49/82 "ANALYSE AF MULTISPEKTRALE SATELLITBILLEDER".
Projektrapport af: Preben Nørregaard.
Vejledere: Jørgen Larsen og Rasmus Ole Rasmussen.
- 50/82 "HERSLEV - MULIGHEDER FOR VEDVARENDE ENERGI I EN LANDSBY".
ENERGY SERIES NO. 6.
Rapport af: Bent Christensen, Bent Hove Jensen, Dennis B. Møller, Bjarne Laursen, Bjarne Lillethorup og Jacob Mørch Pedersen.
Vejleder: Bent Sørensen.
- 51/82 "HVAD KAN DER GØRES FOR AT AFHJÆLPE PICERS BLOKERING OVERFOR MATEMATIK ?"
Projektrapport af: Lis Eilertzen, Lissi Pedersen, Lill Røn og Susanne Stender.
- 52/82 "DESUSPENSION OF SPLITTING ELLIPTIC SYMBOLS".
Af: Bernhelm Booss og Krzysztof Wojciechowski.
- 53/82 "THE CONSTITUTION OF SUBJECTS IN ENGINEERING EDUCATION".
Af: Arne Jacobsen og Stig Andur Pedersen.
- 54/82 "FUTURES RESEARCH" - A Philosophical Analysis of Its Subject-Matter and Methods.
Af: Stig Andur Pedersen og Johannes Witt-Hansen.
- 55/82 "MATEMATISKE MODELLER" - Litteratur på Roskilde Universitetsbibliotek.
En biografi.
Af: Else Høytrup.

Vedr. tekst nr. 55/82 se også tekst nr. 62/83.
- 56/82 "EN - TO - MANGE" -
En undersøgelse af matematisk økologi.
Projektrapport af: Troels Lange.
Vejleder: Anders Madsen.
-
- 57/83 "ASPECT EKSPERIMENTET"-
Skjulte variable i kvantemekanikken?
Projektrapport af: Tom Juul Andersen.
Vejleder: Peder Voetmann Christiansen.
Nr. 57 er udgået.
- 58/83 "MATEMATISKE VANDRINGER" - Modelbetragtninger over spredning af dyr mellem småbiotoper i agerlandet.
Projektrapport af: Per Hammershøj Jensen og Lene Vagn Rasmussen.
Vejleder: Jørgen Larsen.
- 59/83 "THE METHODOLOGY OF ENERGY PLANNING".
ENERGY SERIES NO. 7.
Af: Bent Sørensen.
- 60/83 "MATEMATISK MODEKSPERTISE"- et eksempel.
Projektrapport af: Erik O. Gade, Jørgen Karrebæk og Preben Nørregaard.
Vejleder: Anders Madsen.
- 61/83 "FYSIKS IDEOLOGISKE FUNKTION, SOM ET EKSEMPEL PÅ EN NATURVIDENSKAB - HISTORISK SET".
Projektrapport af: Annette Post Nielsen.
Vejledere: Jens Høytrup, Jens Højgaard Jensen og Jørgen Vogelius.
- 62/83 "MATEMATISKE MODELLER" - Litteratur på Roskilde Universitetsbibliotek.
En biografi 2. rev. udgave.
Af: Else Høytrup.
- 63/83 "CREATING ENERGY FUTURES: A SHORT GUIDE TO ENERGY PLANNING".
ENERGY SERIES NO. 8.
Af: David Crossley og Bent Sørensen.
-
- 64/83 "VON MATEMATIK UND KRIEG".
Af: Bernhelm Booss og Jens Høytrup.
- 65/83 "ANVENDT MATEMATIK - TEORI ELLER PRAKSIS".
Projektrapport af: Per Hedegård Andersen, Kirsten Habekost, Carsten Holst-Jensen, Annelise von Moos, Else Marie Pedersen og Erling Møller Pedersen.
Vejledere: Bernhelm Booss og Klaus Grünbaum.
- 66/83 "MATEMATISKE MODELLER FOR PERIODISK SELEKTION I ESCHERICHIA COLI".
Projektrapport af: Hanne Lisbet Andersen, Ole Richard Jensen og Klavs Frisdahl.
Vejledere: Jørgen Larsen og Anders Hede Madsen.
- 67/83 "ELEPSOIDE METODEN - EN NY METODE TIL LINEÆR PROGRAMMERING?".
Projektrapport af: Lone Billmann og Lars Boye.
Vejleder: Mogens Brun Heefelt.
- 68/83 "STOKASTISKE MODELLER I POPULATIONSGENETIK" - til kritikken af teoriladede modeller.
Projektrapport af: Lise Odgård Gade, Susanne Hansen, Michael Hviid og Frank Mølgaard Olsen.
Vejleder: Jørgen Larsen.

