ASSESSING, COMPARING AND MANAGING RISKS FROM ENERGY SUPPLY STRATEGIES ON A REGIONAL BASIS — A CASE STUDY FOR BADEN-WÜRTTEMBERG

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Abstract

In this paper a regional case study within the envisaged joint inter-agency project on 'Assessing and Managing Health and Environmental Risks from Energy and Other Complex Industrial Systems' is proposed for Baden-Württemberg. Baden-Württemberg is a state located in the southwest of the Federal Republic of Germany, sharing about 15.1 % of it's population and about 14.4 % of it's area. Around 15.7 % of the German Gross Domestic Product are obtained in Baden-Württemberg.

The Institut für Kernenergetik und Energiesysteme (IKE) has performed a number of studies dealing with the evaluation and reduction of emissions and risks of energy systems. So, a very detailed data base is available which can serve as a suitable basis for further investigations related to risk management. Consequently this paper consists of three main sections with emphasis on:

- description of research projects carried out by IKE in the field of energy systems and risk evaluations,
- description of aims and procedures of an ongoing study on restructuring measures for the energy system in Baden-Württemberg and,
- the proposal for a regional case study on risk management in the energy field for Baden-Württemberg.

1 Introduction

The IKE has performed a number of research activities dealing with environmental impacts and public risks from conventional and nuclear energy. These activities comprised besides others:

- siting of power plants,
- ecological impacts of roads,
- environmental control of air pollutants,
- evaluation of hypothetical accidents in nuclear power plants,
- evaluations for the licensing procedure of nuclear power stations.

In order to highlight the general background and experiences available the following studies will be described here in some more detail:

- 'Costs and Effectiveness of Environmental Control of SO_2 and NO_x and its Impact on the Energy Production Systems',

- 'Cost-Effectiveness Analyses of Measures and Strategies for the Reduction of SO_2- and NO_x-Emissions from Industrial Furnaces',

- 'Evaluation of Time-Dependent Emission Inventories on an 1 x 1 Kilometer Scale for Baden-WÜrttemberg', and

- 'Cost-Effectiveness of Risk Reduction by Engineered Safeguards in Biblis-B-Type Nuclear Power Reactor Systems'.

Thereafter, an assessment project on 'Restructing Measures for the Energy System in Baden-WÜrttemberg' which has most recently been started will be presented. Major parts of this project are felt to be closely related to the envisaged inter-agency project. It is strongly believed that the project could result in a most valuable basis for further more ambitious and more comprehensive assessments of important contributors to the overall risk and for risk management approaches.

Consequently, a proposal for a regional case study within the envisaged joint inter-agency project is made in the concluding section of this paper and a provisional framework for the implementation of the case study is given.

2 Research Project: "Costs and Effectiveness of Environmental Control of SO_2 and NO_x and its Impact on the Energy System"

This project comprised two studies on environmental control of SO_2 and NO_x, respectively. The studies have been carried out in 1983 and 1984. Their general background could be characterized as follows:

The observed damages to forests have increased very rapidly over the last years. In 1982 about 8 % of the total forest area in the Federal Republic of Germany was more or less badly affected. Since then, the damage has increased dramatically, as can be seen from Figure 1. A detailed damage survey carried out in 1983 indicated that the total area of forest affected had increased to 34 % and the figures for 1984 show that about half of all forest area is affected by this new widespread chronic damage. While the intensity of damage differs among tree species, fir, pine, spruce, beech and oak are particularly affected. In the case of fir, for example, the extend of the damage has increased to about

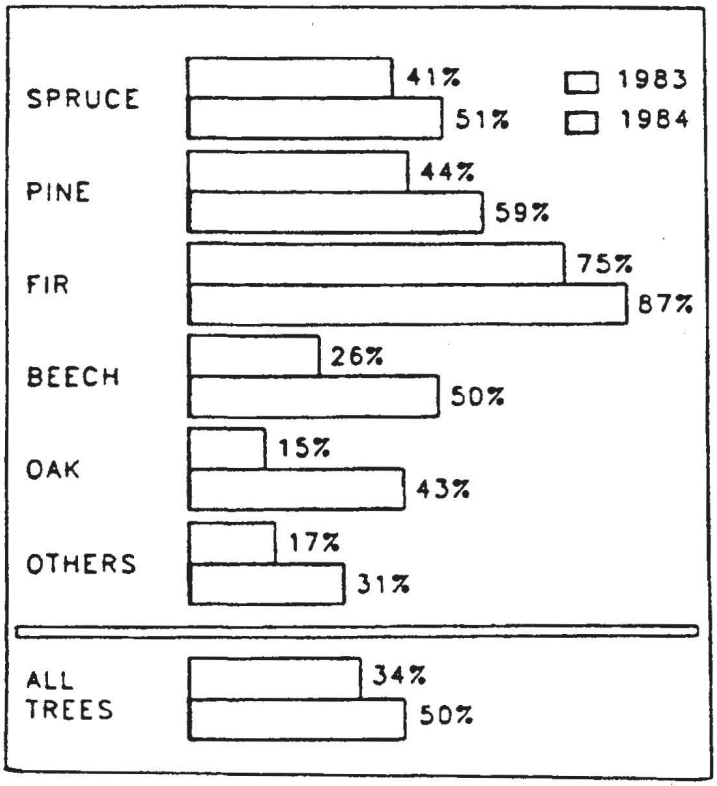

FIG.1. Damages to forests in the Federal Republic of Germany (1983-1984).

90 % of its total population. Most recent damage reports indicate that the intensity of damage has been stabilized at high levels.

Rational policy making related to acid rain or, more broadly speaking, to air quality control is particularly difficult because of the scientific uncertainties and different value judgements.

Within the following paragraphs it will be shortly described how and to what extent a 'cost-effectiveness-analysis' is able to support a rational decision making process under these circumstances, based on the experience and results of a real case.

In 1983/84 the state government of Baden-Württemberg set up two commissions to investigate an optimal control strategy to reduce SO_2- and No_x-emissions from public power plants, taking into account the rapidly increasing damages to the forest especially the 'Black Forest'. The commissions consisted of state government officials, representatives of the regional electric power companies and some scientists.

Approximately 33 % of the total SO_2-emissions and 20 % of the total NO_x- emissions in Baden-Württemberg emanate from public power plants. Furthermore, it is important to point out that it is estimated that about 50 % of the acidic depositions in Baden-Württemberg are attributable to emissions released outside Baden-Württemberg (in turn, about 50 % of the power plant emissions in Baden-Württemberg are 'exported').

To be able to quantify the costs of alternative emission control measures and strategies a 'reference scenario' has been set up, describing the development of electricity consumption, the production of the different power plants, their fuel input and resulting SO_2- and NO_x-emissions. Subsequently, starting from the reference scenario, the surplus costs and emissions avoided for every measure were calculated over the time horizon 1984 to 1995.

Fig. 2 shows the development of electricity supply in Baden-Württemberg, differentiated into energy sources in the reference scenario. Total electricity supply will increase from 43 TWh/a in 1980 to about 63 TWh/a in 1995.

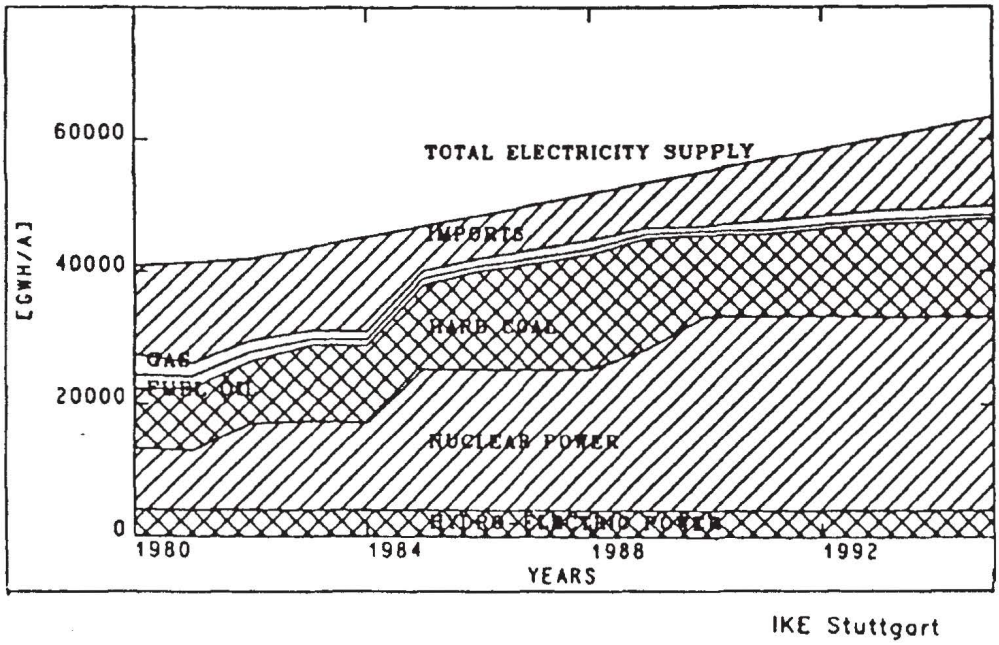

FIG.2. Electricity production of public power plants in Baden-Württemberg.

Also electricity production of nuclear plants will rise from currently 23 % to nearly 60 % of the total by 1995, growing electricity consumption requires increasing electricity generation from coal power plants.

A broad variety of technical as well as fuel and power-plant management measures were investigated. They included the use of low sulphur fuel, the extended use of natural gas, combustion modifications and different flue gas treatment technologies (to mention only a few).

