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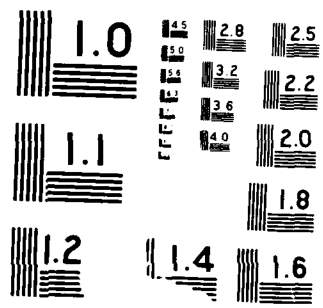

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Systems Analysis Department Annual Progress Report 1987

Edited by E. C. Fuller, H. Larsen, G. A. Mackenzie

Risø National Laboratory, DK-4000 Roskilde, Denmark
March 1988

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Systems Analysis Department
Annual Progress Report 1987

Edited by E. C. Fuller, H. Larsen, G. A. Mackenzie

Abstract.
The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1987. The activities may be classified as energy systems analysis and risk and reliability analysis. The report includes a list of staff members.

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1. Introduction

The mission of systems analysis is to analyse the interaction between technologies and systems within industry and the energy sector, and to evaluate the interplay with the surrounding society in order to assess questions related to the economy, environmental impact and associated risks.

The activities of the Systems Analysis Department in 1987 covered research related to the development of risk and reliability models, and energy-economy models. A number of studies were carried out dealing with subjects such as risk assessment, environmental consequences, energy planning, and technology assessment. The research and development activities of the department were undertaken by the Energy Systems Group (ESG) and the Risk Analysis Group (RAG).

Four postgraduate research projects were in progress in 1987. Of these, two were initiated during the year and concerned economic interdependencies between industrialized and developing countries, and consequence management models for risk analysis. One ongoing project concerns energy planning and project assessment in developing countries. Finally, a project dealing with unwanted chemical reactions in the chemical process industries has been completed.

The mission of energy systems analysis is to contribute to the establishment of a suitable energy system for society. This goal is pursued by undertaking R&D concerning energy-economy models, and by carrying out specific studies in collaboration with industry and public authorities.

The research and development activities of the Energy Systems Group in 1987 included work in connection with the energy-modelling programme of the Commission of the European Communities dealing with a macrosectoral model (HERMES), a European version of the Danish Energy System model (DESS), and an environmental module for the energy flow optimization model (EFOM). A Nordic project on the incorporation of uncertainties in economic calculations for energy technologies has been completed. The Danish Energy Systems model (DES), and the simulation model for combined collective energy systems (SIKKE) are continously being updated and modified. Work has continued on the development of techno-economic models in the oil and gas area to be used in connection with field developments in the North Sea.

The Energy Systems Group has collaborated closely with the Danish Ministry of Energy and the Danish Energy Agency for many years on Danish energy planning. The work in 1987 included preparation of the Energy Review 1987. The activities concerning wind-energy economy and simulation of wind-diesel systems have been continued as has the project dealing with the prospects for absorption cooling. Finally, a study dealing with decentralized combined heat and power productic has been carried out.

The mission of risk analysis is to meet the demands of society for improved safety and of industry for improved reliability. This goal is pursued by undertaking R&D on reliability and risk analysis methods and tools, conveying know-how on these to industry and public authorities, and performing specific risk analysis studies.

In 1987 the research and development activities of the Risk Analysis Group included participation in three European benchmark exercises, concerning structural reliability, human factors and event sequences. In collaboration with JRC-Ispra and others, the development of a new tool for computer-aided risk analysis (STARS) has been initiated. Work has continued on the development of models for consequence management and on risk analysis within the research programme of the Nordic Laison Committee for Atomic Energy. In addition, work on the creation of a hazardous materials data base has been initiated.

Finally, a number of risk management activities in an international context have been taken up.

Several specific risk and reliability studies dealing with offshore oil and gas installations and the natural gas transmission system were carried out. Risk assessment studies have been made for a number of chemical industries in Denmark. Finally, the study on reliability of smaller windmills and economic consequences has been continued.

In conjunction with the work of the Risk Analysis Group, Risø hosted the annual symposium of the Society of Reliability Engineers, Scandinavian Chapter, SRE-Symposium 1987, which took place 5-7 October in Helsingør.

The above-mentioned tasks were carried out either as basic R&D studies or under contract with organizations, public authorities and industry. The majority of the studies involve close collaboration among Danish and foreign companies, consulting firms, ministries, and international organisations, such as the Danish Ministry of Energy, the Danish Energy Agency, the National Agency of Environmental Protection, the Nordic Council of Ministers, and the Commission of the European Communities.

In 1987 Members of the Systems Analysis Department have participated in a number of Danish committees dealing with questions of energy or risk and reliability. In addition, members of the Department have participated in international committees within the Nordic collaboration, the IEA, and European Communities, and have presented papers at various international conferences.

2. Risk and Reliability Models

Society and industry require risk and reliability analyses of higher and higher quality; hence, new methods of analysis must be developed and old ones improved to meet these new standards. Work in the Risk Analysis Group ranged from participation in multinational Reliability Benchmark Exercises conducted under the auspices of the Commission of the European Communities to internal Risø projects such as the development of computer software for consequence management.

In the framework of a major Scandinavian project on Operational Reliability and preventive maintenance the Risk Analysis Group is engaged in the subjects "Techno-economic framework for maintenance of process plants" and "Information exchange between designer and operator (on process equipment)". The project is in the planning stage.

Of a more practical nature, an international project concerning the physical modelling of torch fires was initiated by the end of 1987. The project is sponsored by the Commission of the European Communities (CEC) under the Major Technological Hazards programme and involves Risø, TNO (Holland), ARS (Italy), and DMI (Denmark).

The major research and development activities performed in 1987 will be described in detail in the following chapter.

2.1. European Reliability Benchmark Exercises

The analysis of a given problem by several research teams is the central idea of Reliability Benchmark Exercises (RBE). Their purpose is to compare and improve the methods and tools used for system reliability analysis.

In 1987, Risø took part in three such exercises sponsored by the CEC, one dealing with human factors, a second with structural reliability, and a third (still in the conceptual phase) with event sequence modelling. The event sequence modelling benchmark exercise will deal with the probability of a core meltdown in the Grohnde pressurized water reactor (PWR) in the first twelve hours following loss of offsite power. It is planned that the teams will analyse several systems and include component failures as well as human errors and common cause failures. The other two benchmark exercises will be described below.

2.1.1. Human Factors

A reliability benchmark exercise (RBE) concerning human factors began in 1986 under the Shared Cost Action programme of the Commission of the European Communities. Teams participated from the following countries: Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Spain, Sweden, UK, and USA. The human factors study was proceeded by a Common Cause Failure Reliability Benchmark Exercise, for which a final report was published this year (ref. 2).

The exercise concerns human errors during the testing and operation of the emergency feed-water system in the German Grohnde PWR nuclear power plant. The success of a routine functional test was first studied, and later the handling of an operational transient was examined.

The first phase of the study was started and reported on in 1986. After evaluating the results, the study was continued with a more selective second phase to allow a closer comparison of team results. Only one event was selected for analysis: non-detection of failures of a free-flow check valve. Each team used three methods: The THERP-method, the HCR-model and the SLIM-method. Satisfactory results were obtained using the first two methods, whereas results from application of the SLIM-method showed some disagreement.

The human error analysis concerned an operational transient caused by a loss of the external power supply, followed by additional irregularities of the Grohnde emergency systems. The study was based on detailed descriptions of the supposed reactions of the control staff, supported by a video recording produced for the purpose of this study. The video recording shows in a step-wise manner the actual instrument panels parallelled by the speaker's comments on signals and proper actions. In contrast to the video recording made for the first study case, this recording does not show operations or even simulated actions in the control room.

The human error probabilities were estimated by both the THERP-method and the HCR-model. The results disagreed by a factor 5 which is more than in the first phase of the study. Trouble was also experienced using the HCR-model, related especially to time estimate parameters.

A comparison with the results of other teams shows large disagreements, particularly with application of the HCR-model and with time estimates.

2.1.2. Structural Reliability Benchmark Exercise

The structural Reliability Benchmark Exercise concerned the reliability and structural integrity of pressure vessels. Teams from Risø, Framatome (France), Joint Research Centre Ispra as coordinator, participated in this Shared Cost Action programme.

These teams set up probabilistic models for the crack growth in and subsequent failure of such vessels.

A 1/5-scale pressure vessel, located at JRC-Ispra, was fatigue tested and leaked at approximately 350,000 cycles. The vessel contained both natural and artificial defects. The vessel was subjected to repeated cycles of pressurization and inspection. During this procedure a leak was located in the nozzle corner, repaired, and the cycling was continued.

Repeated ultrasonic inspections showed a very wide scatter in the data but indicated some crack growth in the artificial defects in one of the longitudinal welds. Preliminary crack growth calculations (deterministic) indicated that the crack initiation phase (i.e. the artificial defect becoming a real crack) is very important, but difficult to quantify. Stress calculations were performed using the ADINA-code on a 2-dimensional grid.

2.2. Computer Aided Risk Analysis

A collaborative project between Risø and JRC-Ispra began in 1986. Its purpose was to develop an integrated software package for use in the risk analysis of chemical process plants and nuclear power facilities. In 1987, the collaboration was expanded to include VTT (Finland) and possibly other institutions beginning 1988. This new system, called a Software Tool for Advanced Reliability and Safety analysis (STARS), was planned to be the next generation of programs such as RIKKE (developed at Risø) and CAFTS (developed at JRC-Ispra). STARS will not only be able to perform the same tasks better and more effectively than the two previous systems, but perform some new tasks as well.

STARS will take advantage of the latest developments in Information Science, borrowing techniques and ideas from Artificial Intelligence and expert systems. It will be developed to operate on IBM/PC-AT compatible computer systems which use the UNIX system V operating system.

The project is divided into the following subprojects:

1) The development of software to perform a preliminary evaluation of a process plant, identify and rank the possible hazards, and construct pertinent event sequences.

2) The development of software for the construction of logic models, e.g. fault trees and event trees, for the pertinent event sequences identified in the preliminary hazard evaluation, as well as the development of software for analysis and evaluation of the resulting logic models.

with JRC-Ispra as the coordinating body, and Risø as a participant in both subprojects.