- 69/83 "ELEVFORUDSÆTNINGER I FYSIK"
- en test i l.g med kommentarer.
Af: Albert C. Paulsen.
- 70/83 "INDLÆRINGS - OG FORMIDLINGSPROBLEMER I MATEMATIK PÅ VOKSENUNDERVISNINGSNIVEAU".
Projektrapport af: Hanne Lisbet Andersen, Torben J. Andreasen, Svend Åge Houmann, Helle Glerup Jensen, Keld Fl. Nielsen, Lene Vagn Rasmussen.
Vejleder: Klaus Grünbaum og Anders Hede Madsen.
- 71/83 "PIGER OG FYSIK"
- et problem og en udfordring for skolen?
Af: Karin Beyer, Sussanne Blegaa, Birthe Olsen, Jette Reich og Mette Vedelsby.
- 72/83 "VERDEN IFVLGE PEIRCE" - to metafysiske essays, om og af C.S Peirce.
Af: Peder Voetmann Christiansen.
- 73/83 ""EN ENERGIANALYSE AF LANDBRUG"
- økologisk contra traditionelt.
ENERGY SERIES NO. 9
Specialeopgave i fysik af: Bent Hove Jensen.
Vejleder: Bent Sørensen.
-
- 74/84 "MINIATURISERING AF MIKROELEKTRONIK" - om videnskabeliggjort teknologi og nytten af at lære fysik.
Projektrapport af: Bodil Harder og Linda Szkotak Jensen.
Vejledere: Jens Højgaard Jensen og Bent C. Jørgensen.
- 75/84 "MATEMATIKUNDERVISNINGEN I FREMTIDENS GYMNASIUM"
- Case: Lineær programmering.
Projektrapport af: Morten Blomhøj, Klavs Frisdahl og Frank Mølgaard Olsen.
Vejledere: Mogens Brun Heefelt og Jens Bjørneboe.
- 76/84 "KERNEKRAFT I DANMARK?" - Et høringssvar indkaldt af miljøministeriet, med kritik af miljøstyrelsens rapporter af 15. marts 1984.
ENERGY SERIES No. 10
Af: Niels Boye Olsen og Bent Sørensen.
- 77/84 "POLITISKE INDEKS - FUP ELLER FAKTA?"
Opinionsundersøgelser belyst ved statistiske modeller.
Projektrapport af: Svend Åge Houmann, Keld Nielsen og Susanne Stender.
Vejledere: Jørgen Larsen og Jens Bjørneboe.
- 78/84 "JÆVNSTRØMSLEDNINGSEVNE OG GITTERSTRUKTUR I AMORFT GERMANIUM".
Specialrapport af: Hans Hedal, Frank C. Ludvigsen og Finn C. Physant.
Vejleder: Niels Boye Olsen.
- 79/84 "MATEMATIK OG ALMENDANNELSE".
Projektrapport af: Henrik Coster, Mikael Wennerberg Johansen, Povl Kattler, Birgitte Lydholm og Morten Overgaard Nielsen.
Vejleder: Bernhelm Booss.
- 80/84 "KURSUSMATERIALE TIL MATEMATIK B".
Af: Mogens Brun Heefelt.
- 81/84 "FREKVENSafhængig LEDNINGSEVNE I AMORFT GERMANIUM".
Specialrapport af: Jørgen Wind Petersen og Jan Christensen.
Vejleder: Niels Boye Olsen.
- 82/84 "MATEMATIK - OG FYSIKUNDERVISNINGEN I DET AUTOMATISEREDE SAMFUND".
Rapport fra et seminar afholdt i Hvidovre 25-27 april 1983.
Red.: Jens Højgaard Jensen, Bent C. Jørgensen og Mogens Niss.
- 83/84 "ON THE QUANTIFICATION OF SECURITY":
PEACE RESEARCH SERIES NO. 1
Af: Bent Sørensen
nr. 83 er p.t. udgået
- 84/84 "NOGLE ARTIKLER OM MATEMATIK, FYSIK OG ALMENDANNELSE".
Af: Jens Højgaard Jensen, Mogens Niss m. fl.
- 85/84 "CENTRIFUGALREGULATORER OG MATEMATIK".
Specialrapport af: Per Hedegård Andersen, Carsten Holst-Jensen, Else Marie Pedersen og Erling Møller Pedersen.
Vejleder: Stig Andur Pedersen.
- 86/84 "SECURITY IMPLICATIONS OF ALTERNATIVE DEFENSE OPTIONS FOR WESTERN EUROPE".
PEACE RESEARCH SERIES NO. 2
Af: Bent Sørensen.
- 87/84 "A SIMPLE MODEL OF AC HOPPING CONDUCTIVITY IN DISORDERED SOLIDS".
Af: Jeppe C. Dyre.
- 88/84 "RISE, FALL AND RESURRECTION OF INFINITESIMALS".
Af: Detlef Laugwitz.
- 89/84 "FJERNVARMEOPTIMERING".
Af: Bjarne Lillethorup og Jacob Mørch Pedersen.
-
- 90/84 "ENERGI I L.G - EN TEORI FOR TILRETTELÆGGELSE".
Af: Albert Chr. Paulsen.
-
- 91/85 "KVANTETEORI FOR GYMNASIET".
1. Lærervejledning
Projektrapport af: Biger Lundgren, Henning Sten Hansen og John Johansson.
Vejleder: Torsten Meyer.
- 92/85 "KVANTETEORI FOR GYMNASIET".
2. Materiale
Projektrapport af: Biger Lundgren, Henning Sten Hansen og John Johansson.
Vejleder: Torsten Meyer.
- 93/85 "THE SEMIOTICS OF QUANTUM - NON - LOCALITY".
Af: Peder Voetmann Christiansen.
- 94/85 "TREENIGHEDEN BOURBAKI - generalen, matematikeren og ånden".
Projektrapport af: Morten Blomhøj, Klavs Frisdahl og Frank M. Olsen.
Vejleder: Mogens Niss.
- 95/85 "AN ALTERNATIV DEFENSE PLAN FOR WESTERN EUROPE".
PEACE RESEARCH SERIES NO. 3
Af: Bent Sørensen
- 96/85 "ASPEKTER VED KRAFTVARMEFORSYNING".
Af: Bjarne Lillethorup.
Vejleder: Bent Sørensen.
- 97/85 "ON THE PHYSICS OF A.C. HOPPING CONDUCTIVITY".
Af: Jeppe C. Dyre.
- 98/85 "VALGMULIGHEDER I INFORMATIONSDEREN".
Af: Bent Sørensen.
- 99/85 "Der er langt fra Q til R".
Projektrapport af: Niels Jørgensen og Mikael Klintorp.
Vejleder: Stig Andur Pedersen.
- 100/85 "TALSYSTEMETS OPBYGNING".
Af: Mogens Niss.
- 101/85 "EXTENDED MOMENTUM THEORY FOR WINDMILLS IN PERIURBATIVE FORM".
Af: Ganesh Sengupta.
- 102/85 OPSTILLING OG ANALYSE AF MATEMATISKE MODELLER, BELYST VED MODELLER OVER KØERS FODEROPTAGELSE OG - OMSÆTNING".
Projektrapport af: Lis Eilertzen, Kirsten Habekost, Lill Røn og Susanne Stender.
Vejleder: Klaus Grünbaum.