Fig. 3 shows the development of SO_2-emissions from public power plants for different control strategies. The solid top line indicates the development of SO_2-emissions if no control measures are taken. In the long run the 'Ordiance of Large Firing Installation' (Großanlagenfeuerungsverordnung) will reduce SO_2-emissions

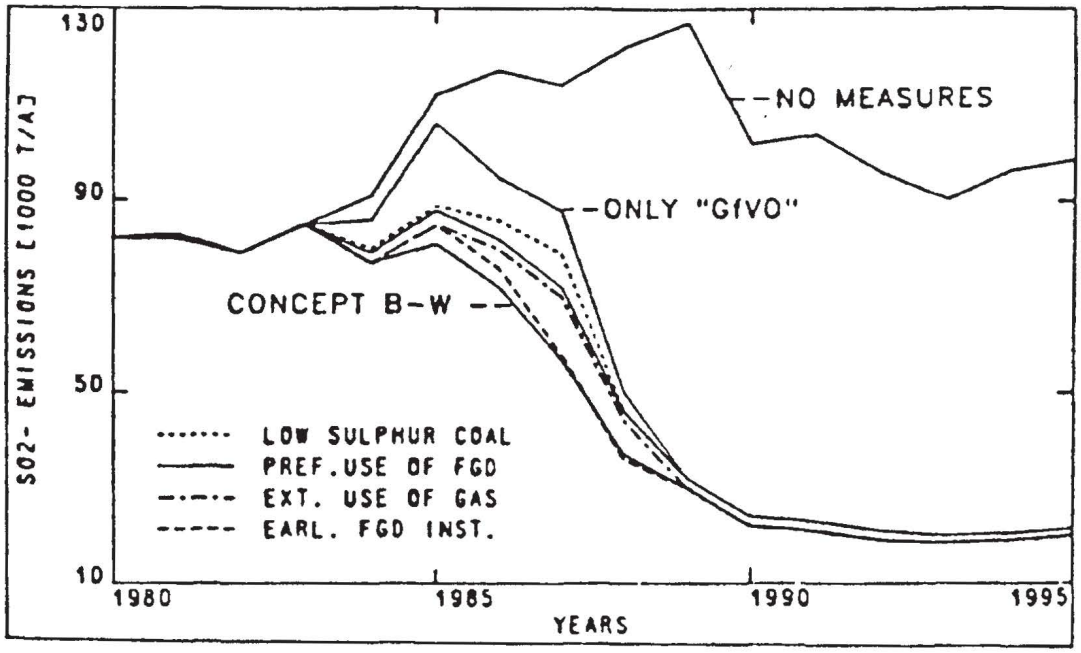

FIG.3. SO_2-emissions from public power plants.

to about 25 % of the 1984 level by the year 1990. It requires the implementation of flue gas scrubbers by 1988. In the short run, however, the emissions would increase by about 25 % and would reach todays level again not before 1987. Fig. 3 shows clearly that the increasing SO_2-emissions in the next years were the real issue. Therefore, more measures regarding power-plant- and fuel management have to be investigated and applied. All these measures presented in this figure will reduce the SO_2-emissions to appr. a level of 25 % in the period from 1985 to 1988, including the avoidance of the increase of emissions above the initial level in the years 1985 to 1987 (see Fig. 3). Fig. 4 provides a trade off curve between SO_2-emission control and the additional costs. It can be seen that the most effective measures A-D have a strong gradient. The uneffective measures have only a little respectively no decrease. In this figure it is clearly pointed out whether a measure is useful or not. It is a good way for the representation of results to the decision maker.

Nitrogen oxides were the second air pollutant for which a cost-effectiveness analysis as the basis for the formulation of a control strategy was carried out. NO_x-control techniques can be classified into two main groups: those based on the combustion modifications, and those based on the elimination of NO_x from flue gas.

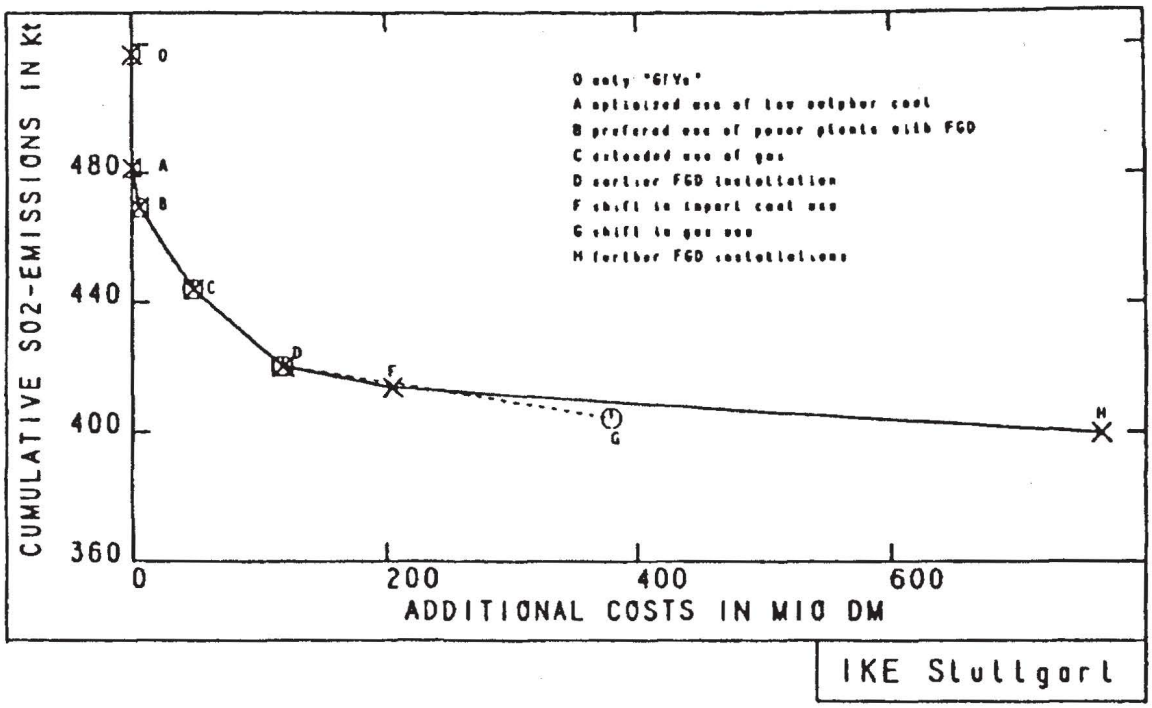

FIG.4. Trade-off between SO_2-emissions and additional costs.

Concerning flue-gas denitrification techniques, the selective catalytic reduction (SCR) process progressed rapidly, while other techniques are still in the stage of development or demonstration. The different NO_x-control measures were carefully examined regarding their technical applicability, their expected results in reduction rates and their overall costs. Fig. 5 shows the development of NO_x-emissions for different control strategies from public power plants in Baden-Württemberg. Without any control measures, NO_x-emissions would increase from 55 000 t/a to 67 000 t/a in 1988. Reductions thereafter are a result of an increased nuclear production and a higher share of modern boilers with dry ash extraction, having lower specific NO_x-emissions than boilers with liquid ash extraction.

Combustion modification measures will reduce NO_x-emissions in the short run by about 10 %. Further drastic reductions of the emission level will be achieved by the installation of flue-gas denitrification facilities. By the end of this decade NO_x-emission will drop below than 25 % of 1984's level by increased use of hard coal.

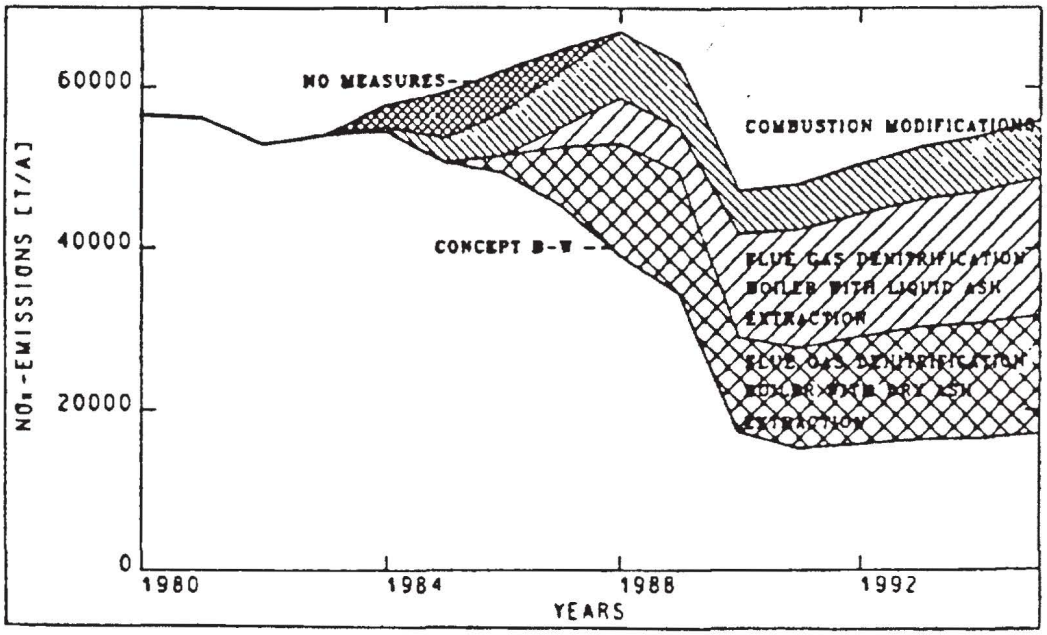

FIG.5. Reduction of NO_x-emissions by various measures.

Concerning the cost-effectiveness of the different NO_x-reduction measures, it should be noted that they form a broad range from less than 1 to as high as 8 DM per kg NO_x avoided (see Fig. 6). The cost-effectiveness of combustion modification is very attractive (< 1 DM/kg NO_x), but the strict emission standards (e.g. 200 mg/m³) cannot be met. The cost-effectiveness of flue gas denitrification depends to a great extend on the size of the plant, the boiler type and the load factor. In the case of Baden-Württemberg, they range from 3 to 8 DM/kg NO_x.

	[DM / kg NOx]
- COMBUSTION MODIFICATIONS	0 - 1
- FLUE-GAS DENITRIFICATION	3 - 8
- THREE-WAY CATALYTIC CONVERTER (NEW CARS)	6 - 8
- RETROFIT MEASURE FOR USED CARS	3 - 8

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FIG.6. Cost-effectiveness of NO_x reduction measures.

Both, the SO_2- and NO_x-control strategy as described above will of course have an impact on the electricity production costs. To realize the SO_2- and NO_x-control strategy (concept B-W) the electric utilities will have to invest 1.75 Billion DM (see Fig. 7). The annual operating costs of the flue gas treatment facilities will amount at about 480 Mio DM. The electricity generation cost of coal fired power plants will increase by an average of 3.7 Dpf/kWh_{el}, that is roughly 15 % of present electricity consumer prices. When this is related to the total electricity production, the average cost increase due to the control strategy will be about 1.1 Dpf/kWh_{el}.

Investments and Costs

Investments	[Mio DM]
desulphurisation plants	1000
denitrification plants	705-745
Annual costs	[Mio DM/a]
desulphurisation	300
denitrification	180
Average coal electricity production cost increase	[Dpfg/kWh]
desulphurisation	2.4
denitrification	1.3
Average electricity production cost increase	[Dpfg/kWh]
desulphurisation	0.7
denitrification	0.4

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FIG.7. Investments and costs.

3 Research Project: 'Cost-Effectiveness Analyses of Measures and Strategies for the Reduction of SO_2- and NO_x-Emissions from Industrial Furnaces'

The study described below is - in principal - an application of methodologies developed during the studies already mentioned above to all furnaces > 1 MW in Baden-Württemberg. It has been carried out within the frame of a comission set up by the prime ministry of Baden-WUrttemberg in 1984. The questions which had to be investigated by the project group have been:

- How will emissions of SO_2 and NO_x from industrial furnaces in Baden-WUrttemberg develop until the year 1995?

- Which measures for the reduction of these emissions are applicable?

- What are the costs of these control measures?

The overall aim was again to derive rational indications for methods to control and reduce air pollution by measures which are reasonable under ecological as well as economical aspects.
The most challenging requirement for this study was the necessity of compiling and specifically evaluating complete data concerning the furnaces and the emissions of the roughly 8000 industrial installations in Baden-Württemberg. Data available from official authorities within the region differed substantially, which caused all data to be refined and balanced systematically with obedience of existing regulations concerning the protection of personal data. Where necessary, new data collections have been performed in close cooperation with the industrial associations in Baden-Württemberg. According to this, all furnaces investigated have been grouped into three categories:

- Category 1: Furnaces which are subject to the Großfeuerungsanlagenverordnung (GFAVO) (in general plant larger 50 MW),

- Cateogry 2: Furnaces which are subject to the Technische Anleitung Luft - Issue 1986 (TA Luft 86) (in general plant between 1 - 50 MW), and

- Category 3: Furnaces which are not subject to a licensing procedure.