The aim of the first subproject is to develop a software system that can perform a HAZOP (HAZard and OPerability) type analysis, that is, a computer program that can point out the probable hazards for a given type plant and then rank them in terms of their respective probabilities. The system will use three separate knowledge bases, supplied by Risø; and a central program which will perform the actual analysis. A computer program called HAZOPEX from one of the other partners (VTT Finland) will be examined for suitability as the central code.

A proposed structure for the software system in this subproject is shown in Figure 2.1. Work has already begun on the knowledge bases.

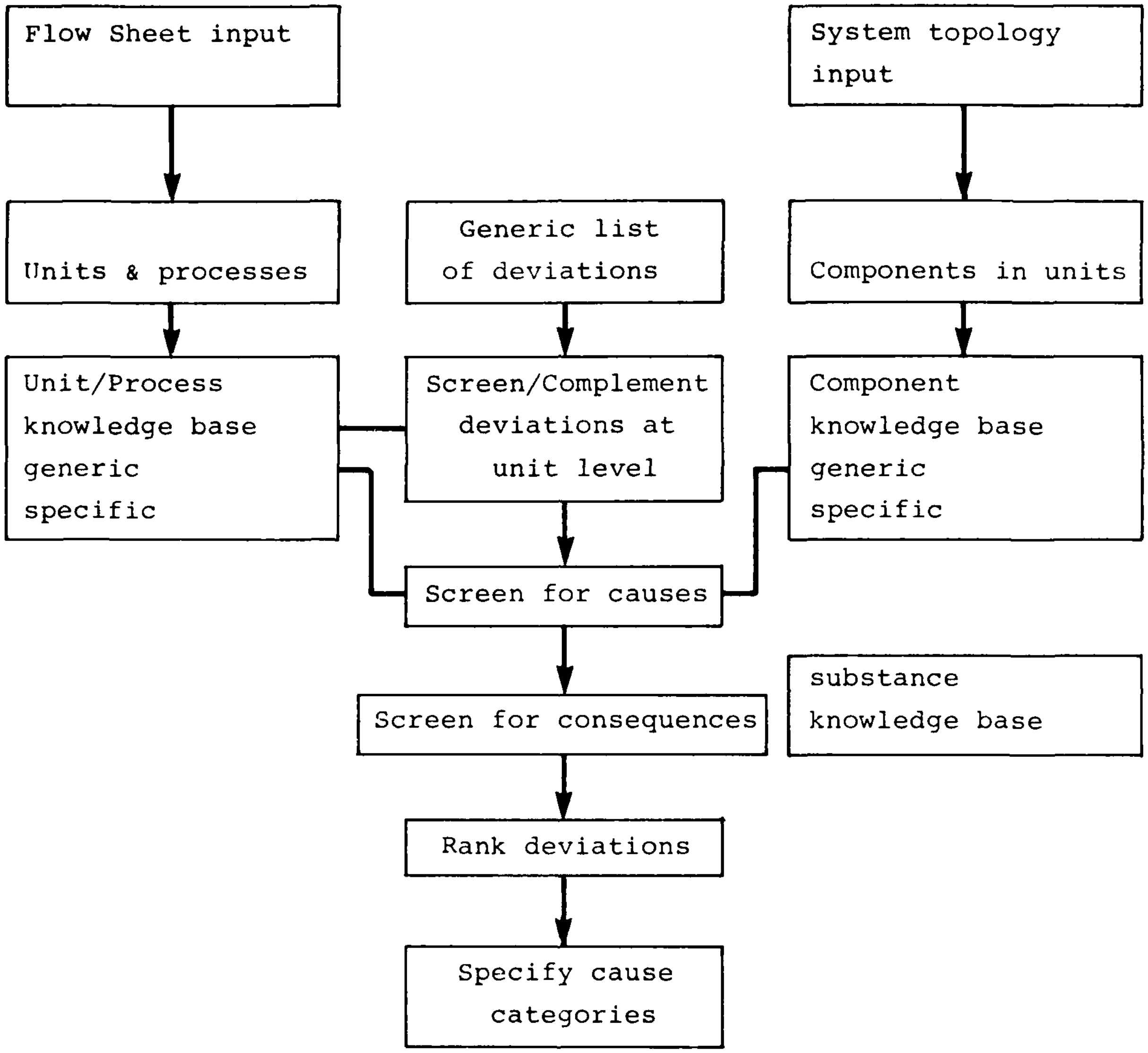

Fig. 2.1. Program structure for the identification and analysis of hazards.

In the light of Risø's development of the RIKKE package for the construction of fault trees, it was logical that Risø should also take part in the second subproject. Until now, work has focused on a detailed analysis of the RIKKE knowledge base and on the underlying theory of automated fault tree construction. Future work at Risø will focus on the development of knowledge bases containing generic information about types of equipment commonly found in chemical process plants and nuclear power facilities.

In a later stage in the project, Risø will develop more detailed knowledge bases for specific types or pieces of equipment, as well as take part in the integration and implementation of the software. By the end of 1988, it is planned to have a prototype system running that is able to analyse a representative problem (a nitric acid plant).

2.3. Consequence Management models

In connection with the approval by the authorities of chemical process plants the probability distribution of the consequences of potential accidents is an important consideration. However, the determination of such consequences is still largely based on fairly simple models and limited experimental evidence. Therefore, efforts are being directed toward model-building and experimental research.

To meet the above demands, concepts have been developed for an interactive computer program called COMA. COMA should be able to dynamically simulate a sequence of events (starting with release from containment) on the basis of a library of physical models which, by virtue of a powerful interface, can be easily expanded with new models. The initial development phase began in 1987. An APOLLO work station was chosen as the computer system and programing began using PASCAL.

A Ph.D. study, initiated in January 1987, concerns the micrometeorological aspects of risk assessment. The purpose of the project is to investigate and develop methods to predict the atmospheric dispersion of accidentally released chemicals.

In connection with this study, a PC-based implementation of the dense gas dispersion model, Heavy Puff, has been carried out in collaboration with Risø's Meteorology Department. The program contains the original Puff Model (Ref. 3) supplemented with a flash model describing the rupture of a pressurised tank containing liquified gas. The program has many user-friendly features, such as a data base with thermodynamical data for a number of substances, various graphical representations, print-out documentation, etc. It is hoped that the program will be useful in practical risk analysis, since it greately reduces the time needed to carry out calculations and for documentation. With easier access to results, consequence calculations can enter in an early stage of the analysis, and a broader spectrum of potential accident scenarios can be taken into account.

A series of calculations was made in order to check the model against the results of the Thorney Island large-scale trials. Although the model is basically uncalibrated, predictions compare very well with the experimental results, and no adjustment of the parameters has been found to be necessary. Figure 2.2 shows results of the comparison for one of the test trials.

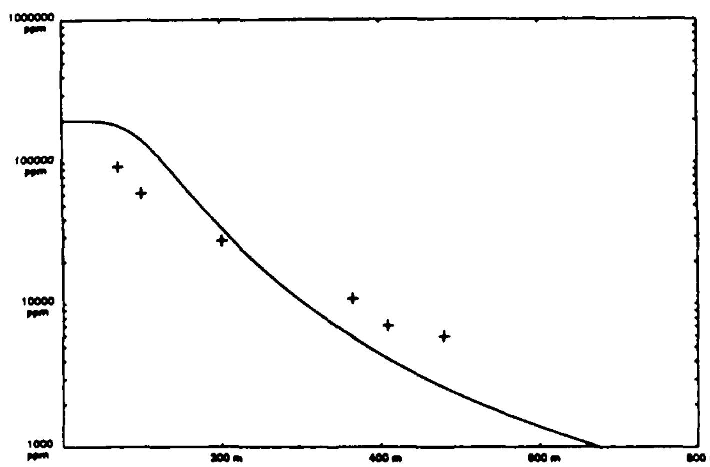

Fig. 2.2. Comparison of Heavy Puff Program with Thorney Island Results.

The program assumes the basic initiating event to be the rupture of a pressurised tank, but other discharge mechanisms are also relevant. A jet-plume model has been developed describing a continuous discharge in the form of an unobstructed jet. The model makes a smooth transition between a turbulent jet (close to the outlet) and passive tracer-like dispersion at large downwind distances. It resembles other jet models, but also takes buoyancy into account.

Buoyancy effects are sometimes important. In the two examples shown below, material is released under stable conditions (inversion). In the first example (Fig. 2.3), the gas is light/hot and the plume rises, but levels off at a certain height much lower than for a neutral condition. In the second example (Fig. 2.4), the gas is heavy and cold, and the release point is elevated. It turns out that the plume sinks but that the centre line does not strike the ground. This means that in this case a heavy gas blanket should not form. For neutral conditions the predictions of the model are similar to those obtained using Briggs formulae.

The turbulent dispersion of a contaminant is governed by the structure of the turbulence, which again may be influenced by the presence of the spreading cloud. In the top layer of a heavy cloud, this will be the case. Here the strong density gradient will cause attenuation of the turbulence, and "eddies" will mix with gravity waves. Since (ideal) waves are inefficient in transporting material, the impact of the density gradient on the transport properties is quite complex. Methods that deal with problems of this type are being studied.

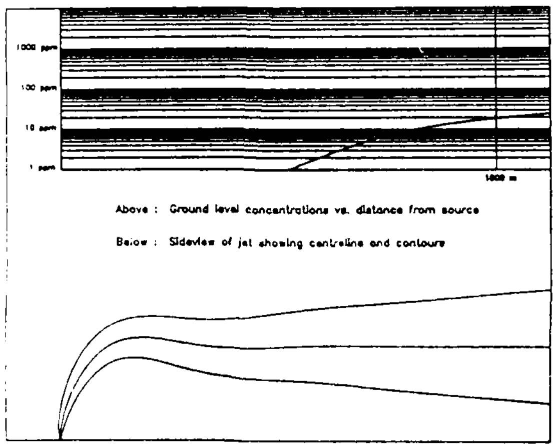

Fig. 2.3. Concentration profile for grand release of a light and hot gas.