- 103/85 "ØDSLE KOLDKRIGERE OG VIDENSKABENS LYSE IDEER".
 Projekt rapport af: Niels Ole Dam og Kurt Jensen.
 Vejleder: Bent Sørensen.
- 104/85 "ANALOCREGNEMASKINEN OG LORENZLIGNINGER".
 Af: Jens Jæger.
- 105/85 "THE FREQUENCY DEPENDENCE OF THE SPECIFIC HEAT OF THE
 GLASS TRANSITION".
 Af: Tage Christensen.
- "A SIMPLE MODEL OF AC HOPPING CONDUCTIVITY".
 Af: Jeppe C. Dyre.
 Contributions to the Third International Conference
 on the Structure of Non - Crystalline Materials held
 in Grenoble July 1985.
- 106/85 "QUANTUM THEORY OF EXTENDED PARTICLES".
 Af: Bent Sørensen.
- 107/85 "EN MYG GØR INGEN EPIDEMI",
 - flodblindhed som eksempel på matematisk modelle-
 ring af et epidemiologisk problem.
 Projekt rapport af: Per Hedegård Andersen, Lars Boye,
 Carsten Holst Jensen, Else Marie Pedersen og Erling
 Møller Pedersen.
 Vejleder: Jesper Larsen.
- 108/85 "APPLICATIONS AND MODELLING IN THE MATHEMATICS CUR-
 RICULUM" - state and trends -
 Af: Mogens Niss.
- 109/85 "COX I STUDIETIDEN" - Cox's regressionsmodel anvendt på
 studenteroplysninger fra RUC.
 Projekt rapport af: Mikael Wennerberg Johansen, Poul Kat-
 ler og Torben J. Andreasen.
 Vejleder: Jørgen Larsen.
- 110/85 "PLANNING FOR SECURITY".
 Af: Bent Sørensen
- 111/85 "JORDEN RUNDT PÅ FLADE KORT".
 Projekt rapport af: Birgit Andresen, Beatriz Quinones
 og Jimmy Staal.
 Vejleder: Mogens Niss.
- 112/85 "VIDENSKABELIGGØRELSE AF DANSK TEKNOLOGISK INNOVATION
 FREM TIL 1950 - BELYST VED EKSEMPLER".
 Projekt rapport af: Erik Odgaard Gade, Hans Hedal,
 Frank C. Ludvigsen, Annette Post Nielsen og Finn
 Physant.
 Vejleder: Claus Bryld og Bent C. Jørgensen.
- 113/85 "DESUSPENSION OF SPLITTING ELLIPTIC SYMBOLS II".
 Af: Bernhard Booss og Krzysztof Wojciechowski.
- 114/85 "ANVENDELSE AF GRAFISKE METODER TIL ANALYSE
 AF KONFIGURATIONSTABELLER".
 Projekt rapport af: Lone Billmann, Ole R. Jensen
 og Anne-Lise von Moos.
 Vejleder: Jørgen Larsen.
- 115/85 "MATEMATIKKENS UDVIKLING OP TIL RENÆSSANCEN".
 Af: Mogens Niss.
- 116/85 "A PHENOMENOLOGICAL MODEL FOR THE MEYER-
 NELDEL RULE".
 Af: Jeppe C. Dyre.
- 117/85 "KRAFT & FJERNVARMOPTIMERING"
 Af: Jacob Mørch Pedersen.
 Vejleder: Bent Sørensen
- 118/85 "TILFÆLDIGHEDEN OG NØDVENDIGHEDEN IFØLGE
 PEIRCE OG FYSIKKEN".
 Af: Peder Voetmann Christiansen
- 119/86 "DET ER Ganske vist - - EUKLIDS FEMTE POSTULAT
 KUNNE NOK SKABE RØRE I ANDEDÅMMEN".