Based on this classification, investigations concentrated on the following areas:

- Establishment of the state of art and of costs of measures for the control of emissions from industrial furnaces and evaluation of the applicability of these measures to existing and new installations in Baden-Württemberg.

- Cost-effectiveness analyses of possible measures and strategies for the reduction of SO_2- and NO_x-emissions from industrial furnaces.

In order to analyse the effectiveness and costs of possible future measures up to the year 1995 a "reference scenario" was set up, describing expected fuel consumptions and industrial emissions. This assumed development of industrial emissions, which should not be misinterpreted as a forecast, serves as a quantitative basis for the quantitative time-dependent evaluation of measures to reduce emissions.

For this scenario a mean annual increase of industrial net production between 2 % and 2.5 % has been assumed for the time horizon 1984 to 1995. The overall annual fuel input to the industry in Baden- Württemberg decreases continuously between 1983 and 1989 from 209 PJ to 205 PJ; followed by an increase of roughly 2.5 % up to 210 PJ until the end of the time interval investigated. The behavior of fuel consumption corresponding to this general development is given in Fig. 8. It is characterized by a continuous substitution of heavy fuel oil by natural gas and hard coal.

The development shown can be regarded as a conservative estimate and as an upper bound for fuel consumption of the industry to be expected. The statement is strongly supported by the fact, that industrial companies indicated the overall expectation of a de-

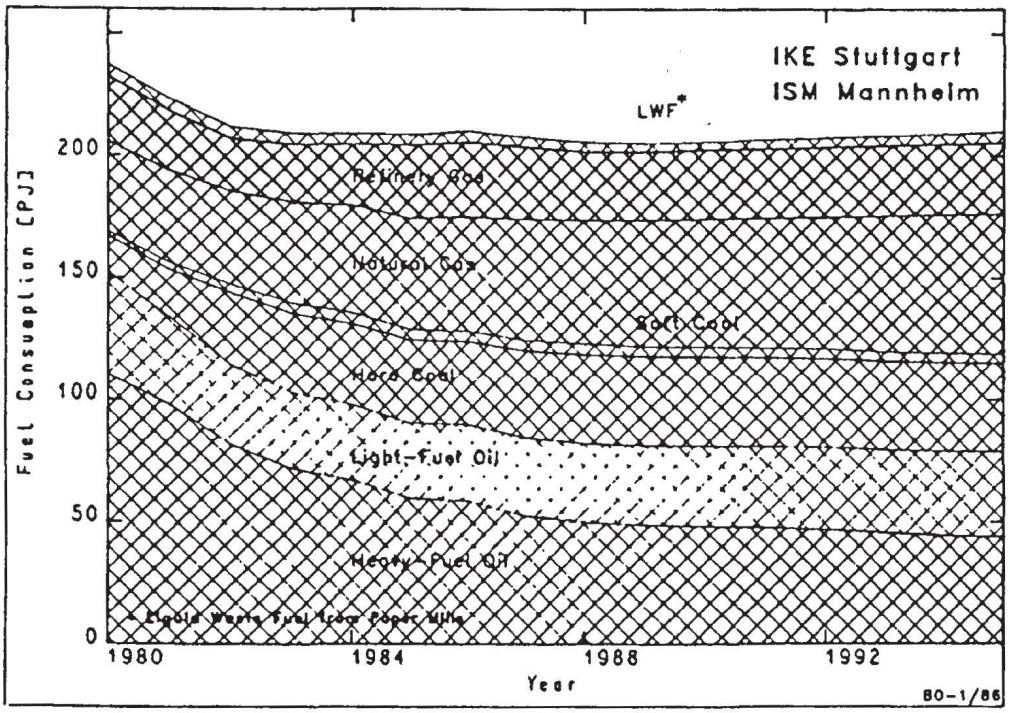

FIG.8. Fuel consumption in the industry.

creasing fuel consumption during the consultations performed within the course of the data collection.

Based on this projection of fuel consumption by industrial branches and under the assumption that the requirements of the GFAVO will be fulfilled, the development of industrial emissions of SO_2 and NO_x in Baden-Württemberg have been plotted in Figs. 9 and 10.

Fig. 9 indicates that - for the 'Reference Case' where requirements of the TA Luft 86, recent extension of the GFAVO and further measures have not been taken into account - emissions of SO_2 will decrease continuously from 87 000 metric tons (t) in 1983 to roughly 61 000 t in 1995. This corresponds to a reduction of 30 % with respect to 1983's level of emissions.

As shown in Fig. 10, NO_x-emissions also decrease continuously from 38 000 t to 34 500 t. This reduction of emissions in the 'Reference Case' originates from successful measures to control emissions which have been started by the industry in the past.

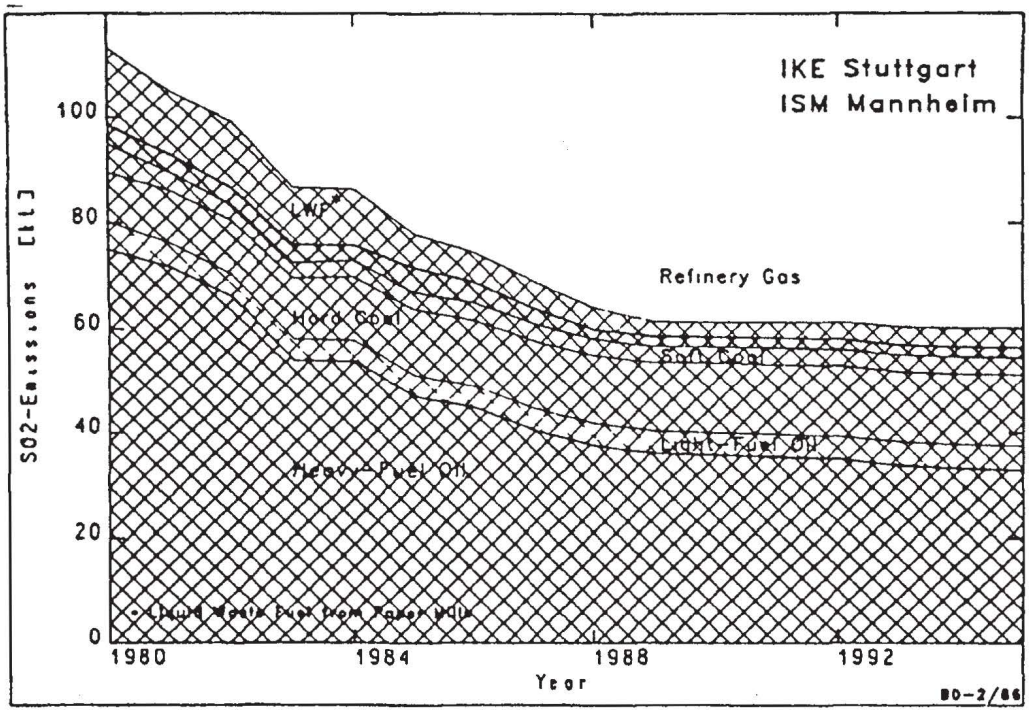

FIG.9. SO_2-emissions from the industry.

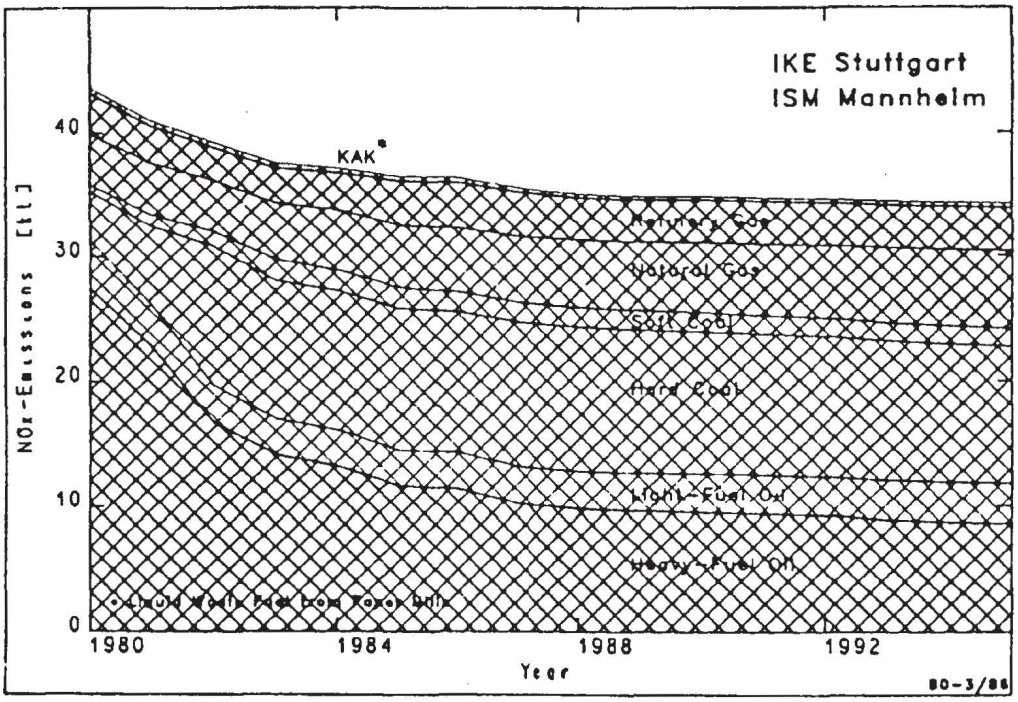

FIG.10. NO_x-emissions from the industry.

Their effects are primarily due to fuel conservation and substitution as well as to the introduction of more ecologically harmless power production processes and measures for flue gas treatment.

One main purpose of the study, presented here, was to examine and systematically evaluate further measures to reduce emissions with regard to

- possible field of application,
- state of technology,
- waste management,
- specific investments required and
- overall costs.

These analyses required the development of an extensive computer-based simulation model which includes all industrial furnaces in Baden-Württemberg which require a license. The model enables the IKE to individually simulate alternative control measures for each of the single furnaces. As criterion for the evaluation of economical efficiency of the single control measures, the so-called specific reducement costs (Germ.: Spezifische Minderungskosten - SMK) per unit of pollutant removed, have been chosen. These are defined as the quotient of the annual costs caused by an individual measure and the annual reduction of emission reached by means of that measure. The single measures at individual furnaces are then ordered according to their respective SMK and their successive implementation is simulated by IKE.

A typical result is presented in Fig. 11 in form of a trade-off curve between costs and reduction of SO_2-emissions. Measures which have been found highly recommendable are in this case:

- implementation of flue gas desulphurisation plants at furnaces with high load factors,
- substitution of heavy-fuel-oil by natural gas, where natural gas supply is already available or could be implemented at resonable costs, and
- extensive desulphurisation of light-fuel-oil.