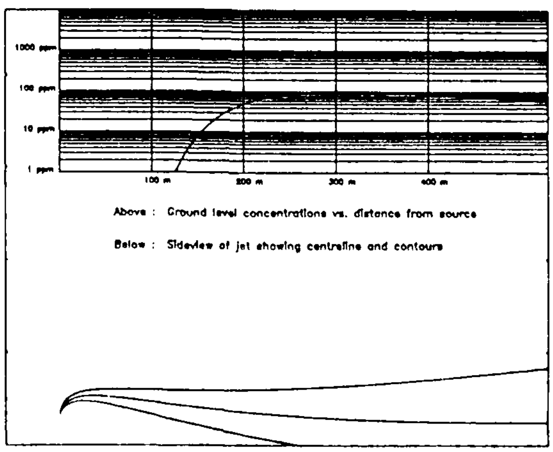

Fig. 2.4. Concentration profile for elevated release of a heavy and cold gas.

2.4. Unwanted Chemical Reactions in the Chemical Process Industry

A Ph.D. study concerning unwanted reactions in the chemical process industry was completed in 1987. The project was carried out in collaboration with the Institute for Chemical Industries, at the Technical University of Denmark.

The purpose of the study was to establish a basis on which the efficiency of risk analysis methods and laboratory tests can be assessed in order to identify unwanted chemical reactions. The main questions are:

- Are the methods used/known by the designers?
- Are the methods sufficient?
- How can the methods be improved?

The approach that was used in order to answer the basic questions of the origin, occurrence and importance of unwanted chemical reactions was a study of accident case histories. In all, 190 accident case histories were analysed.

Accidents in batch reactions were much more frequently reported than in continuous process plants. The former accounted for 57% and the latter 10% of the 190 accident case histories. A remarkable result was that a relatively large percentage, 24%, occurred during the holding or storage phase.

The most important causes of unwanted chemical reactions were found to be: impurities, contaminations and stray catalysts (20%), mixing of wrong chemicals (20%), mischarging, incorrect process conditions (19%), and insufficient mixing (13).

In the last part of the analysis of the accident case histories, it was discussed whether or not one of the existing methods could have identified the hazardous situation. In about half of the cases, the accident could have been foreseen by use of risk analysis and in about one-third by use of laboratory tests. In 15% of the cases it was not possible to suggest a method which might have identified the hazard.

The advantages and limitations of four thermal stability tests were evaluated by a detailed investigation of an incident that occurred at a Danish process unit, a runaway reaction in a batch reactor containing 1200 l of reaction mixture for preparing a joint-filler. One of the consequences was a release of HCl and Cl_2.

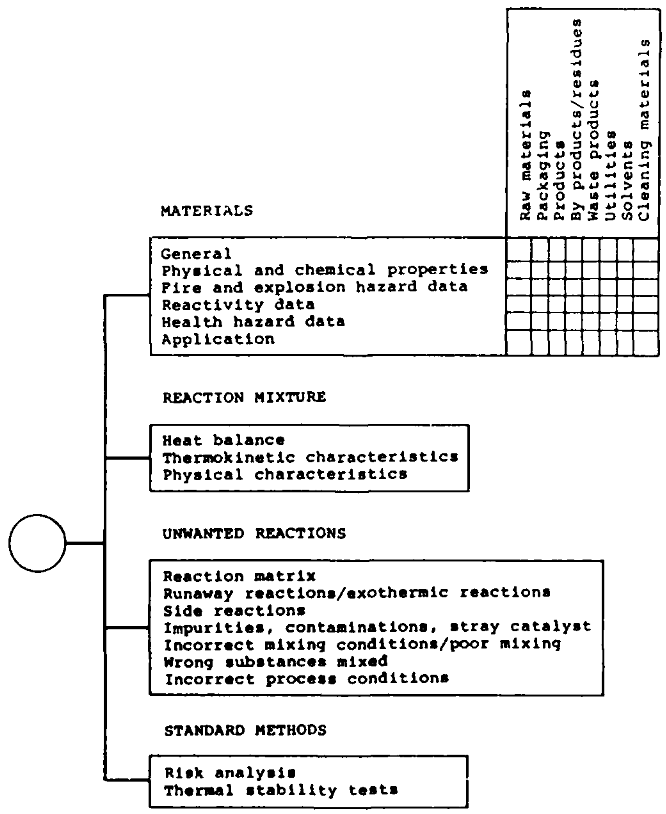

Fig. 2.5. Structure of the checklist for identifying unwanted chemical reactions.

The mixture was tested by Differential Scanning Calorimetry, Differential Thermal Analysis, Thermogravimetry, and a Thermal Activity Monitor. The first named was the only method that could identify the hazard in question. This test determined that the reaction enthalpy was about 3600 J/g in the temperature range 90-500°C with an initial temperature of about 90°C. As the maximum normal process temperature was 60°C, this yields a rather low safety margin of about 30°C. A safety margin of at least 50-60°C is normally recommended.

A checklist for identifying unwanted chemical reactions is proposed which is based on results from the present study and checklists found in the open literature. The checklist is structured in four main groups, which again are divided into subclasses.

(See Fig. 2.5)

Comments about the checklist:

Materials: First, it is important to ensure that all the relevant information about the chemical substances involved is available.

Reaction mixture: The next step is to establish information about the chemical reactions, the reaction mixture, and the process equipment. The purpose of this part of the checklist is to verify that the process design fits the process conditions.

Unwanted reaction: This part of the checklist is the most difficult to formulate. Complete answering of the questions requires extensive knowledge, fantasy, and creativity. It is not only a question of going through checklists, etc. but also one about attitudes. The designers and chemists must constantly be aware of the unexpected and unknown.

Standard methods: Finally, it is checked whether or not risk analysis and/or thermal stability tests have been used during the analysis.

2.5. Risk Analysis, NKA

The project "Risk Analysis" within the Nordic Liaison Committee for Atomic Energy (NKA) Research Programme concentrated in 1987 on analysis of human interactions and the Summary Report on the Benchmark Exercise concerning common cause failure events for motor-operated valves in Swedish boiling water reactor plants was completed.

The work on human interactions consisted of

- qualitative and quantitative retrospective analyses of all Swedish and some selected non-Scandinavian probabilistic safety analyses
- comparison of methods for modelling human interactions
- reference study on human behaviour under accident conditions.

The main effort was concentrated on the latter item. A study of a selected accident situation at the Forsmark 3 plant was performed. The accident sequence comprised a loss of off-site power and a total failure of the auxiliary feed-water system. This situation requires a depressurization initiated by an operator action. The goal of the reference study was to describe and analyse the human interactions.

As a part of the study, an exercise at the Swedish Training Simulator was performed. A crew of training instructors acted as operators during the sequence. The purpose was to get a better understanding of the possibilities of the operators taking into account the information available, the alarms, the time available and their cooperation during the sequence. The exercise gave valuable insight into the complexity of human behaviour during an accident sequence.

The analysis of the accident sequence resulted in a recommendation for improvement of the instructions and changes in the control system.

2.6. Hazardous Materials Data Base

In connection with risk analysis for the chemical industry, it is essential to have access to information about hazardous chemical substances. In order to provide easier access to this information, a new data base was created. The data base contains information on substances examined in previous risk analysis studies (see 4.2), and is able to be altered to include the newest available information.

The data base contains unambiguous identification of the chemical substance, that is Chemical Abstracts Service (CAS) number and International Union of Pure and Applied Chemistry (IUPAC) name, as well as physical, chemical and toxicological information about the chemical substance.

Several ways of searching the data base are possible, e.g. after CAS number, common name or formula. Furthermore, it is possible to list the substances in the data base with a specific property, e.g. carcinogenicity, flammability.

At the moment, the data base contains about 75 different hazardous chemical substances. It is planned that it will contain 200-300 substances by the end of 1988.

The software used was Dbase-III-plus, and the computer is an IBM/PC-AT with a hard-disc.

In addition to information about hazardous chemicals, access to information about toxic substances which are produced as a result of the combustion of such chemicals is essential to the risk analyst. A research project about this subject has been started.

2.7. Risk Management

The World Bank is preparing a research programme on Safety Control and Risk Management. Work has begun with the aim of identifying the basic research topics. This includes risk analysis, planning of operation and maintenance, staff planning and organisational systems. A large effort and cooperation among scientists within several research areas will be required.

Ongoing R&D projects might fit into this programme.

The practical side of risk analysis, that is definite projects such as those described in 4.2, often play a role in shaping the research activities in the Risk Analysis Group.

Risø performed a risk analysis of a new production of the herbicide phenmedipham for the company KVK (Kemisk Værk Køge). That work was reported in 1986 and the report was used as part of an application to the relevant authorities for approval of the new production line.

Early this year, public discussion started in the news media about the case. Acceptance criteria were questioned, the risk analysis reported by Risø was subject to some criticism, and prohibition of the particular production was supported by groups of citizens in the region. There have been other cases with public discussion of the acceptance and the relevance of the criteria used, but on this occasion even the methods and quality of a risk analysis have been questioned in public.

The Risk Committee of the ATV (Danish Academy of Technical Sciences) is working on the promotion of Danish risk research and risk management. Therefore, the committee has shown great interest in following public discussions and the handling of the KVK-case. Two members of the risk analysis group participate in the committee's work.

3. Energy Economy Models

Fluctuations in energy prices, structural changes in society, and the introduction of renewable and indigenous energy sources make the energy future uncertain and increase the complexity of the energy system. In trying to cope with these future energy challenges the development and application of energy-economy models are important.

Model development in the Energy Systems Group takes place at two levels:

- advanced, detailed and highly developed models for the forecasting and analysis of energy consumption and supply to be used on large mainframe computers,
- relatively simple models for partial analyses and forecasts of energy demand and supply, and/or specific parts of the energy system (e.g. energy technologies) to be used on personal computers.

3.1. European Commission Energy-Economy and Environmental Models

The Energy Systems Group is responsible for the Danish implementation of a number of models developed within the energy modelling programme of the Commission of the European Communities. The models presently under development or implementation are the econometric model HERMES, the simulation model DESS, and the optimization model EFOM with an extension for taking into account environmental effects.