 Af: Iben Maj Christiansen
 Vejleder: Mogens Niss.
- 120/86 "ET ANTAL STATISTISKE STANDARDMODELLER".
 Af: Jørgen Larsen
- 121/86 "SIMULATION I KONTINUERT TID".
 Af: Peder Voetmann Christiansen.
- 122/86 "ON THE MECHANISM OF GLASS IONIC CONDUCTIVITY".
 Af: Jeppe C. Dyre.
- 123/86 "GYMNASIEFYSIKKEN OG DEN STORE VERDEN".
 Fysiklærerforeningen, IMFUFA, RUC.
- 124/86 "OPGAVESAMLING I MATEMATIK".
 Samtlige opgaver stillet i tiden 1974-jan. 1986.
- 125/86 "UVBY, 8 - systemet - en effektiv fotometrisk spektral-
 klassifikation af B-, A- og F-stjerner".
 Projekt rapport af: Birger Lundgren.
- 126/86 "OM UDVIKLINGEN AF DEN SPECIELLE RELATIVITETSTEORI".
 Projekt rapport af: Lise Odgaard & Linda Szkotak Jensen
 Vejledere: Karin Beyer & Stig Andur Pedersen.
- 127/86 "GALOIS' BIDRAG TIL UDVIKLINGEN AF DEN ABSTRAKTE
 ALGEBRA".
 Projekt rapport af: Pernille Sand, Heine Larsen &
 Lars Frandsen.
 Vejleder: Mogens Niss.
- 128/86 "SMÅKRYB" - en ikke-standard analyse.
 Projekt rapport af: Niels Jørgensen & Mikael Klintorp.
 Vejleder: Jeppe Dyre.
- 129/86 "PHYSICS IN SOCIETY"
 Lecture Notes 1983 (1986)
 Af: Bent Sørensen
- 130/86 "Studies in Wind Power"
 Af: Bent Sørensen
- 131/86 "FYSIK OG SAMFUND" - Et integreret fysik/historie-
 projekt om naturanskuelsens historiske udvikling
 og dens samfundsmæssige betingethed.
 Projekt rapport af: Jakob Heckscher, Søren Brønd,
 Andy Wierød.
 Vejledere: Jens Høyrup, Jørgen Vogelius,
 Jens Højgaard Jensen.
- 132/86 "FYSIK OG DANNEELSE"
 Projekt rapport af: Søren Brønd, Andy Wierød.
 Vejledere: Karin Beyer, Jørgen Vogelius.
- 133/86 "CHERNOBYL ACCIDENT: ASSESSING THE DATA.
 ENERGY SERIES NO. 15.
 Af: Bent Sørensen.
-
- 134/87 "THE D.C. AND THE A.C. ELECTRICAL TRANSPORT IN AsSeTe SYSTEM"
 Authors: M.B.El-Den, N.B.Olsen, Ib Høst Pedersen,
 Petr Visčor
- 135/87 "INTUITIONISTISK MATEMATIKS METODER OG ERKENDELSES-
 TEORETISKE FORUDSÆTNINGER"
 MATEMATIKSPECIALE: Claus Larsen
 Vejledere: Anton Jensen og Stig Andur Pedersen
- 136/87 "Mystisk og naturlig filosofi: En skitse af kristendommens
 første og andet møde med græsk filosofi"
 Projekt rapport af Frank Colding Ludvigsen
 Vejledere: Historie: Ib Thiersen
 Fysik: Jens Højgaard Jensen
- 137/87 "HOPMODELLER FOR ELEKTRISK LEDNING I UORDNEDE
 FASTE STOFFER" - Resume af licentiatforhandling
 Af: Jeppe Dyre
 Vejledere: Niels Boye Olsen og
 Peder Voetmann Christiansen.