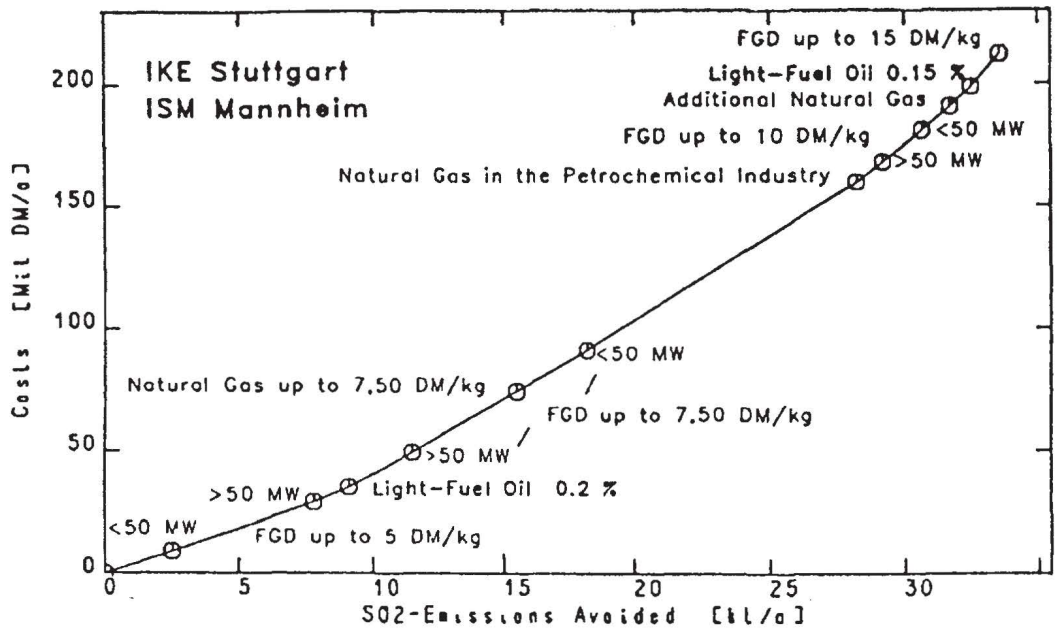

FIG.11. Relationship between costs and reduction of SO_2-emissions.

Similar results have been obtained with respect to the emissions of NO_x. It should be noted that the results shown have been derived for an assumed best-estimate scenario of fuel prices. However influences of alternative fuel prices have also been analysed in detail.

The possible uses of these quantitative results are twofold:

- after having defined some quantitative goals concerning emissions control, it is possible to estimate the additional expenditures which have to be borne by the industry in Baden-Württemberg, and

- having defined some economical limit or a level of costs of clean air measures which is considered reasonable with respect to a certain industrial policy, it is possible to estimate the level of reduction of emission which is reachable.

4 Research Project: Small-Scale Investigation of the SO_2- and NO_x-Emissions in Baden-Württemberg

The aim of this study was to determine the amount of emissions of SO_2 and NO_x for the local state of Baden-Württemberg during the period of the TULLA-experiment (Transport und Umwandlung von Luftschadstoffen im Lande Baden-Württemberg und aus Anrainerstaaten). While the studies, mentioned above, aimed at the development of optimized strategies for emission control, the project described below followed the main purpose of establishing a detailed data base with an extremely high spatial and temporal resolution. In contrast to the studies which evaluated annual values of emissions and emission reduction, the emissions have been calculated here for every hour during the 'Tulla-period' and in a scale of 1 x 1 Kilometer. Furthermore, the evaluation of emissions has been separated by the height of the emission sources. The following sectors have been investigated separately:

- public power plants,
- industry,
- small consumers,
- private households,
- internal community transportation, and
- external community transportation.

The data base has been built up using an inquiry of the operators of furnaces larger 10 MW as well as specific models for emissions which could not directly be acquired. These models are based on data such as annual energy consumption, data concerning building structures, numbers of employees, volumes of traffic and others which were available from the energy suppliers and other source with sufficient spatial resolution (Fig. 12). Exemplary, the model used for evaluation of emissions from private households is given in Fig. 13. As the figure shows, 40 different classes of household have been considered. Each of them is differentiated by meteorology dependent hourly variations of the energy demand. Energy consumption data has been validated by means of statistical data.

AIM OF THE PROJECT

Evaluation of the hourly emissions (SO_2 and NO_x) during the measuring-campaign in Baden-Wuerttemberg

- in the scale of 1 km x 1 km
- seperated by the height of the emission-sources
- for all sectors (households, transportation, industry, other consumers and power-plants)

DATA-BASE

- inquiry of the operators of furnaces greater 10 MW
- statistical data
- meteorological data
- inquiry of the energy-suppliers

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FIG.12. Research project: Small-scale investigation of the SO_2- and NO_x-emissions in Baden-Württemberg.

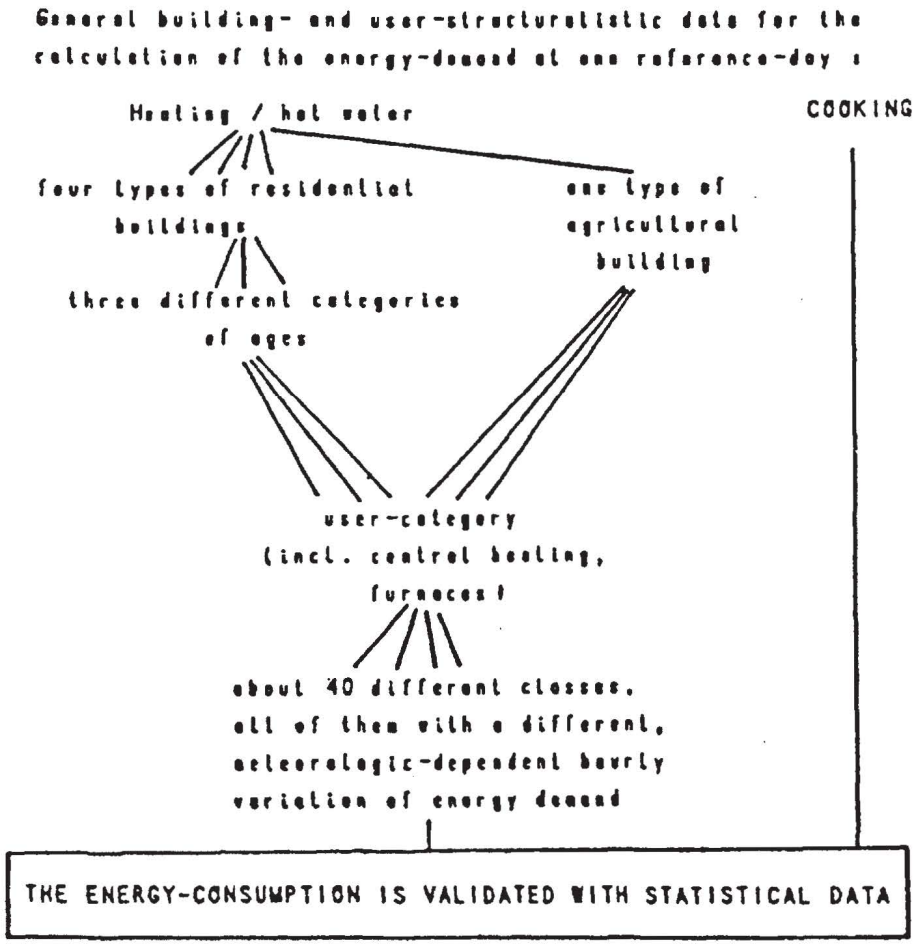

FIG.13. Energy model for the sector 'private households'.

The results are stored in form of a 'cadastre' of the whole state of Baden-Württemberg which is made up of elements of 1 x 1 Kilometer. 288 hourly values for the SO_2-emission and the same number of values for the NO_x-emission have been assigned to each of these elements (see for example Fig. 14) resulting in an extensive data base of roughly 37 million single data.

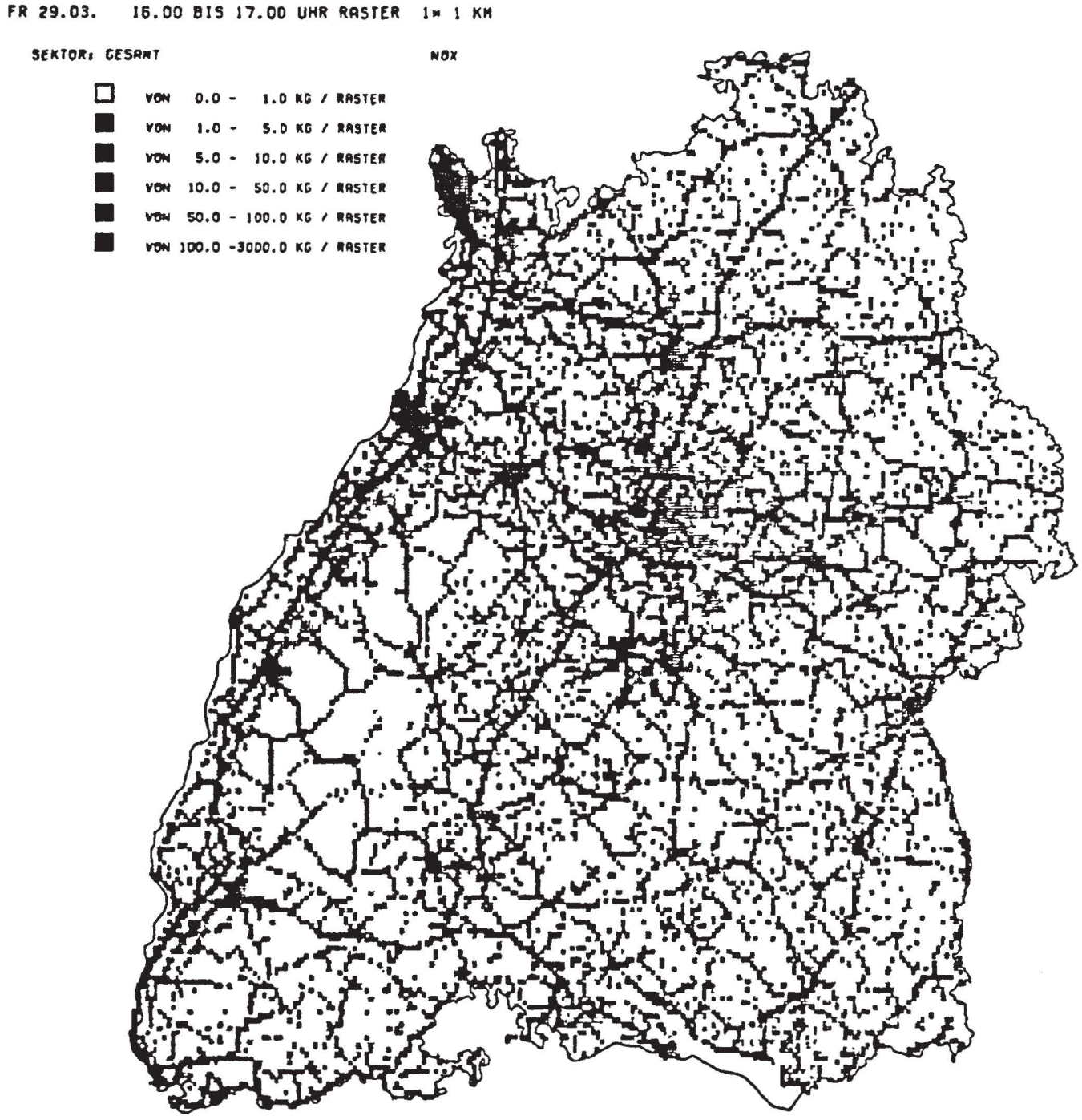

FIG.14. NO_x-emissions from all sectors (Friday, 29 March 1985, 4-5 p.m.).