3.1.1. The Macrosectoral Model, HERMES

The HERMES-model is an econometric medium-term model for determining the economic development with special emphasis on energy-economy interactions. Work on the model began in 1981 with the objective of developing national models of similar structure for each of the EC-countries and interlinking these to create a multinational model.

In 1987 work on the Danish national model concentrated on pinpointing and changing particular areas of the model in order to get the model to reproduce the observed past development. As the model is still unable to reproduce past development satisfactorily this work will be continued in 1988. Other tasks have been the updating of the data base of the model to 1983 and transferring the incomplete model to the central project group.

3.1.2. The Detailed Energy Systems Simulation (DESS) Model

The overall purpose of the work is to develop a flexible and easily understandable tool for translating energy demand forecasts into their economic and environmental consequences. The project aims to develop and extend a model that has been used in Denmark (The DES-Model) into one that is able to simulate different national energy supply systems, in particular the power-generating and space-heating systems. The model is being implemented for Denmark, the Federal Republic of Germany, and Italy. This project was begun in 1985, and is expected to be finished in 1988.

The transcription of the software to commonly used mainframe computers and the development of a rigorous modular structure of the model was completed in 1986. In 1987 the new model and some extensions of it have been used for the Danish energy system (see Section 3.3), data have been collected during visits to Germany and Italy, and the model has been implemented at the University of Essen for a study of the German power system. A status report was submitted to the EC in September. This report includes a description of the structure of the model, the data requirements, some tentative results, and a user's manual for the software.

3.1.3. The Energy Flow Optimization Model (EFOM)

The EFOM model is the supply part of the Commission's energy model complex. It uses the technique of linear programing to find the optimal energy supply structure that satisfies a given demand vector.

An extension of the EFOM model that includes emissions of pollutants as well as emission abatement techniques was developed by three German institutes during 1986 and 1987 as part of the research project "Optimal Control Strategies for Reducing Emissions from Energy Production and Energy Use on a European level". This model is being implemented for all the EC countries in order to study various scenarios for the reduction of SO_2 NO_x.

The emission reduction measures considered are: fuel switching, new energy conversion technologies, and the introduction of emission abatement technologies.

All scenarios are based on the same forecast for the economic development and the demand for useful energy. In particular, the following scenarios are studied:

"Doing Nothing" Case, assuming no abatement technologies and the 1980 legal situation.

"Legal" Case, assuming existing national and EC emission regulation measures.

"Cost-efficient" Cases, assuming overall emission reductions by 30 to 70 per cent, and

a case describing an EC proposal for emission reduction for large-scale combustion installations.

The model has been implemented on Risø's VAX computer, and an interface to the DESS model has been established in order to facilitate data collection and documentation. The results from the project will be published by the Commission in 1988.

3.2. Uncertainties in Energy Economic Calculations

The MUSA model (Model to include Uncertainties in System Analyses) is a general tool for stochastic modelling aimed primarily at handling uncertainty aspects emerging in energy economic calculations. The model has been structured so as to obtain high flexibility in a large variety of applications.

The model contains a calculation structure for performing comparative economic analyses of energy technologies. Economic analyses of difference projects are performed on a private economic basis and a social economic basis. Employment and import coefficients can be taken into account in national economic calculations. Assumptions on overall shadow prices can also enter the calculations. Probabilistic calculations are based on detailed data for the various components. The model calculates probability distributions (density functions) for such quantities as present values and levelized cost of energy.

The structure of the MUSA model allows all data to be defined by probability distributions. Facilities give access to a large number of commonly used theoretical and practical distribution types for specifying uncertainties of input variables. Facilities have been developed to allow stochastic relationships between input variables to be taken into account. Correlation, stochastic relations between input variables and new variables and relations can be added to the calculation structure as data input to the model. Furthermore, facilities for stating assumptions on uncertainties in fuel price forecasts

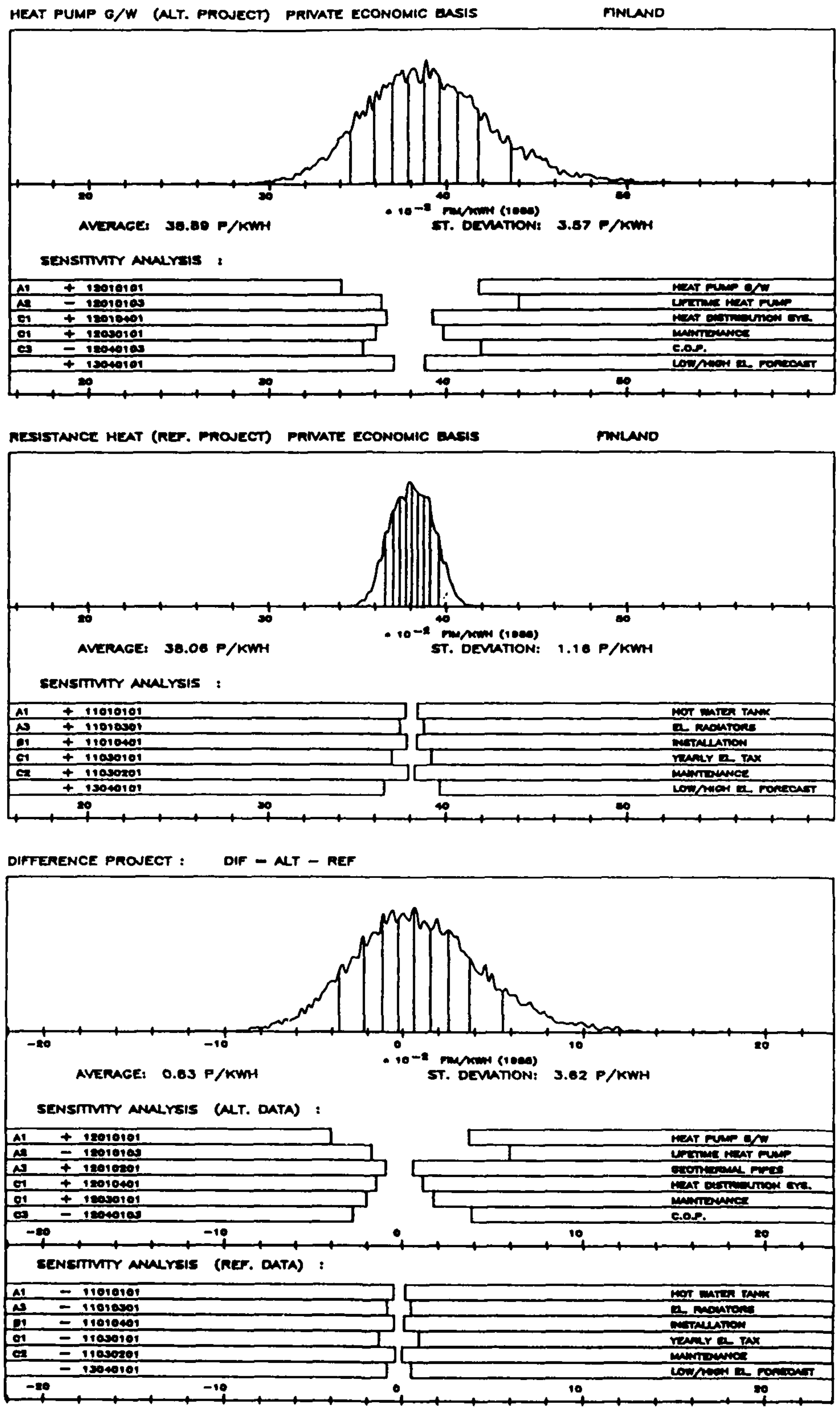

Figure 3.1. Example presentation sheet from the MUSA-model.

are available in the model.

The model combines probabilistic calculations with sensitivity analyses based on specified uncertainties in input data. Sensitivity analyses describe the influence from individual data distributions on the calculated overall uncertainty, and thus point out major and minor risk-contributing factors. Data and results from the models are presented graphically and provide a basis for applying various decision criteria.

An example of a presentation sheet from the MUSA-model is shown in figure 3.1. The example is part of a study carried out under contract with the Nordic Council of Ministers and the Danish Ministry of Energy, and completed in 1987.

Figure 3.1 consists of three parts. The upper part relates to the alternative project, a heat pump system, the central part to the reference project, a resistance heat system for comfort heating in dwellings, and the bottom part shows results of the difference project calculations.

Levellized cost of energy in Finnish pennies (p) per kWh is shown along the x-axis throughout the figure. The irregular figures are calculated probability distributions. Vertical lines divide the figures into sections (fractiles) each covering 10% of probability. The fractiles, standard deviations and average values are main results of the probabilistic calculation.

Sensitivity analyses are shown as gaps in the horizontal bars below a calculated probability distribution. When varying a corresponding data variable over the interval $[\mu - 2\sigma; \mu + 2\sigma]$, where μ is the average value and σ the standard deviation, while all independent stochastic variables are kept at their mean value, the effect on the result is a variation within the displayed gap in a bar.

A probabilistic calculation on the difference project, as shown in the bottom figure, shows the two projects to be equal. Due to symmetry in this example, possible gains or losses in choosing the one project rather than the other are almost equal.

If however, a risk-avoiding attitude is chosen, by using a decision criterion ranking the project according to lowest values of 90% fractiles, the reference project will be favoured.

From the figure it can be seen that the 90% fractile value of the reference project is near 39.5/kWh and the 90% fractile value of the alternative project comes out as about 43.5/kWh. A levellized cost value of 39.5/kWh in the alternative project case can be expected to be exceeded with a probability of about 40% as seen in the figure.

3.3. Simulation Models for the Danish Energy System

The DES-Model (Danish Energy System) is the origin of the DESS-Model, which is now being developed for the EC (see Section 3.1); it has been used for several years as the most comprehensive model for Danish national energy planning. It translates useful-energy forecasts for the various demand sectors and exogenous development plans for conversion units into annual energy requirements as well as fuel, operation and maintenance, and investment costs.