- 138/87 "JOSEPHSON EFFECT AND CIRCLE MAP."
Paper presented at The International Workshop on Teaching Nonlinear Phenomena at Universities and Schools, "Chaos in Education". Balaton, Hungary, 26 April-2 May 1987.
By: Peder Voetmann Christiansen
- 139/87 "Machbarkeit nichtbeherrschbarer Technik durch Fortschritte in der Erkennbarkeit der Natur"
Af: Bernhelm Booss-Bavnbek
Martin Bohle-Carbonell
- 140/87 "ON THE TOPOLOGY OF SPACES OF HOLOMORPHIC MAPS"
By: Jens Gravesen
- 141/87 "RADIOMETERS UDVIKLING AF BLODGASAPPARATUR - ET TEKNOLOGIHISTORISK PROJEKT"
Projektrapport af Finn C. Physant
Vejleder: Ib Thiersen
- 142/87 "The Calderón Projektor for Operators With Splitting Elliptic Symbols"
by: Bernhelm Booss-Bavnbek og
Krzysztof P. Wojciechowski
- 143/87 "Kursusmateriale til Matematik på NAT-BAS"
af: Mogens Brun Heefelt
- 144/87 "Context and Non-Locality - A Peircean Approach"
Paper presented at the Symposium on the Foundations of Modern Physics The Copenhagen Interpretation 60 Years after the Como Lecture. Joensuu, Finland, 6 - 8 august 1987.
By: Peder Voetmann Christiansen
- 145/87 "AIMS AND SCOPE OF APPLICATIONS AND MODELLING IN MATHEMATICS CURRICULA"
Manuscript of a plenary lecture delivered at ICMTA 3, Kassel, FRG 8.-11.9.1987
By: Mogens Niss
- 146/87 "BESTEMMELSE AF BULKRESISTIVITETEN I SILICIUM"
- en ny frekvensbaseret målemetode.
Fysikspeciale af Jan Vedde
Vejledere: Niels Boye Olsen & Petr Višćor
- 147/87 "Rapport om BIS på NAT-BAS"
redigeret af: Mogens Brun Heefelt
- 148/87 "Naturvidenskabsundervisning med Samfundsperspektiv"
af: Peter Colding-Jørgensen DLH
Albert Chr. Paulsen
- 149/87 "In-Situ Measurements of the density of amorphous germanium prepared in ultra high vacuum"
by: Petr Višćor
- 150/87 "Structure and the Existence of the first sharp diffraction peak in amorphous germanium prepared in UHV and measured in-situ"
by: Petr Višćor
- 151/87 "DYNAMISK PROGRAMMERING"
Matematikprojekt af:
Birgit Andresen, Keld Nielsen og Jimmy Staal
Vejleder: Mogens Niss
- 152/87 "PSEUDO-DIFFERENTIAL PROJECTIONS AND THE TOPOLOGY OF CERTAIN SPACES OF ELLIPTIC BOUNDARY VALUE PROBLEMS"
by: Bernhelm Booss-Bavnbek
Krzysztof P. Wojciechowski
- 153/87 "HALVLEDERTEKNOLOGIENS UDVIKLING MELLEM MILITÆRE OG CIVILE KRÆFTER"
Et eksempel på humanistisk teknologihistorie
Historiespeciale
Af: Hans Hedal
Vejleder: Ib Thiersen
- 154/87 "MASTER EQUATION APPROACH TO VISCOUS LIQUIDS AND THE GLASS TRANSITION"
By: Jeppe Dyre
- 155/87 "A NOTE ON THE ACTION OF THE POISSON SOLUTION OPERATOR TO THE DIRICHLET PROBLEM FOR A FORMALLY SELFADJOINT DIFFERENTIAL OPERATOR"
by: Michael Pedersen
- 156/87 "THE RANDOM FREE ENERGY BARRIER MODEL FOR AC CONDUCTION IN DISORDERED SOLIDS"
by: Jeppe C. Dyre
- 157/87 "STABILIZATION OF PARTIAL DIFFERENTIAL EQUATIONS BY FINITE DIMENSIONAL BOUNDARY FEEDBACK CONTROL: A pseudo-differential approach."
by: Michael Pedersen
- 158/87 "UNIFIED FORMALISM FOR EXCESS CURRENT NOISE IN RANDOM WALK MODELS"
by: Jeppe Dyre
- 159/87 "STUDIES IN SOLAR ENERGY"
by: Bent Sørensen
- 160/87 "LOOP GROUPS AND INSTANTONS IN DIMENSION TWO"
by: Jens Gravesen
- 161/87 "PSEUDO-DIFFERENTIAL PERTURBATIONS AND STABILIZATION OF DISTRIBUTED PARAMETER SYSTEMS: Dirichlet feedback control problems"
by: Michael Pedersen
- 162/87 "PIGER & FYSIK - OG MEGE' MERE"
AF: Karin Beyer, Sussanne Blegaa, Birthe Olsen, Jette Reich, Mette Vedelsby
- 163/87 "EN MATEMATISK MODEL TIL BESTEMMELSE AF PERMEABILITETEN FOR BLOD-NETHINDE-BARRIEREN"
Af: Finn Langberg, Michael Jarden, Lars Frellesen
Vejleder: Jesper Larsen
- 164/87 "Vurdering af matematisk teknologi
Technology Assessment
Technikfolgenabschätzung"
Af: Bernhelm Booss-Bavnbek, Glen Pate med
Martin Bohle-Carbonell og Jens Højgaard Jensen
- 165/87 "COMPLEX STRUCTURES IN THE NASH-MOSER CATEGORY"
by: Jens Gravesen