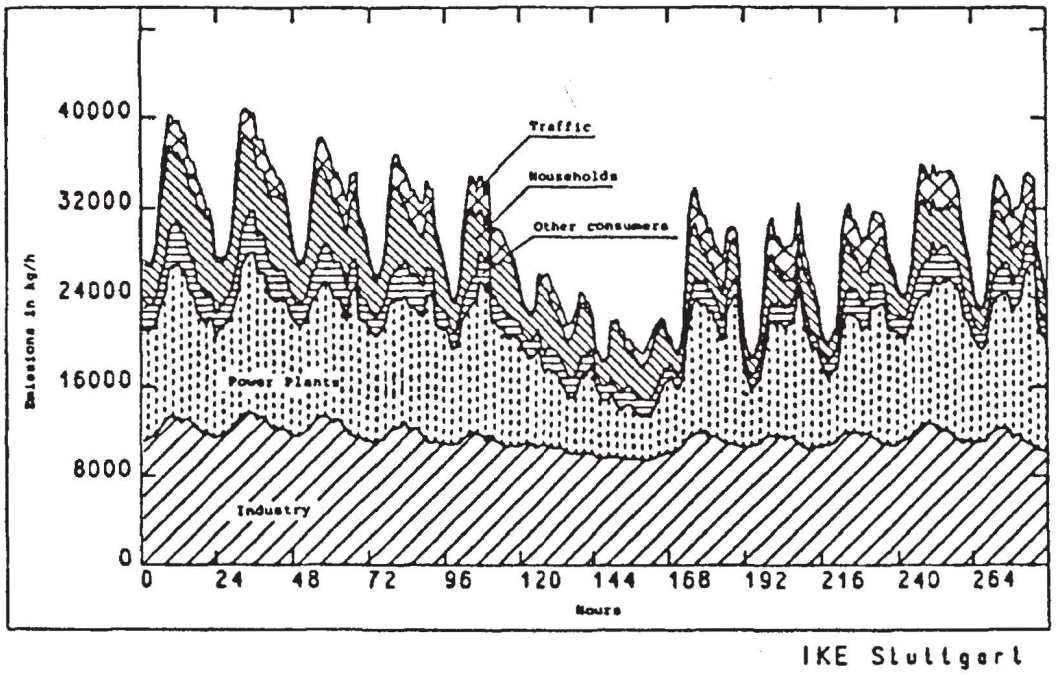

FIG.15. SO_2-emissions in Baden-Württemberg (hourly values).

A comtemplation of major results demonstrates the following general findings:

Main sources of SO_2-emissions are established by the industrial and public power plant sectors (see Fig. 15). The industry's contribution to the emissions during the period investigated is almost constant.

This is primarily due to high base-load factors of the primary, the heavy, the petrochemical and the cement producing industries. Compared to them, other important sectors show a behavior, which is deeply influenced by the outdoor temperature and largely changing by the days of the week.

The spatial distribution of emissions indicates - in the case of SO_2 - major local accumulations around the cities of Stuttgart, Heilbronn, Karlsruhe, the Mannheim region, the Upper Rhine Region and to some extent the city of Freiburg (see Fig. 16).

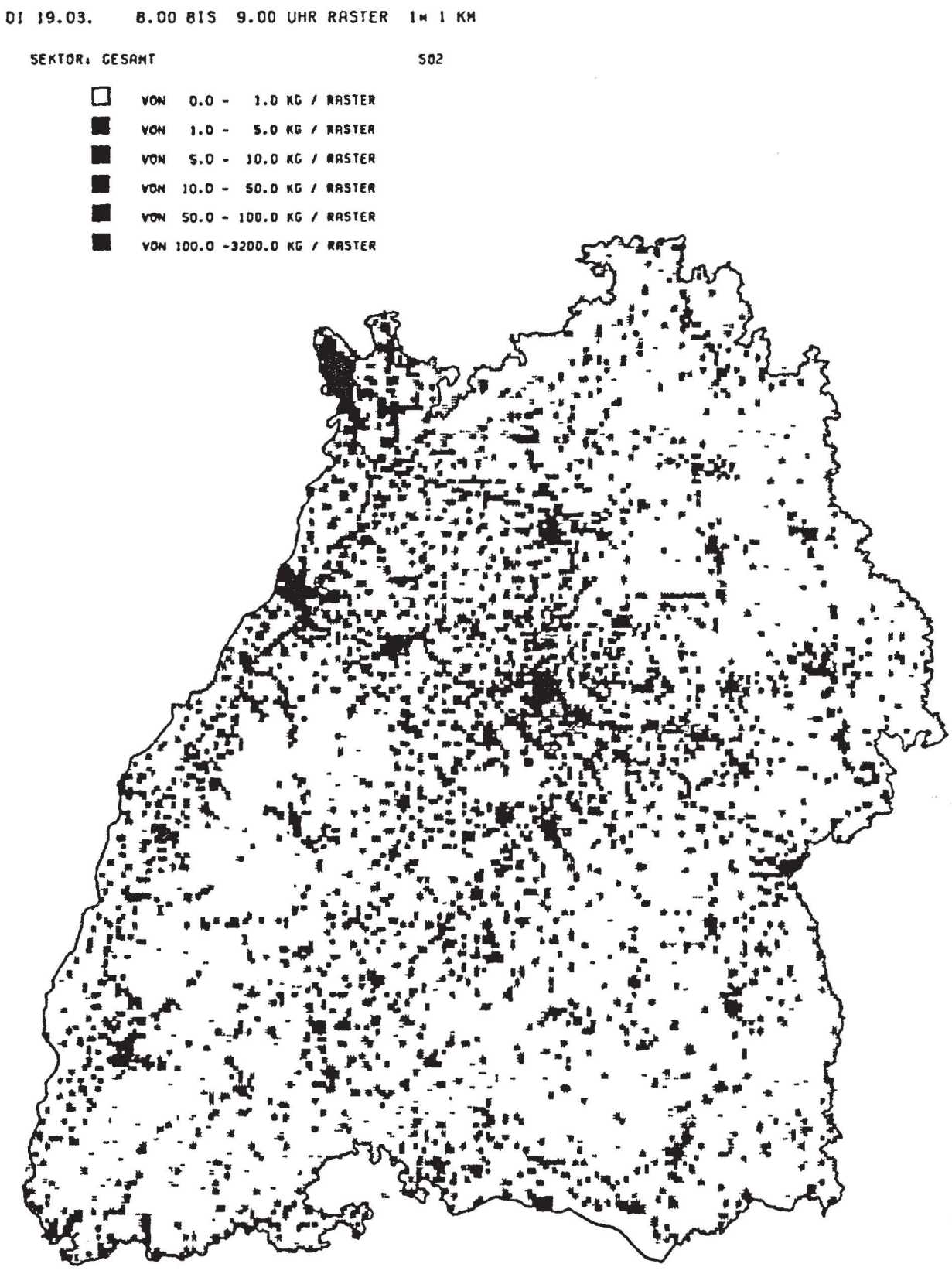

FIG.16. SO_2-emissions in Baden-Württemberg (19 March 1985, 8-9 a.m.).

Turning to NO_x-emissions, it becomes obvious, that the spatial and temporal distribution of emission is by far dominated by contributions from the transportation sector. The temporal fluctuations, shown in Fig. 17, clearly follow the traffic volume which causes high emission peaks during the rush hours. A typical spatial distribution of NO_x-emissions is given by Fig. 18. A comparison of the hourly emissions in the transportation sector on March, 29th, 1985 between 4 - 5 p.m. (Fig. 19) and a corresponding cadastre of NO_x-emissions from all other sectors except transportation (Fig. 20) demonstrates clearly, that the major roads and the downtown areas within the conurbanitions are the places with the highest emissions.

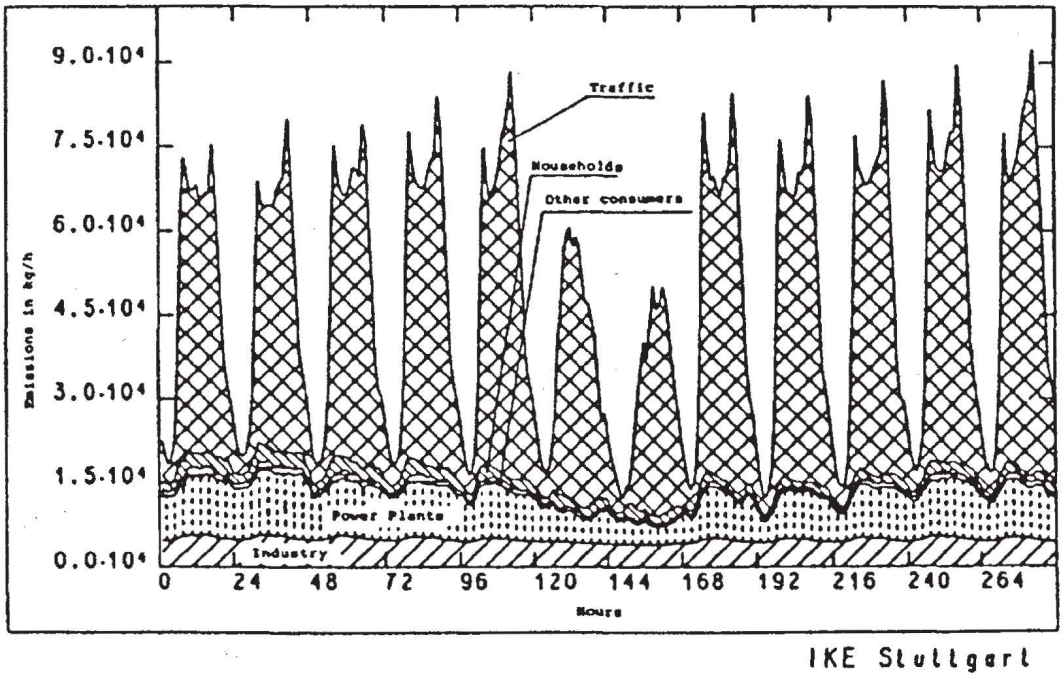

FIG 17. NO_x-emissions in Baden-Württemberg (hourly values).