In 1987 the model version which had been used for the Energy Review 1986 was transferred to the new DESS software and model structure, and the model was updated and used for the Energy Review 1987 issued by the Ministry of Energy.

The latest developments in energy consumption have shown that there is a need to investigate in more detail the effect of the heat demand on air pollution, including the importance of a future heat demand different from the official forecasts. This question has been examined by Risø in collaboration with Rockwool A/S, and the results were published in three Danish technical journals.

Based on the official forecasts of the development of the heat demand some alternatives were set up, and the environmental consequences were calculated using the DESS-Model.

The purpose was to examine the contribution of the heating sectors to the emissions of SO_2, NO_x, CO_2, CO and particles as well as to establish a basis for an evaluation of the investments required to achieve a reduction of these through savings.

The reference scenario is described in status report 1986 of the Ministry of Energy (Energiministeriet 1986). Calculations have been made of the environmental consequences of 4 alternatives for which the total useful heat demand varies from 145 to 195 PJ in 2000.

3.4. Simulation Model for Collective Combined Energy Systems

The simulation model, SIKKE, was originally developed in 1984 for simulation of combined energy systems. SIKKE evaluates the economics of different system set-ups and control strategies by simulating over the year with fixed time steps, e.g. 10 minutes or 1 hour.

In 1987 a further development of the model was financed by the Nordic Council of Ministers and this work will be finished in 1988. The model was extended to include storage of both heat and electricity. The subroutine describing electricity storage can be used for many kinds of such storage. The only parameters needed in the outputs are: the initial, minimum and maximum content, maximum charging and discharging rate, charging and discharging efficiency, investment and operational costs.

These new subroutines were used in a simulation of a small pumped storage plant on the island of Bornholm, where the degree of self-sufficiency with respect to electricity supply for a small community were computed by a simulation over a year with time steps of one hour. Two 95-kW wind turbines supplied electricity to the pumps at the storage tank when demand was low. Calculations were done for two capacities of pumped storage.

The SIKKE model has also been used in a benchmark exercise in the IEA wind energy programme under annexe VIII (decentralised application of wind energy). Data for a wind/diesel system at ECN in The Netherlands were used for the exercise where the results from simulation models in differenct IEA countries were compared.

3.5. Technical/Economic Models for Offshore Oil and Gas Activities

During 1987 the work on the Sequencing Model for Oil and Gas fields (SMOG) has been continued. The work is carried out in close cooperation with the Chr. Michelsen Institute (CMI) in Bergen, Norway, as a part of a joint contract with the Danish authorities and Dansk Olie og Gas Production A/S (DOPAS).

SMOG is a comprehensive model for the offshore sector. From a detailed description of the oil and gas fields and the transport systems, and from some economic parameters, the model maximizes the net present value and points out which fields and field alternatives should be developed and when this should take place.

In the model each existing or potential field is described in terms of time series for

- oil, gas, and NGL production
- investments
- fixed and variable operation costs
- fixed and variable transport costs
- consumption of user-defined resources
- oil and gas processing capacity
- Each transport system is described by a time series for transport capacity.

Economic data are given as time series for oil, gas and NGL prices, dollar exchange rate, discount rate, investment and operation budget, and the budgets for user-defined resources.

Moreover, some global production constraints are modelled by time series for maximum oil and gas production and minimum gas production.

The above data are the main data used during the maximization of the net present value.

Special constraints (called logical constraints) are also modelled:

The user may specify for a group of fields that exactly one or at most one of the fields in the group should be developed.

The user may specify for a field F that it should not be developed unless at least one field within a certain group of fields is developed. For each field in the group a minimum and maximum time lag relative to field F may be specified.

The user may specify for a group of fields that no one of these fields should be developed unless a certain other field is also developed.

During 1987 detailed design specifications of the user interface were worked out and the programing was almost completed.

4. Risk Assessment

During 1987 the Risk Analysis Group was engaged in risk and safety analyses on a consultancy basis for Danish industry and authorities. These include analyses of the Danish natural gas system, a wood preservation facility and the crude oil terminal in Fredericia.

Furthermore, advice and assistance were given in connection with the application for public approval of an insecticide plant and an ammonia storage facility.

4.1. Offshore Oil and Gas Production

Stabilized crude oil produced in the Danish North Sea is transported 320 km through a 20" pipeline to an oil receiving terminal. The submarine crude line terminates at Kjærgård on the west coast of Jutland. From there the pipeline continues across Jutland ending at the terminal facilities in Fredericia, located next to the Danish Shell refinery. The crude is then transported to the municipal harbour for tanker loading or to the Shell refinery for further processing.

In 1986, a modification was made which would permit an increase of the oil receiving capacity of the terminal.

On behalf of Dansk Olierør A/S, owner of the Danish crude oil transportation system, the Danish firm of consulting engineers, Nielsen & Rauschenberger, together with Risø National Laboratory performed a safety evaluation of the modified terminal. This safety evaluation was submitted to the Danish environmental authorities in connection with an application for approval of the project.

In the safety evaluation, potential events (fires, explosions, unignited releases of hydrocarbons) which may endanger the safety of the people and the environment were identified; and the evaluation was performed with special attention paid to assuring that reasonable and relevant precautions against accidents were included in the construction and in the operating instructions as well.

A project concerning the security of supply of the Danish natural gas transmission system is started. The aim is to access possible loss of supply events, evaluate their probabilities and economic consequences, and propose taking measures against such events.

Finally, the Risk Analysis Group represented Risø at two international conferences the Danish national stand at the World Petroleum Congress in Houston and Offshore Europe in Aberdeen.

4.2. Risk Analyses for the Chemical Industry

The EEC directive concerning "Major Accident Hazards of Certain Industrial Activities" has been implemented in Denmark. Therefore, chemical plants are now required to submit risk analyses of their operations. The Risk Analysis Group has performed or taken part in several of these analyses.

In 1987 the Risk Analysis Group made supplementary analyses to several of the previously performed analyses, due to changes in plant lay-out or authorities requirements. These were the risk analyses of an ammonia storage and transfer facility, a pesticide formulating plant and a herbicide production plant. (See 2.7).

A project concerning the risk analyses of 23 similar wood preservation plants has been initiated. The project is structured as follows:

A detailed risk analysis is being performed for one of the plants selected as being representative of all of them.

For the remaining plants, similarities and differences in relation to the detailed analysis will be identified and their impact on plant risks will be assessed.

4.3. Reliability of Smaller Windmills and Economic Consequences

A project was started as part of the Danish Energy Research Programme 1986 (EFP86) with the aim of including reliability analyses as a part of the technical and economic assessments of smaller windmills. The first generation of windmills experienced severe failures. The wind power industry learned much from them and later designs showed considerably improved reliability. However, a systematic utilization of the operating experience gained has not yet been made.

The project aims to meet this need. Through reliability analysis technical and economic consequences will be assessed from the existing materials on operating experience. The work is carried out in collaboration with the producers of windmills.

The project is structured as follows:

1) On the basis of published operating experience, a statistical analysis of 55-kW wind turbines has been performed. 264 wind turbines were included in the analysis and in all 764 failures were registered (from 1980 to 1985). The results are shown in figure 4.1. The critical affected systems have been identified and the most important were the control system (including the wind vane), the blades, and the yaw system. The analysis showed that there were no significant differences in operating experience from one design to another. For this reason a particular design has been selected for the detailed reliability analysis.

2) The wind turbine has been divided into 12 subsystems, and for each of these a fault tree has been constructed. The next step is to perform a fault tree analysis of the wind turbine in its entirety.
3) On the basis of the reliability calculations, an economic analysis will be carried out. The aim of this part of the project is to investigate the economic consequences of different strategies concerning maintenance, construction, selection of components, etc.

The results that arise from the project are suggestions for improved design, strategies for operation and procedures for operation and maintenance; the main purpose is to reduce the expense of repair and to increase the availability of the windmills, based on assessing the life-cycle costs.

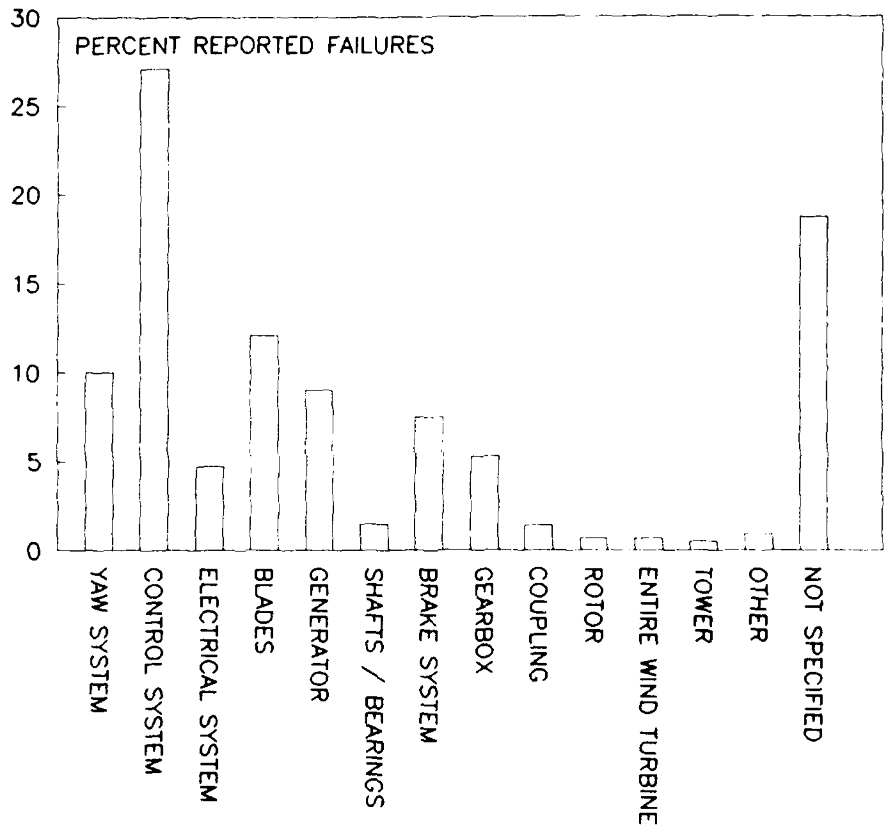

Figure 4.1. Numbers of failures in subsystems for 55-kW wind turbines.