- 166/88 "Grundbegreber i Sandsynlighedsregningen"
Af: Jørgen Larsen
- 167a/88 "BASISSTATISTIK 1. Diskrete modeller"
Af: Jørgen Larsen
- 167b/88 "BASISSTATISTIK 2. Kontinuerte modeller"
Af: Jørgen Larsen
- 168/88 "OVERFLADEN AF PLANETEN MARS"
Laboratorie-simulering og MARS-analoger undersøgt ved Mössbauerspektroskopi.
Fysikspeciale af:
Birger Lundgren
Vejleder: Jens Martin Knudsen
Fys.Lab./HCØ
- 169/88 "CHARLES S. PEIRCE: MURSTEN OG MØRTEL TIL EN METAFYSIK."
Fem artikler fra tidsskriftet "The Monist" 1891-93.
Introduktion og oversættelse:
Peder Voetmann Christiansen
- 170/88 "OPGAVESAMLING I MATEMATIK"
Samtlige opgaver stillet i tiden 1974 - juni 1988
- 171/88 "The Dirac Equation with Light-Cone Data"
af: Johnny Tom Ottesen
- 172/88 "FYSIK OG VIRKELIGHED"
Kvantemekanikkens grundlagsproblem i gymnasiet.
Fysikprojekt af:
Erik Lund og Kurt Jensen
Vejledere: Albert Chr. Paulsen og Peder Voetmann Christiansen
-
- 173/89 "NUMERISKE ALGORITMER"
af: Mogens Brun Heefelt
- 174/89 "GRAFISK FREMSTILLING AF FRAKTALER OG KAOS"
af: Peder Voetmann Christiansen
- 175/89 "AN ELEMENTARY ANALYSIS OF THE TIME DEPENDENT SPECTRUM OF THE NON-STATONARY SOLUTION TO THE OPERATOR RICCATI EQUATION"
af: Michael Pedersen
- 176/89 "A MAXIMUM ENTROPY ANSATZ FOR NONLINEAR RESPONSE THEORY"
af: Jeppe Dyre
- 177/89 "HVAD SKAL ADAM STÅ MODEL TIL"
af: Morten Andersen, Ulla Engström, Thomas Gravesen, Nanna Lund, Pia Madsen, Dina Rawat, Peter Torstensen
Vejleder: Mogens Brun Heefelt
- 178/89 "BIOSYNTESEN AF PENICILLIN - en matematisk model"
af: Ulla Eghave Rasmussen, Hans Oxvang Mortensen, Michael Jarden
vejleder i matematik: Jesper Larsen
biologi: Erling Lauridsen
- 179a/89 "LÆRERVEJLEDNING M.M. til et eksperimentelt forløb om kaos"
af: Andy Wierød, Søren Brønd og Jimmy Staal
Vejledere: Peder Voetmann Christiansen
Karin Beyer
- 179b/89 "ELEVHÆFTE: Noter til et eksperimentelt kursus om kaos"
af: Andy Wierød, Søren Brønd og Jimmy Staal
Vejledere: Peder Voetmann Christiansen
Karin Beyer
- 180/89 "KAOS I FYSISKE SYSTEMER eksemplificeret ved torsions- og dobbeltpendul".
af: Andy Wierød, Søren Brønd og Jimmy Staal
Vejleder: Peder Voetmann Christiansen
- 181/89 "A ZERO-PARAMETER CONSTITUTIVE RELATION FOR PURE SHEAR VISCOELASTICITY"
by: Jeppe Dyre
- 183/89 "MATHEMATICAL PROBLEM SOLVING, MODELLING. APPLICATIONS AND LINKS TO OTHER SUBJECTS - State. trends and issues in mathematics instruction
by: WERNER BLUM, Kassel (FRG) og MOGENS NISS, Roskilde (Denmark)
- 184/89 "En metode til bestemmelse af den frekvensafhængige varmfylde af en underafkølet væske ved glasovergangen"
af: Tage Emil Christensen
-
- 185/90 "EN NÆSTEN PERIODISK HISTORIE"
Et matematisk projekt
af: Steen Grode og Thomas Jessen
Vejleder: Jacob Jacobsen
- 186/90 "RITUAL OG RATIONALITET i videnskabers udvikling"
redigeret af Arne Jakobsen og Stig Andur Pedersen
- 187/90 "RSA - et kryptografisk system"
af: Annemette Sofie Olufsen, Lars Frellesen og Ole Møller Nielsen
Vejledere: Michael Pedersen og Finn Munk
- 188/90 "FERMICONDENSATION - AN ALMOST IDEAL GLASS TRANSITION"
by: Jeppe Dyre
- 189/90 "DATAMATER I MATEMATIKUNDERVISNINGEN PÅ GYMNASIET OG HØJERE LÆREANSTALTER
af: Finn Langberg