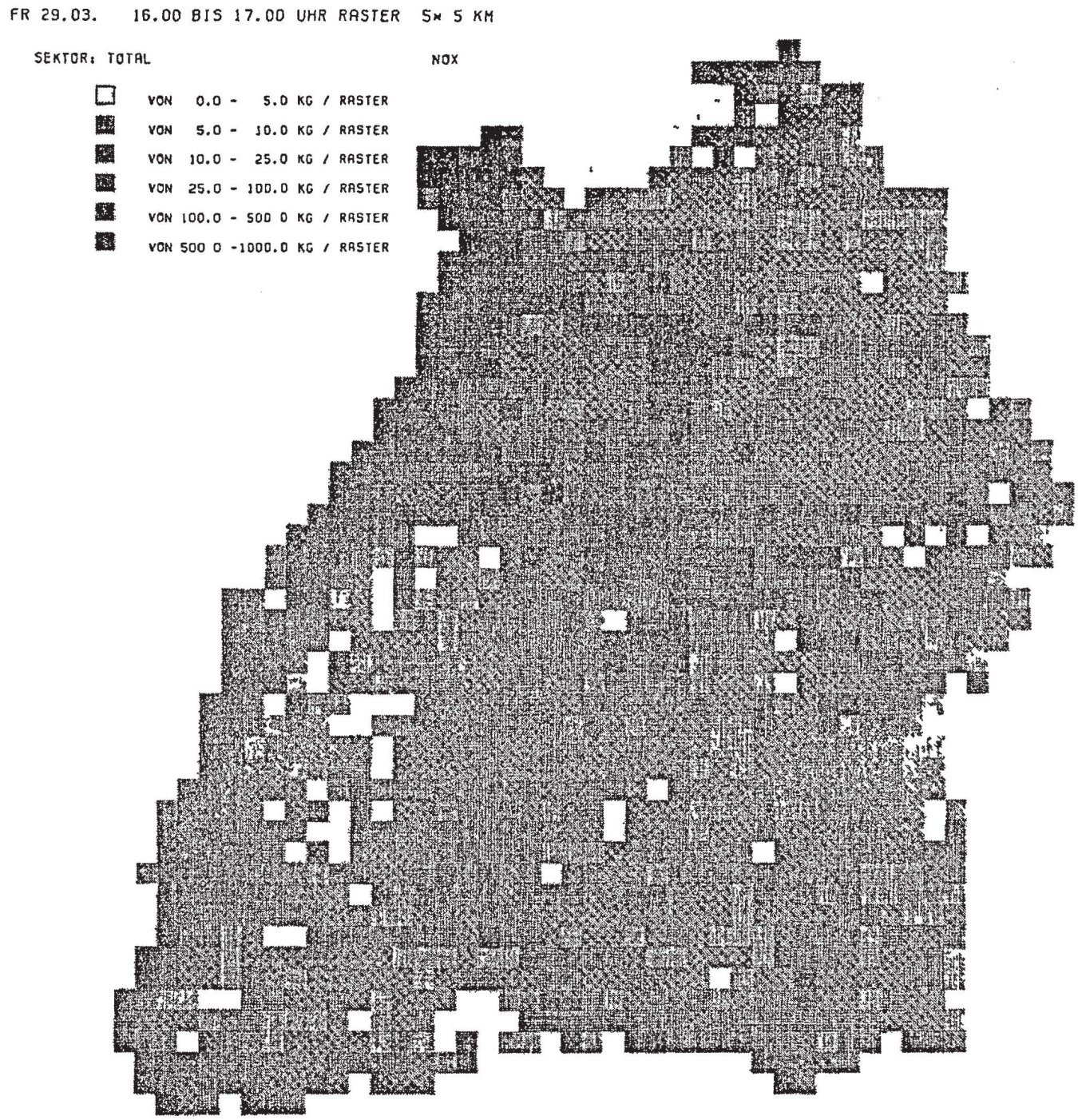

FIG.18. Total NO_x-emissions on Friday, 29 March 1985, 4-5 p.m.

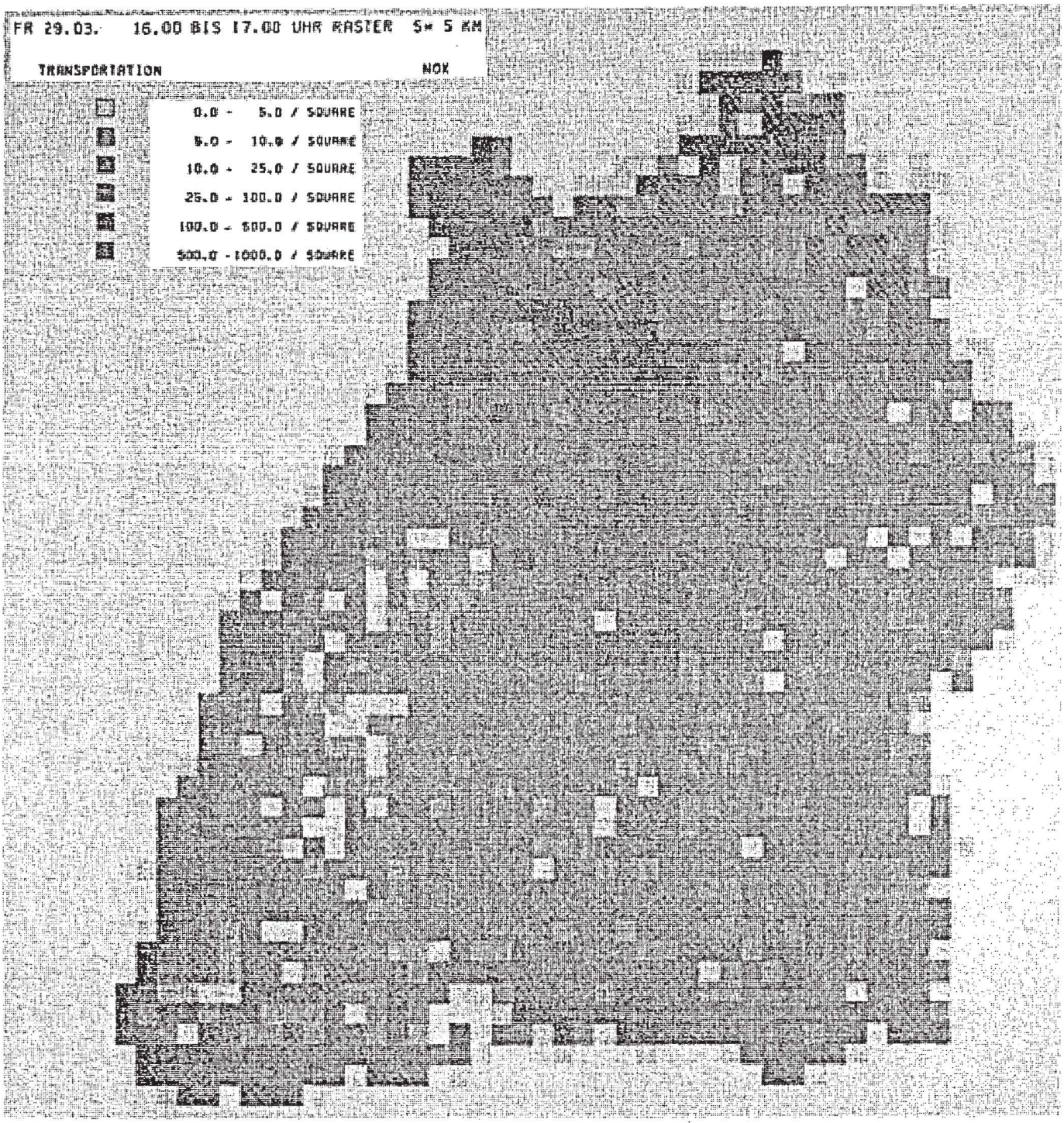

FIG.19. NO_x-emissions of sector Transportation.

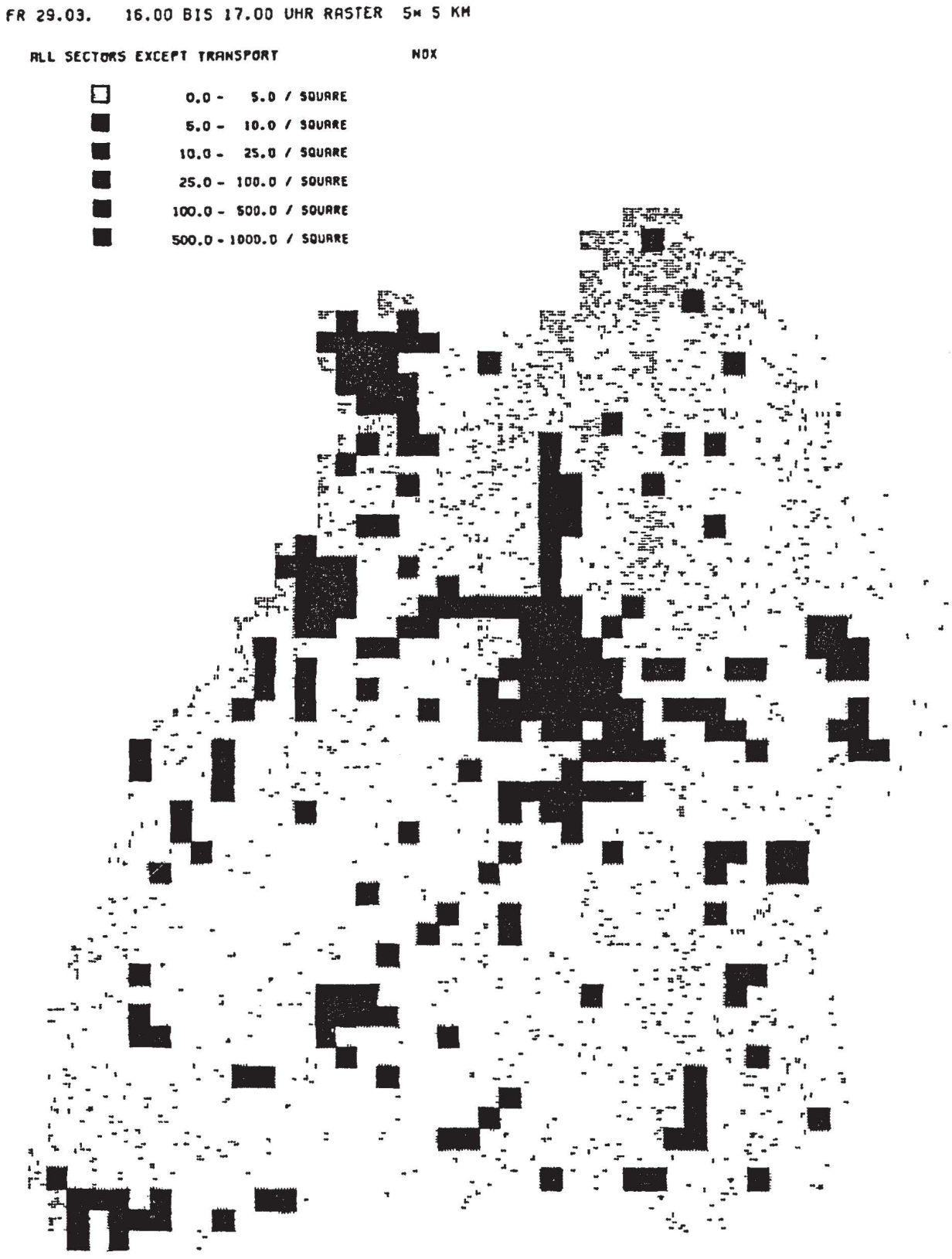

FIG.20. NO_x-emissions of all sectors except Transportation.