5. Energy Planning and Technology Assessment

The Energy Systems Group collaborates closely with the Danish authorities, especially the Ministry of Energy and the Energy Agency. ESG has participated in the ongoing energy planning, the preparation of energy reviews etc., and contributed to answering parliamentary questions. ESG is involved in the Staff Training and Institutional Strengthening programme (STIS) initiated by the Energy Agency. Finally, the group has carrried out a number of specific studies, in collaboration with industry and public authorities.

5.1. Danish Energy Planning

The main task in this area has been work in connection with the latest Energy Review. ESG contributed to the preparation of this review by performing the calculation for the various supply scenarios using the DES-Model. Furthermore, industrial energy demand and household demand for electricity was forecast, applying the technical-economic industry model and the household appliance model, respectively.

Renewable energy technologies are an important issue in Danish energy planning. The Energy Systems Group has calculated the economic and financial costs for wind turbines in collaboration with the Ministry of Energy and the Energy Agency.

5.2. Energy Planning and Project Assessment in Developing Countries

A study of the project administration procedures in Zambia was performed including both the principle formal structures and the actual informal practice. This was part of the continued collaboration with the Department of Energy (DOE) in Zambia. The study was conducted as a part of the Ph.D. project concerning methods of analysis applicable to rural energy projects. One of the conclusions of the study is that international development organisations and national aid agencies play a very important role in both the preparation and selection of projects.

These donors are often involved at a very early stage of the preparation phase. Due to the informal contacts gained at an early stage, their policy views and priorities have a strong influence on which projects are actually selected for execution. This tendency is naturally emphasized by the present deterioration of the Zambian economy, because the need for foreign support has increased substantially. The situation is, however, not specific for Zambia but is common for many of the countries in sub-Saharan Africa.

Besides this specific study the revision and development of the **PR**oject **A**nalysis **M**odel (PRAM) has continued on the basis of the comments obtained during the presentation in DOE late 1986.

The "Southern African Development Coordination Conference (SADCC)-Fuelwood" project, in which the Energy Systems Group participated as part of an international team of consultants, was finished early in 1987. The results were presented to the SADCC Energy Technical and Administrative Unit in Angola in a series of reports and video and tape slide shows.

5.3. The Channels of Interdependence between the Industrial and Developing Countries

A Ph.D. project was initiated in 1987 concerning the channels of interdependence between the industrial and developing countries, with emphasis on the changes in the oil price. The precise mechanism through which these effects are transmitted is complex and is so far only partially understood.

Special attention will be given to the effects of the changes in the oil prices on both fuel-exporting and fuel-importing developing countries. The economic development of these two groups has differed sharply since 1972. The study will also examine whether there is asymmetry in the effects of the increase in the oil price in the period 1971-1980 and the effects of the following decline in the oil price after 1980.

The financial transmission has become more important, especially after 1978 because of the significant increase in indebtedness of the developing countries and the increased capital mobility. The financial transmission operates through changes in the international interest rates and the exchange rates of the industrial countries.

A significant part of the project will be an empirical (multicountry) macromodel where both the transmission through the goods markets and the financial markets can be analyzed and quantified.

In the model, the developing countries will be split into homogeneous blocks, in order to identify the sources of transmission. The main categories will be fuel-exporting and fuel-importing countries. This will allow the possibility of assessing the effects of a) the increase in oil prices in the period 1971-1980 and b) the following decline in the prices up to the present. The countries will also be grouped according to types of export, the level of debt burden, and the level of income.

5.4. Wind Energy

Within the past 10 years the importance of wind power in Denmark has increased substantially. Not only has the importance of wind turbines as a renewable source of energy increased rapidly, but especially the Danish export of wind turbines has had an impact upon industrial development in Denmark. Table 5.1 shows the number of wind turbines erected in Denmark and exported, including the installed capacity and the value of sales.

Table 5.1. Wind turbines erected in Denmark and exported

	Installed in Denmark			Export		
	Number	Capacity (MW)	Sales (Mkr)	Number	Capacity (MW)	Sales (Mkr)
Year						
1976-78	50	0.5	-	-	-	-
1979	120	1.6	-	-	-	-
1980	200	5	25	-	-	-
1981	220	7	50	30	0.4	4
1982	150	7	50	50	1.0	10
1983	100	4	35	360	20	200
1984	150	8	80	1600	110	1000
1985	314	25	200	3000	200	2000
1986	320	30	250	2000	170	1200
mid-1987	120	12	100	-	-	-

In 1986 a project to analyse the economics of wind power was initiated by the Energy Systems Group in collaboration with the Test Station for Windmills at Risø. A preliminary report was published in 1987, and some of the results will be summarised shortly.

A statistical analysis of wind turbines already existing in the Danish energy systems shows that

- the annual production of electricity by new 55-kW wind turbines has on average increased by more than 50% from 1981 to 1986. This is caused mainly by better sitings, higher efficiency, and more reliable wind turbines.
- using typical assumptions for investments, repair and maintenance costs, and lifetime for a 55-kW wind turbine, the costs of wind-produced electricity are shown in Table 5.2 for different statistically based production assumptions.

Table 5.2. Production costs for electricity produced by a typical 1985 model 55-kW wind turbine using actual production values (adjusted for the energy content in the wind)

Production		MWh	Production costs øre/kWh
Maximum	1986	147	38.3
Average for wind farm	1986	134	42.1
Overall average	1986	116	48.6

The size of commercial wind turbines has increased considerably in the past 10 years. Most of the wind turbines on the market today are in the range 100-200 kW. Using typical economic assumptions the costs of electricity produced by a hypothetical 165 kW wind turbine are shown in Table 5.3.

Table 5.3. Production costs per kWh for a hypothetical 165-kW wind turbine. Production is estimated for roughness class 1 and 2, and adjusted for shadow and production losses (10%)

Production	MWh	Production costs øre/kWh
Class 1	342	34.4
Class 2	265	44.4

Figure 5.1 shows the dependence of production costs upon the production of electricity and the real interest rate.

Comparisons show that the costs of wind-produced electricity are about 10-20% higher than the costs of electricity produced at conventional power plants, taking into account an increase in the future prices of coal following the latest assumptions from the Danish Ministry of Energy. However, if the ratio of electricity production to costs for wind turbines continues to improve (e.g. by introducing larger sizes of turbines), and/or if environmental restrictions on the utility companies make their production more expensive, wind-produced electricity might be competitive in the near future.

5.5. Absorption Cooling

Almost all cooling in Denmark is provided by electrically driven compressor units but there are a few installations with absorption machines. Such machines can utilize surplus heat from combined heat and power (CHP) plants, incinerators, and industry as energy sources. A substitution of compressor units by absorption units would result in lower electricity consumption, especially in the summer, and a levelling off of the heat consumption. A project is in progress in collaboration with the Engineering and Electronics Departments at Risø together with Sabroe A/S. The purpose of the project is to study the potential use of absorption cooling and to give a quantitative estimate of the profitability.

As a part of the project, the existing absorption refrigeration plant at Herlev Hospital has been equipped with a computerized data logging system to gather practical experience and performance data from a plant under normal operation. Data was collected during the summer of 1987, which unfortunately was unseasonably cold. This resulted in the actual refrigeration load being very low and never exceeding 60% of design load.

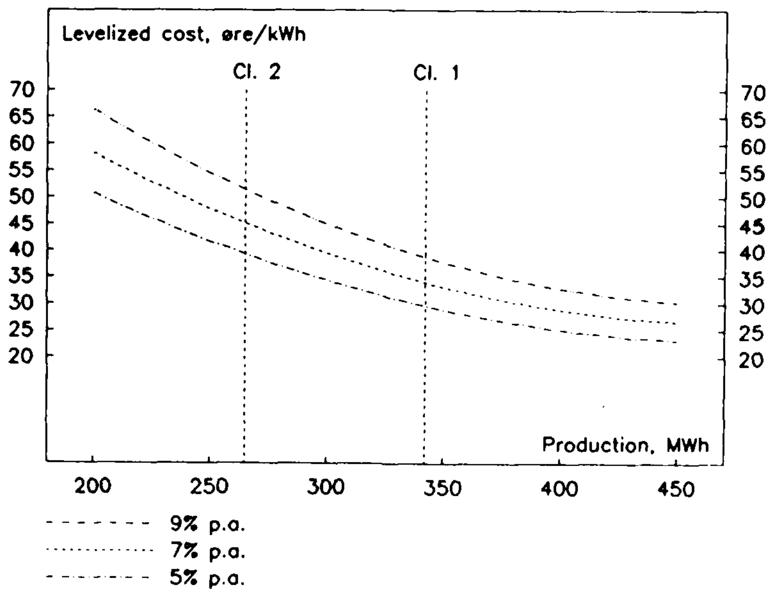

Figure 5.1. The dependence of production costs per kWh total on annual production of electricity and the real interest rate.