- 190/90 "FIVE REQUIREMENTS FOR AN APPROXIMATE NONLINEAR RESPONSE THEORY"
by: Jeppe Dyre
- 191/90 "MOORE COHOMOLOGY, PRINCIPAL BUNDLES AND ACTIONS OF GROUPS ON C^* -ALGEBRAS"
by: Iain Raeburn and Dana P. Williams
- 192/90 "Age-dependent host mortality in the dynamics of endemic infectious diseases and SIR-models of the epidemiology and natural selection of co-circulating influenza virus with partial cross-immunity"
by: Viggo Andreasen
- 193/90 "Causal and Diagnostic Reasoning"
by: Stig Andur Pedersen
- 194a/90 "DETERMINISTISK KAOS"
Projektrapport af : Frank Olsen
- 194b/90 "DETERMINISTISK KAOS"
Kørselsrapport
Projektrapport af: Frank Olsen
- 195/90 "STADIER PÅ PARADIGMETS VEJ"
Et projekt om den videnskabelige udvikling der førte til dannelse af kvantemekanikken.
Projektrapport for 1. modul på fysikuddannelsen, skrevet af:
Anja Boisen, Thomas Hougård, Anders Gørm Larsen, Nicolai Ryge.
Vejleder: Peder Voetmann Christiansen
- 196/90 "ER KAOS NØDVENDIGT?"
- en projektrapport om kaos' paradigmatiske status i fysikken.
af: Johannes K. Nielsen, Jimmy Staal og Peter Bøggild
Vejleder: Peder Voetmann Christiansen
- 197/90 "Kontrafaktiske konditioner i HOL"
af: Jesper Voetmann, Hans Oxvang Mortensen og Aleksander Høst-Madsen
Vejleder: Stig Andur Pedersen
- 198/90 "Metal-Isolator-Metal systemer"
Speciale
af: Frank Olsen
- 199/90 "SPREDT FÆGTNING" Artikelsamling
af: Jens Højgaard Jensen
- 200/90 "LINEÆR ALGEBRA OG ANALYSE"
Noter til den naturvidenskabelige basisuddannelse.
af: Mogens Niss
- 201/90 "Undersøgelse af atomare korrelationer i amorfe stoffer ved røntgendiffraction"
af: Karen Birkelund og Klaus Dahl Jensen
Vejledere: Petr Višcor, Ole Bakander
- 202/90 "TEGN OG KVANTER"
Foredrag og artikler, 1971-90.
af: Peder Voetmann Christiansen
- 203/90 "OPGAVESAMLING I MATEMATIK" 1974-1990
 afløser tekst 170/88
-
- 204/91 "ERKENDELSE OG KVANTEMEKANIK"
et Breddemodul Fysik Projekt
af: Thomas Jessen
Vejleder: Petr Višcor
- 205/91 "PEIRCE'S LOGIC OF VAGUENESS"
by: Claudine Engel-Tiercelin
Department of Philosophy
Université de Paris-1
(Panthéon-Sorbonne)
- 206a+b/91 "GERMANIUMBEEAMANALYSE SAMT A - GE TYNDFILMS ELEKTRISKE EGENSKABER"
Eksperimentelt Fysikspeciale
af: Jeanne Linda Mortensen og Annette Post Nielsen
Vejleder: Petr Višcor
- 207/91 "SOME REMARKS ON AC CONDUCTION IN DISORDERED SOLIDS"
by: Jeppe C. Dyre
- 208/91 "LANGEVIN MODELS FOR SHEAR STRESS FLUCTUATIONS IN FLOWS OF VISCO-ELASTIC LIQUIDS"
by: Jeppe C. Dyre
- 209/91 "LORENZ GUIDE" Kompendium til den danske fysiker Ludvig Lorenz, 1829-91.
af: Helge Kragh
- 210/91 "Global Dimension, Tower of Algebras, and Jones Index of Split Seperable Subalgebras with Unitality Condition.
by: Lars Kadison
- 211/91 "J SANDHEDENS TJENESTE"
- historien bag teorien for de komplekse tal.
af: Line Arleth, Charlotte Gjerrild, Jane Hansen, Linda Kyndlev, Anne Charlotte Nilsson, Kamilla Tulinius.
Vejledere: Jesper Larsen og Bernhelm Booss-Bavnbek
- 212/91 "Cyclic Homology of Triangular Matrix Algebras"
by: Lars Kadison
- 213/91 "Disease-induced natural selection in a diploid host
by: Viggo Andreasen and Freddy B. Christiansen