More and extensive results can be gained, if the data base elaborated is fed into suitable pollutant transportation and conversion models which are currently being developed by other institutions. A verification of these models will also be possible using measurements of immissions which have been carried out within the frame of overall 'TULLA'-project.

The methods and models developed here are currently being extended in order to allow the determination of spatially and temporally resoluted emissions not only for the specified period which was subject of the 'TULLA'-project but also for other periods of time. This provides the opportunity of evaluating future environmental control measures with respect to their influence on spatially and temporally distributed emission peaks. At the same time an extension of the land register to other air pollutants (especially volatile organic compounds) is well under way. However, a major problem in this area is the large number of hydrocarbons of different toxicity, causing an enormous, and even increasing data base.

5 Research Project: Cost-Effectiveness of Risk Reduction by Engineered Safeguards in Biblis-B-Type Reactor Systems'

The research projects, presented so far, are dealing with the assessment of air pollutants - in particular SO_2 and NO_x - and the development of rational strategies for their control. Besides this, the IKE has performed research activities in the area of nuclear safety engineering since 1971. These activities compraised the development and utilization of deterministic as well as probabilistic techniques, which have been used in the licensing process and for the evaluation of hypothetical accidents.
Within the last years, especially since the TMI incident, reactor safety research programs focussed on a more realistic description of the operational and accidential behavior of nuclear power plants. The complete modeling of reactor safety problems requires new and non-conventional computer techniques. Thus, the IKE-Plant Simulation and Analysis System (SASYST) has been developed and is

being developed further in order to allow deterministic and probabilistic analyses in a less conservative manner. The modular concept of SASYST as shown in Fig. 21 is based on the data and software management system RSYST of IKE which provides techniques for statistical analyses, interactive graphics and other general purpose modules. SASYST has already proven to be a very flexible and efficient advanced tool in a large number of reactor safety analysis applications. It incorporates well introduced code systems like TRAC, ADINA, SAP, RELAP, SSYST, KESS and MELSIM.

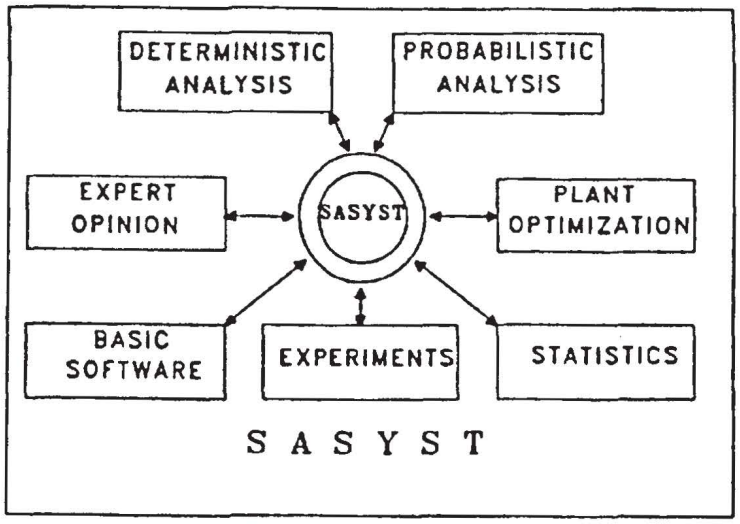

FIG.21. Plant simulation and analysis system of IKE.

Examples of successful applications of SASYST concepts have been e.g.

- Analyses of blow down and melting experiments of PNS at KfK,
- Core melt and thermal hydraulics calculations for the German Risk Study Phase B,
- Investigation of low pressure melt down accidents,
- Statistical analysis of various thermalhydraulics codes,
- Determination of recoolable reactor states during severe damage accidents,

- Analysis of TMI-2 degraded core,

- Design and interpretation of severe fuel damage experiments,

- Investigation of the behavior of the reactor pressure vessel under thermal shock conditions

to mention only a few.

In early 1984 the IKE entered the IAEA coordinated research program on 'Evaluation of Cost-Effectiveness of Risk Reduction Among Different Energy Systems'.

Research activities of the first phase of this study can be summarized as follows:

- Development of a risk matrix formalism approach for an effective representation and evaluation of results of PRA-studies (see Fig. 22).

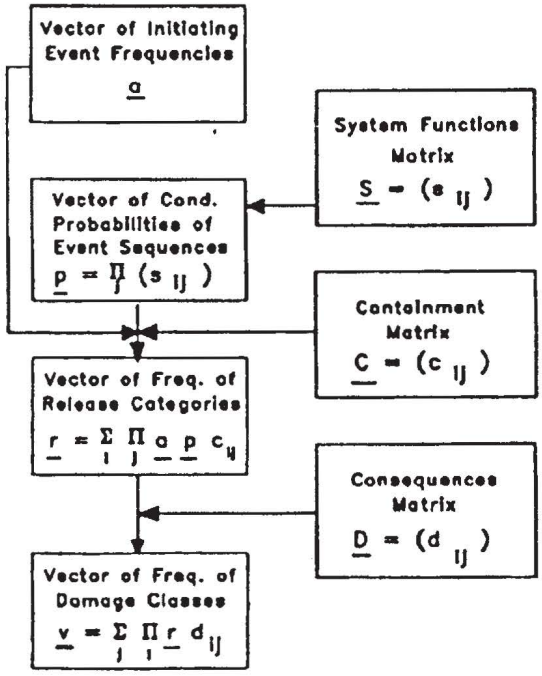

FIG.22. Risk matrix formalism approach.

- Introduction of measures of risk importance for safety relevant installations, i.e. introduction of 'Vesely'-importance measures to the system functions level.

- Evaluation of these importance measures based on the risk matrix formalism approach.

An exemplary result is given in Fig. 23, which shows evaluated risk importances of system functions of the Biblis-B-NPP as they have been analyzed by the German Risk Study (GRS), Phase A. Also, these importance values of course will have to be updated as soon as exhaustive results of Phase B are available, this kind of representation is extremely useful because it demonstrates the different contributions to the overall risk considered. By this way, it clearly points to individual merits and potentials for reinforcement of the system functions analyzed.

Furthermore, areas of necessary extensions of research have been identified. Ongoing analyses showed an urgent need for further methodological improvements in order to meet requirements as e.g. consistency of models and limitations of uncertainties. Especially a consistent method for the evaluation of impacts of changes in a plants's design on the risks associated with the operation of the plant seemed to be highly favorable. Such method is important since e.g. design measures reducing the portional contribution of a specific event sequence may increase the relative risk importance of other sequences, which might have been neglected; or 'new' event sequences may arise from changing a plant's design. This caused the research work to get focussed on methodological improvements of models rather than being primarily concerned with performing a case study on specific event sequences of the GRS. Present major research aims of this project are:

- Definition of model and data interfaces between deterministic and probabilistic techniques of analysis and

- Evaluation of updated estimates of cost and risk reduction achieved by selected engineered safeguards.

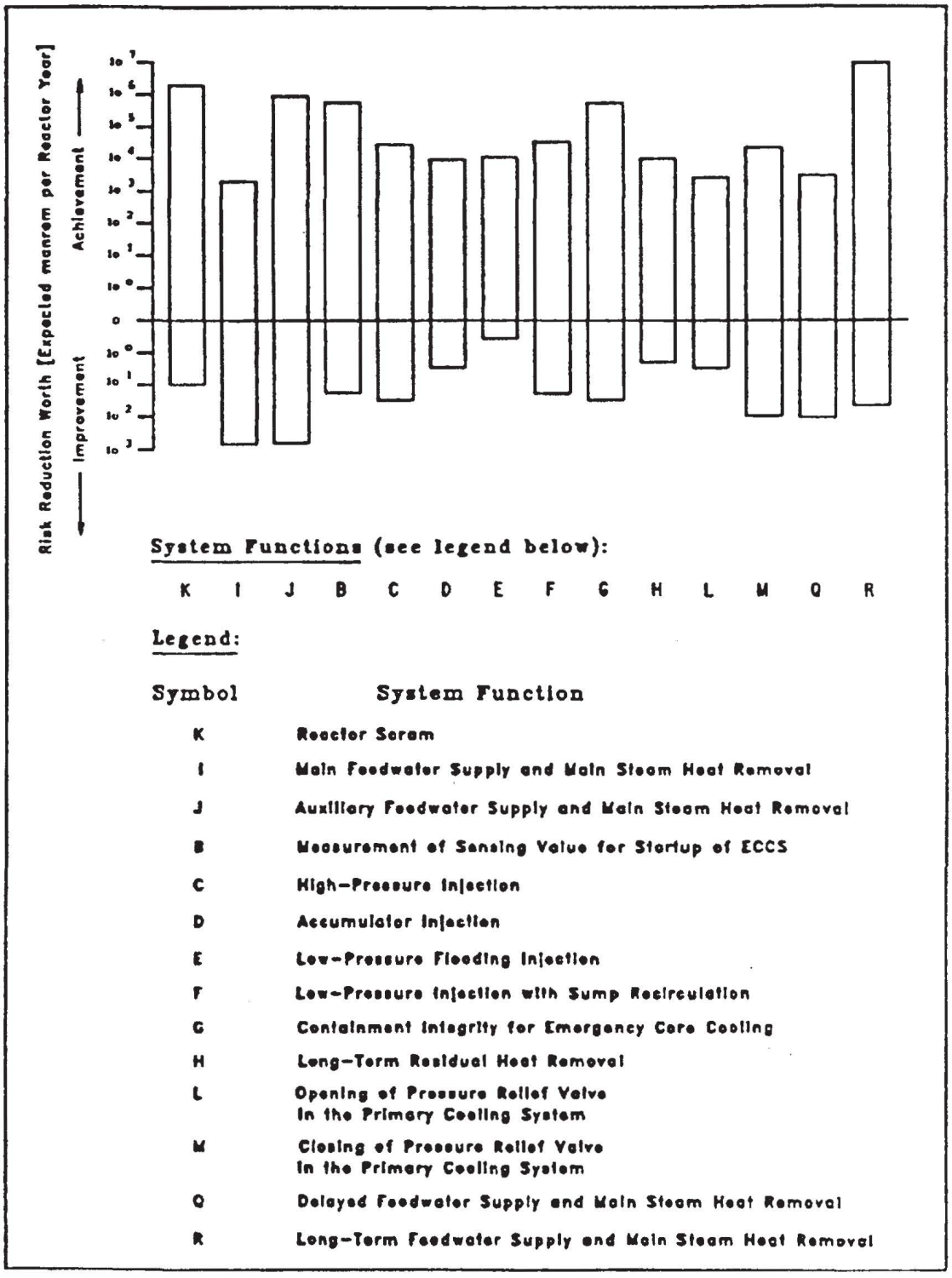

FIG.23. Risk reduction worth for risk measure 'genetically significant dose'.

It is strongly believed that the ongoing research activities should result in a valuable methodology which has the ability to handle design changes in a more consistent way, thus providing extremly useful means for evaluating measures of risk reduction at the plant level.

6 Assessment of Restructuring Measures for the Energy System in Baden-Württemberg with Special Regards toward Electricity Supply

Having put some few highlights on experiences gained and developments started at IKE in the fields of environmental control and nuclear safety, we now turn to an assessment project recently launched which - in our belief - is directly related to the envisaged inter-agency project.