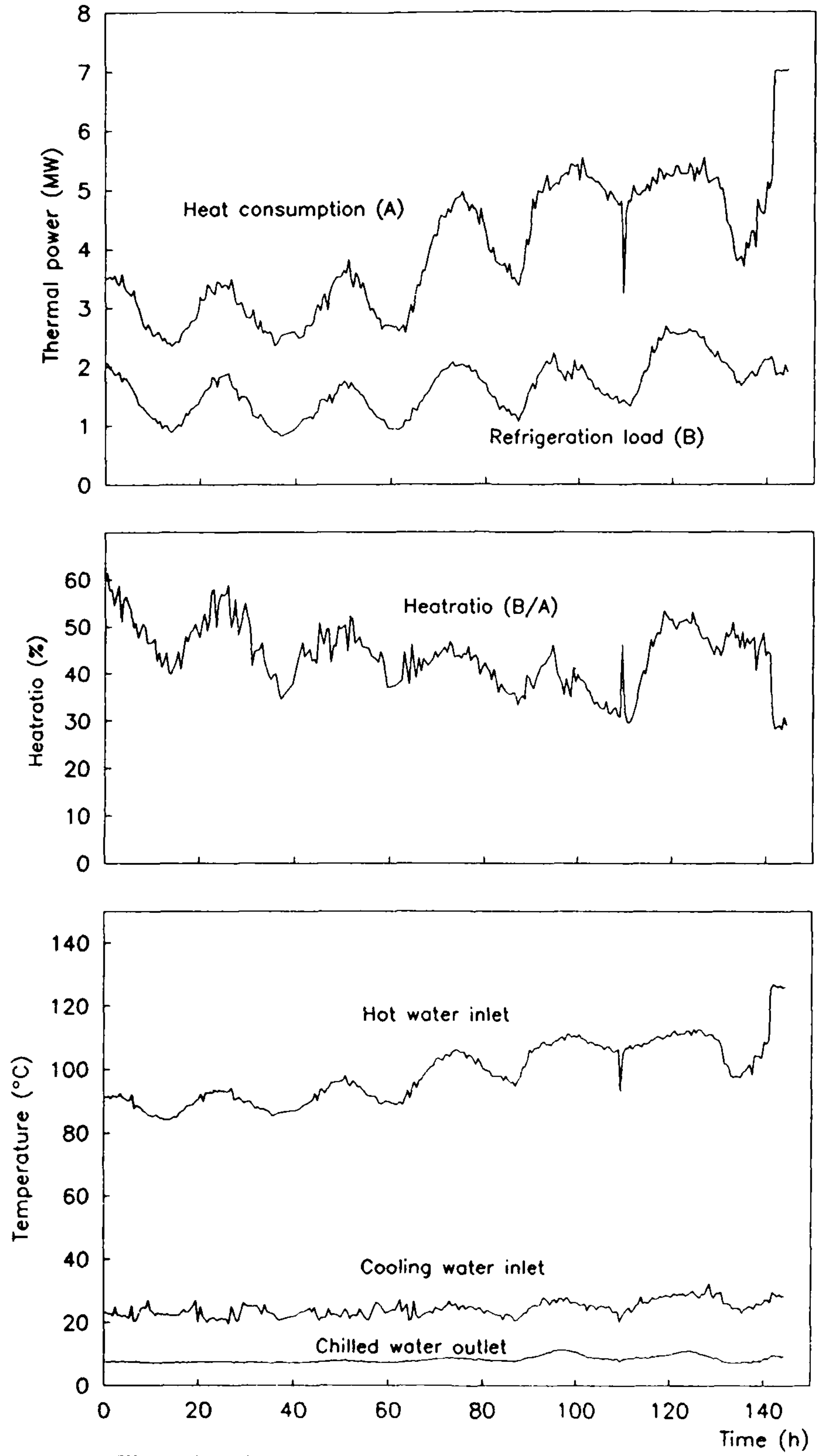

Figure 5.2. Measurements from Herlev Hospital, first week of July.

The Herlev plant consists of two LiBr-water water chillers, each with a design capacity of 4.5 MW. The heat source is hot water from a nearby incinerator plant at 140-160°C. Some measurements from the first week of July are shown in Figure 5.2.

The refrigeration load, heat consumption, and ratio of the first to the second (heat ratio) clearly exhibit a 24-hour cycle. Since external water flows are kept constant, the external operating conditions are given by the three temperatures shown. An attempt is made to keep the cooling water temperature constant by controlling the cooling tower. The temperature of the chilled water produced for air conditioning is kept constant by controlling the hot water inlet temperature and thereby varying the refrigeration load.

As shown in Figure 5.3 the heat consumption is proportional to the hot water inlet temperature. It can also be seen from the figure that the refrigeration load is correlated to the heat source temperature, but the relation is much less clear.

The deviations from the regression line cannot be explained by any of the other temperatures. Figure 5.4 shows the refrigeration load over time as measured and as computed by use of the regression line. The deviation is seen to be time dependent with the same 24-hour period.

The explanation for this is most probably to be found in the dynamic behaviour of the machine. This indicates that refrigeration capacities and heat ratios obtained in practice will differ from those obtained under constant conditions.

The project will be completed during 1988.

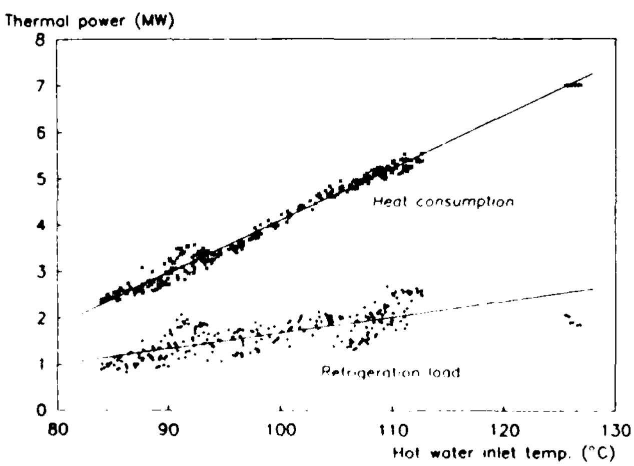

Figure 5.3. Heat consumption and refrigeration load as functions of hot water temperature.

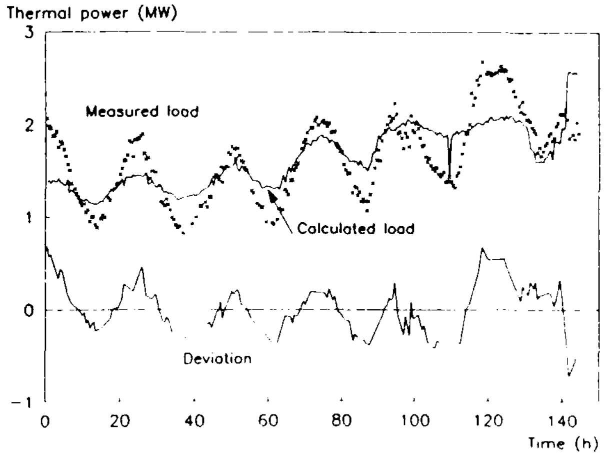

Figure 5.4. Measured and calculated refrigeration load as a function of time.

5.6. Decentralized CHP in the Town of Grenaa

MIDTKRAFT, the utility of eastern Jutland has launched a conceptual design study on a 100 MW_{th} (22 MW_e) coal- and straw-fired CHP plant for the town of Grenaa. This project is part of a programme agreed upon between the Danish government and utilities to build 80-100 MW_e of decentralized CHP in Denmark in the next four years.

In the latter part of 1987, ESG performed an assessment of the plant with respect to both environmental emissions (SO_2, NO_x particles, ash) and the economics as seen from the point of view of both the utility and the nation. The implications for employment and imports were also calculated. The assessments were done using a PC-based model for economic and environmental analysis of CHP-systems, which was expanded to include industrial steam demand.

At present Grenaa has four separate district heating networks that are supplied with heat from six heat plants of which one burns straw and refuse, and the others fuel oil. The plan is to combine these networks and supply the heat from a decentralized CHP plant which in addition will generate process steam to industries in Grenaa.

A number of scenarios were calculated with different fuel price assumptions and different fuel mixes of straw, natural gas, coal and fuel oil. The results will be used by the utility in the application to the authorities for permission to construct the plant.

6. Publications, Lectures and Conferences

6.1. SRE-Symposium 1987

The Systems Analysis Department at Risø hosted a symposium on reliability and risk analysis at Hotel Marienlyst in Helsingør, October 5-7. The symposium was arranged in cooperation with the Society of Reliability Engineeers (SRE) - Scandinavian Chapter. The chapter arranges a symposium in one of the Nordic countries each year; it took place in Denmark for the first time.

At the symposium a broad spectrum of topics within reliability and risk analysis was discussed:

- risk analysis in process industry
- reliability modelling and testing
- expert systems in reliability and risk analysis
- risk management
- case studies concerning reliability analysis.

Professor George Apostolakis from University of California, Los Angeles, gave an opening lecture entitled "Use of expert judgement in risk analysis".

The symposium covered theoretical aspects concerning methods and models, their use within industry and authority as well as practical applications from various industries. The symposium attracted 102 participants, and almost every institute, authority and company involved in reliability and risk analysis in Denmark was represented. Apart from an expected large participation from the Nordic countries, participants came from Germany, Italy, Netherlands, USA, Canada and Taiwan.

As a part of the arrangements, technical visits were paid to the Elektronikcentralen and Danish Hydraulic Institute to look at the facilities available for assessing the reliability of electrical components and apparatus, and measurement of the impact of waves on offshore structures.

6.2 Publications

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2. ANTHONI, U., NIELSEN, P.H., SMITH-HANSEN, L., WIUM-ANDERSEN, S., CHRISTOPHERSEN, C. (1987). Charamin: a quaternary ammonium ion antibiotic from the green alga Chara Globularis. J. Org. Chem., 52, 694.

3. CHRISTENSEN, J.M. (1987). Energy planning and project procedures in Zambia. Risø-M-2676 (Roskilde, Denmark).

4. CHRISTENSEN, J.M., VIDAL, R.V.V. (1987). Project evaluation for energy supply in rural areas of developing countries. IFORS-87 11th Triennial Conference on Operations Research, Buenos Aires, August 10-14, 1987. Risø-M-2677.

5. CHRISTENSEN, P.S. (ed.)(1987). The contribution of Risø National Laboratory to the research programs of the Danish Ministry of Energy: Status December 1986. Risø-M-2628, 78 pp. In Danish.

6. GROHNHEIT, P.E., HALSNÆS, K., SMITH-HANSEN, O. (1987). Renere luft: varmebesparelser giver også renere luft (Cleaner Air - Heat savings give cleaner air). VVS 23 (9) p. 6-8, 10.