214|91 "Halløj i æteren" - om
elektromagnetisme. Oplæg
til undervisningsmateriale
i gymnasiet.
Af: Nils Kruse, Peter Gastrup,
Kristian Hoppe, Jeppe Guldager
Vejledere: Petr Viscor, Hans Hedal

215|91 "Physics and Technology of Metal-
Insulator-Metal thin film structures
used as planar electron emitters
by: A.Delong, M.Drsticka, K.Hladil,
V.Kolarik, F.Olsen, P.Pavelka and
Petr Viscor.

216|91 "Kvantemekanik på PC'eren"
af: Thomas Jessen

217/92 "Two papers on APPLICATIONS AND MODELLING
IN THE MATHEMATICS CURRICULUM"
by: Mogens Niss

218/92 "A Three-Square Theorem"
by: Lars Kadison

219/92 "RUPNOK - stationær strømning i elastiske rør"
af: Anja Boisen, Karen Birkelund, Mette Olufsen
Vejleder: Jesper Larsen

220/92 "Automatisk diagnosticering i digitale kredsløb"
af: Bjørn Christensen, Ole Møller Nielsen
Vejleder: Stig Andur Pedersen

221/92 "A BUNDLE VALUED RADON TRANSFORM, WITH
APPLICATIONS TO INVARIANT WAVE EQUATIONS"
by: Thomas P. Branson, Gestur Olafsson and
Henrik Schlichtkrull

222/92 On the Representations of some Infinite Dimensional
Groups and Algebras Related to Quantum Physics
by: Johnny T. Ottesen

223/92 THE FUNCTIONAL DETERMINANT
by: Thomas P. Branson

224/92 "UNIVERSAL AC CONDUCTIVITY OF NON-METALLIC SOLIDS AT
LOW TEMPERATURES"
by: Jeppe C. Dyre

225/92 "HATMODELLEN" Impedansspektroskopi i ultrarent
en-krystallinsk silicium
af: Anja Boisen, Anders Gorm Larsen, Jesper Varmer,
Johannes K. Nielsen, Kit R. Hansen, Peter Bøggild
og Thomas Hougaard
Vejleder: Petr Viscor

226/92 "METHODS AND MODELS FOR ESTIMATING THE GLOBAL
CIRCULATION OF SELECTED EMISSIONS FROM ENERGY
CONVECTION"
by: Bent Sørensen