Also having caused moderate radiological consequences in the Federal Republic of Germany, the Chernobyl accident has given rise to major public concern about the risks of energy sources, especially nuclear energy. It has provoked violent discussion among political parties and different interest groups questioning the desirable structure of present and future energy supply systems for Germany. In this situation, the state government of Baden-Württemberg appointed the IKE - as an independent scientific installation - to guide and perform a comprehensive study on possible measures of restructuring the energy system in the state of Baden-Württemberg. Within this study special regard shall be paid to electricity supply. The study was started in August, 1986 and has to be completed by end of July, 1987.

The study's overall aim is a comprehensive assessment of technically feasable options for a long-term safe energy supply for Baden-Württemberg as well as the evaluation of ecological, economical and social consequences. Although this study is not anti-nuclear, it will be required to investigate in particular, whether and to what extend it could be possible to substitute nuclear energy; and which consequences would arise from such substitution. Lastly, the study aims at decision aids for a ra-

tional energy policy in order to identify decisions which must be taken now if a sufficient, economically, ecologically and socially favourable energy supply shall be guaranteed. The main steps to reach this goal are summarized below:

- Analysis of the different options of energy supply and efficient energy use with regard to

  - their potentials,

  - their costs and development of cost,

  - their environmental consequences and

  - their risks.

- Analysis of alternative energy supply strategies taking into account economic, ecologic, international and social aspects. In order to put the different strategies into perspective, the following topics are addressed by the study:

- energy consumption and energy supply,
- efficient energy use,
- fossil energy,
- renewable energy,
- nuclear energy,
- comparative risks from different options of energy supply,
- social compliance,
- scenarios of energy consumption and energy supply,
- evaluation of different strategies for energy supply.

Within the frame of this assessment, the IKE collaborates with a large number of institutions in Baden-Württemberg and in the Federal Republic of Germany, providing specific contributions which are compiled and evaluated at IKE.

Also, this study, due to its time schedule, cannot go beyond a critical review of methodologies and assessments already available. However, it is felt to be closely related to the more ambitious tasks followed by the envisaged inter-agency project.

For this reason, the working package on 'Comparative Risks from Different Options of Energy Supply' is presented in more detail. It aims at a systematic review of available quantitative assessments of the overall risks from different options of energy supply and puts special emphasis on a critical estimation of methodological and other shortcomings of today's comparative risk studies. The questions to be investigated are: how and to what extend do the mean individual and collective risk change if nuclear energy is substitued by some other source of energy, and what are the impacts of different scenarios of substitution under a risk point of view. In this context the transferability of results gained abroad to the specific regional situation in the state of Baden-Württemberg will be one of the most important criteria.

Envisaged steps of analysis are listed below:

1. Methodology and uncertainties of comparative risk assessments.

2. Evaluation of existing assessments.

3. Compilation of estimates of risks associated with the following energy supply options:
   - nuclear energy,
   - coal fired plants,
   - oil fired plants,
   - gas fired plants,
   - wind energy,
   - solar energy.
   - hydroelectric energy.

4. Qualitative discussion of possible measures to reduce these risks.

5. Discussion of risks due to sabotage, terrorism, etc.

6. Comparison of the risks with other natural, civilizational and technical risks.

In conclusion, it should be noted, that the ongoing study presented so far, shall neither be confessed with risk evaluations of different strategies of energy supply because of it's limited time schedule and other inherent limitations; nor shall it attempt to identify strategies which are optimized under the aspect of allocation of resources for risk reduction. However, this study seems suitable as a useful basis for such investigations.

7 Proposal for a Regional Case Study on 'Assessing, Comparing and Managing Risks from Energy Supply Strategies in Baden-Württemberg'

Due to the studies presented above, the IKE operates a very detailed data base of the energy system and the emissions in Baden-Württemberg. So, for example, all furnaces larger than 1 MW, their energy demand and their emissions are part of the data base. Furthermore, the hourly numbers of cars on every road in Baden-Württemberg are known. For all sources of emissions, measures to reduce emissions and the costs for these measures have been investigated. Furthermore, experiences available at IKE in the field of nuclear safety engineering have been outlined. Further research in the areas mentioned is already underway and believed to have the potential of substantial improvements. The assessment of restructuring measures for the energy system, recently launched by the state government of Baden-Württemberg, analyses and evaluates the different options of energy supply under economical, ecological, international and social aspects. It has been pointed out, that this study will result in an extremely valuable basis for further investigations.

Based on these experiences and ongoing studies, the IKE proposes a regional case study for Baden-Württemberg as a contribution to the inter-agency project. This envisaged case study shall be divided into two principal phases.

Within Phase I of the case study an attempt shall be made in order to implement a risk management approach by identifying strategies for the regional energy supply. Those strategies should account for an effective allocation of resources for reducing the risks involved.
Research activities of this first phase shall be limited to the energy field according to the data base available. However it is intended to go beyond a conventional comparative risk assessment, since it does not focus solely on risk of electricity generation but includes other sectors of energy use. In this sense, Phase I of the case study will widen the approach of former studies because

- it investigates regional quantitative data for the risks of nuclear, fossil, other conventional and 'new' fuel cycles
- it evaluates different energy supply strategies with respect to the overall risk reduction reached
- it analyses the costs of different measures to reduce the risks of energy systems and identifies measures having the best cost-effectiveness values
- it identifies by these means those strategies which have a maximum efficiency in reaching the goal of reducing energy risks.

Furthermore, it is strongly believed that it will be essential to perform the study on a regional base, since the level of overall risk and even more the risk reduction reachable largely depends upon regional parameters such as structure of population, existing energy system, regional distribution of emission sources, etc.

In spite of their complexity, energy risks could make up only a certain fraction of the overall risk to which the population within a region might be exposed. Other technical activities - such as traffic or process industries - might make similar or even larger contributions. In order to further increase the usefulness of the risk management approach taken, Phase II of the case study should be devoted to an extension of analysis to other sources of risk than energy supply.

A provisional framework for Phase I and a short synopsis of possible extensions during Phase II of the proposed case study is given in the following section.

8 Provisional Framework for the Proposed Regional Case Study

It is proposed that the case study should be based on the results of the assessment project described in Chapter 6. This is felt to be very appropriate since the proposed study is in some way a direct expansion of results reached by the pioneering 'Baden- WÜrttemberg Project'. Besides regional average estimates of energy risks, the individual merits and shortcomings of different methodologies of risk assessment as well as specific problem areas concerning data and models are investigated within this project. In this sense the assessment project for Baden-WÜrttemberg makes up some kind of a 'Phase 0' for the envisaged case study, which points to the areas were further research efforts are needed and promising. For example, it is regarded as a logical straightforward step to expand the analysis from average values over the region to considerations with much higher spatial resolution. However, this should require major efforts to be spend on a number of topics such as models for pollutants transportation and conversion, dose-response relationships or acquisition of data, specific to the regional situation.

Phase I

(i) Delineation of the Area where the Study will be Performed

The case study will be performed for the state of Baden- WÜrttemberg which is located in the southwest of the Federal Republic of Germany. Baden-WÜrttemberg covers about an area of about 35 700 km² and has a population of about 9 200 000 people. The population structure reaches from rural areas to conurbanitons. Around 15.7 % of the German gross domestic product are obtained in Baden-WÜrttemberg. The industrial sector includes primary industries, petrochemical, cement producing and automobile industries and a large number of other branches.

(ii) Description of the System under Study

The system researched is the complete energy system in Baden-WÜrttemberg. It includes the following sectors:
- public power plants,
- industry,

- small consumers,
- private households,
- transportation.

This first phase will limit its scope to risks arising from the conversion and use of energy in the sectors mentioned, i.e. risk as e.g. risks of traffic or inhouse accidents will not be included. However, this phase aims at building a complete model of the energy system for the years 1985 to 1995, which will allow a detailed analysis of different measures with high temporal and spatial resolution.

(iii) Hazard Identification

Hazards associated with the operation and the construction of respective plants, fuel supply (including e.g. mining), waste treatment and disposal will be addressed for each of the energy options:
- nuclear energy,
- coal,
- oil,
- natural gas,
- wind energy,
- solar energy.

For each of these options routine environmental emissions e.g. SO_2, NO_x, routine radioactive emissions to air and water, routine occupational exposures, accidental conditions causing occupational or public hazards will be assessed on a specific regional basis.

Hourly emissions of SO_2 and NO_x are known in form of inventories on the scale of 1 x 1 Kilometers for a 12 days period in March, 1985. A similar cadastre is currently being prepared for other air pollutants (hydrocarbons) and could possibly be included. In addition, the models are extended to allow calculations for any period of time between 1985 and 1995. Routine radioactive emissions will be assessed for each plant in Baden-Württemberg within the frame of the assessment project mentioned above.

(iv) Safety Policy

Relevant safety standards for the energy systems such as standards, regulations and goals concerning public, occupational or environmental issues will be listed here. By these means, the environmental and safety policy followed will be assessed. This explicitly includes the environmental control strategies developed by the studies, mentioned above, Thus, instruments for achieving present and future levels of safety and environmental control (e.g. air quality control) will be assessed and analyzed.

(v) Risk Assessment

The use of suitable models for the transportation and conversion of air pollutants and radioactive release will result in a clear distinction between hazards which originate inside Baden-Württemberg and those which are 'imported' from outside the region. This should be done for routine and accidential emissions. It will result in detailed information about imission originating from sources inside and outside Baden-Württemberg.

Major efforts might be caused by the need for meaningful dose-response relationships. Especially, in the field of routine emissions of air pollutants it will be necessary to carefully evaluate the dose-responses published with particular regard to their transferability to the regional conditions. A careful choice must be made here between qualitative and quantitative approaches of risk assessment in order to reach a reasonable balance between what is desirable and what is practical and useful as described in terms of different risk measures.

(vi) Risk Management

Based on a 'reference scenario' different energy supply strategies will be evaluated with respect to the overall risk reduction reached. The costs of different measures to reduce the risks will be investigated and cost-effectiveness values will be assigned. The resulting relationship

between risk reduction and costs will then be use to identify those strategies with an maximum efficiency. An area which will require major efforts to be spent on is the question of whether and how to aggregate the different risks in order to identify favorable strategies.

Phase II

This phase of the case study will be devoted to an extension of research to other industrial sources of risk. These could be investigated in comparison with energy risks. Such are risks to encounter accidents inhouse, risks of traffic accidents, risks from hazardous materials in the industrial branches, chemical industry risks, etc. Most recent incidents have given rise to major pulbic concern about industrial risks, especially those imposed by the process industry. This should be seriously taken into account, when discussing the scope of Phase II and a useful choice of partner organisations which should collaborate if chemical industry risks are to be incorporated into the case study. Additionally the attempt could be made to systematically introduce other aspects than risk into the procedure of identifying perferable strategies.

It is believed that the efforts to be spent within the frame of the proposed case study should contribute to a more effective way of coping with the various potentials of harm which are inevitably inherent to any industrial activity. Thus, the implementation of the risk management approach will provide rational measures to balance the risks and benefits involved. Finally, performing the case study will enhence the usefulness of the approach itself.

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