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8. GROHNHEIT, P.E., HALSNÆS, K., SMITH-HANSEN, O. (1987). Risiko for mere forurening (The risk of more pollution). Energi & Planlægning 3 (3), 14-17.

9. GROHNHEIT, P.E., and LAUT, P. (1987). Nuclear power and coal-fired CHP. Energy Economics. 9, 82-92.

10. MORTHORST, P.E. (1987). Cost factor formats for wind energy systems. Illustrated by two examples from Denmark. IEA Workshop on the economics of renewable energy technologies, Montebello, Canada, 18-21 October 1987.

11. MORTHORST, P.E. (1987). Er vindmøller samfundsøkonomisk rentable (The economics of wind turbines). Naturlig energi 9 (10), 10-11.

12. MORTHORST, P.E. (1987). Metoder for langsigtet energiplanlægning (Methods for long-term energy planning). Nordic workshop on long-term energy planning, arranged by Nordic Council of Ministers, Helsinki, Finiand, 7-8 December 1987.

13. NIELSEN, L.H. (1987). Inddragelse af usikkerhed i økonomiske beregninger for energiteknologier. (Inclusion of uncertainty in economic assessments of energy technologies) Risø-M-2665. (Roskilde, Denmark) 165 pp.

14. NIELSEN, M. and OTT, S. (1987). Heavy puff an interactive bulk model for dense gas dispersion with thermodynamic effects. Risø-M-2635 (Roskilde, Denmark).

15. OTT, S. and RASMUSSEN, B. (1987). Bhopal og methylisocyanat (Bhopal and methyl-isocyanate), Dansk Kemi 68, 239-241.

16. PETERSEN, K.E., HIRSCHBERG, S., DINSMORE, S.C., and PULKKINEN, U. (1987). Nordic Common Cause Failure Data Benchmark Exercise.
Topical Meeting on Probabilistic Safety Assessment and Risk Management. Zürich, Switzerland, September 1987.

17. PETERSEN, K.E. and POUCET, A. (1987).
A Software Tool for Advanced Reliability and Safety Analysis.
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18. RASMUSSEN, B. (1987). Unwanted Chemical Reactions in the Chemical Process Industry. Risø-M-2631 (Roskilde, Denmark), 116 pp.

19. RASMUSSEN, B. (1987). Identification of hazardous chemical reactions. SRE-Symposium 1987, Helsingør, Dennmark, 5-7 October 1987, 12 pp.

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FENHANN, J. Developments in energy modelling, International course on rural energy planning, 4th May 4th July 1987, University of Twente, Netherlands.

PETERSEN, K.E. Analyse af sikkerhedssystemer (Analysis of safety systems).
Dansk Automationsselskab, Automatisk sikkerhedsovervågning.
4 March 1987, Technical University of Denmark.

PETERSEN, K.E. 2 guest lectures at Technical University of Denmark course on "Reliability Theory" 12th November 1987: Kompleksitet og problemer i pålidelighedsog risikoanalyse (Complexity and problems in reliability and risk analysis).

3 December 1987: Menneskelige fejl i pålidelighedsog risikoanalyse (Human errors in reliability and risk analysis).

PETERSEN, K.E. Analysis Procedures for Identification of CCFs. The experience from the Nordic Benchmark. Ispra Advanced Seminar on Common Cause Failure Analysis in Probabilistic Safety Assessment. November 1987, Ispra, Italy.

RASMUSSEN, B. "Risikoanalyser. Hvad kan de anvendes til?"("Risk analyses. What can they be used for?"). Dansk Ingeniørforening, 24 september 1987.

RASMUSSEN, B. "Brand og Miljø. Risikoanalyser" ("Fire and the environment Risk analyses"). Dansk Brandværns-Komité, 15 October 1987.

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SMITH-HANSEN, L. Risk analysis of a pesticide plant. University of Bradford. May 1987.

Helge V. Larsen, M.Sc. Elec. Eng., Ph.D. The Technical University of Denmark 1974. Storno A/S 1975: development of VHF/UHF equipment. Risø from 1976. Department of Reactor Technology 1976-77. Energy Systems Group from 1977. Main activities: CHP production, modelling of energy systems, economic models for the oil and gas sector.

Gordon A. Mackenzie, B.Sc. Ph.D. (Physics). Guest researcher at Risø 1974-78. Lecturer at Edinburgh University 1978-79. Energy Systems Group from 1980. Main activities: Energy demand modelling, energy in developing countries, energy and the environment. From November 1984 to November 1987 Energy Adviser/Deputy Director at Department of Energy, Zambia on contract with Danida.

Lars Henrik Nielsen, M.Sc. Phys., Math. Risø from 1981. Main activities: Probabilistic methods and model development, technical-economical modelling, assessment of energy technologies, energy conservation, and forecast modelling.

Ole Gravgård Pedersen, M.Econ. Specialized in macro-economics and economic modelling. Worked in the Institute of Agricultural Economics on input-output models. Risø from March 1987. Main activities: energy and environment, implementation of the CEC energy and environment linear programming model, EFOM.

Jesper Munksgaard Pedersen, M.Econ. Ph.D. student at Risø and the Institute of Economics, University of Copenhagen from 1983-86. Ph.D. thesis on energy rationing in the event of acute energy shortage. At Risø until March 1987.

Risk Analysis Group

Per E. Becher, M.Sc. Mech. Eng. Airforce Equipment Command 1970-71. Risø from 1971. Department of Energy Technology 1971-84. Risk Analysis Group from 1984. Main activities: Structural reliability, reliability and safety analysis of nuclear plants, and safety analysis of industrial plants. Head of Risk Analysis Group.

Kurt Erling Petersen, M.Sc. Ph.D. Risø from 1977. Department of Energy Technology 1977-84. Risk Analysis Group from 1984. Main activities: Development of computer codes for reliability analysis, models for mechanical components, and data collecting systems for reliability data. Deputy head of Risk Analysis Group.

Dorte Camilla Bjerre, B.Sc. (food science). Risø from 1986 until March 1987. Main interests: Toxic effects from releases and risk assessment of chemical plants.

Ernest C. Fuller, M.Sc. Chem. Eng. University of Idaho (USA) 1985-86, R&D (unit operations, process simulation and optimization). Risø from 1987. Main activities and interests: Computer codes for risk analysis of chemical process plants and nuclear power facilities, and expert systems.

Carsten D. Grønberg, M.Sc. Elec. Eng. Risø from 1967. Electronics Department 1967-78. Safety Department 1978-83. Risk Analysis Group from 1984. Main activities: Human factors, emergency planning and exercises, and emergency management and communication.

Jens Ole Knudsen, M.Sc. Chem. Eng. Risø from 1987. Main activities: dynamic computer-simulation and physical modelling of release, fire, explosion and dispersion of substances from a chemical process plant.

Hans E. Kongsø, M.Sc. Mech. Eng. Risø from 1957. Research reactor DR 2 1957-63, Department of Energy Technology 1963-84. Risk Analysis Group from 1984. Main activities: Computer codes for reliability and consequence assessment, and risk assessment of nuclear and industrial plants.

Dan S. Nielsen, M.Sc. Elec. Eng. Risø from 1962. Electronics Department, 1962-84. Instrumentation 1962-70. Reliability and Safety Group, 1970-84 responsible for development of analysis methods and analysis of practical systems. Risk Analysis Group from 1984. Main activities: Process plant reliability and safety analysis, and offshore production systems.

Birgitte Rasmussen, M.Sc. Chem. Eng. Ph.D. The Technical University of Denmark from 1981-84. Risø from 1984. Main activities: Risk assessment of chemical plants, identification of chemical hazards, and toxic effects from releases.

Lene Smith-Hansen, M.Sc. (Chemistry). Risø from 1986. Main activities: Risk assessment of chemical plants, toxic effects from releases, and quantitative assessment of toxic chemical substances from combustion.

Niels Kristian Vestergaard, M.Sc. Eng. Akvadan 1983-84, R&D environmental engineering. Risø from 1984 until May 1987.

Postgraduate students

John Møbjerg Christensen, M.Sc. Eng. National Agency of Technology 1980-83, R&D initation and administration for Council of Technology, Oilconsult 1983-84, R&D Energy Planning. Risø from 1984 as Ph.D. student. Subject: Assessment methods applicable to energy projects in rural areas in developing countries.

Søren Ott, M.Sc. Phys., Math. Risø from 1985. Main activities: Models and computer codes for consequence assessment; real time simulation of blow-downs, plume formation, and gas explosions. Ph.D. student from 1987, subject: "Micrometeorological aspects of risk assessments".

Sverrir Sverrisson, M.Econ. Risø from 1985. Main activities: Macro-economics, econometrics and international economics, development, and implementation of the CEC macro-sectoral model HERMES. Started Ph.D. programme January 1987. Subject: The channels of integration between the industrial and the developing countries.

Temporary staff

Imad Amin, B.Sc. (chemistry). Risø from June 1987. Main interests: Safety analysis.

Consultant

Peter Laut, Professor, Engineering Academy of Denmark.

Programmers

Maria Sonia Ca'rdenas Alvarado. Born in Chile. Educated programmer 1986 in Denmark. Risø from March 1987. Working on the event modelling program.

Ulla Dollerup Hansen. Educated 1987. Risø from 1987. Computer programs for consequence modelling, and safety and reliability.

Søren Præstegaard, datanom. Regnecentralen 1973-79. Risø from 1979. Datanom with special subject: optimization completed 1985 at Edp-school, Copenhagen. Working on simulation models and graphics.

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The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1987. The activities may be classified as energy systems analysis and risk and reliability analysis. The report includes a list of staff members.

Descriptors – EDB

ENERGY MODELS; ENERGY SYSTEMS; PROGRESS REPORT; RELIABILITY; RISK ASSESSMENT; RISOE NATIONAL LABORATORY; SYSTEMS ANALYSIS; TECHNOLOGY ASSESSMENT

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pert Systems) for data base system development and emergency management in non-nuclear industries. Review report for JRC-Ispra. Final Report 17 Dec. 1985. Risø-M-2639 and EUR 11228 EN.

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