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Electronics Department. Progress report. Basic and applied research activity 1975-1977

Forskningscenter Risø, Roskilde

Publication date:
1978

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

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Citation (APA):
Risø National Laboratory, R. (1978). Electronics Department. Progress report. Basic and applied research activity 1975-1977. (Risø-M; No. 2134).

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Risø

Risø-M- 2134

Risø-M- 2134

Title and author(s)

PROGRESS REPORT
BASIC AND APPLIED RESEARCH ACTIVITY
1975-1977

Date October 1978

Department or group

Electronics

Group's own registration number(s)

R-7-78

pages + tables + illustrations

Copies to

Abstract

This report describes the activities of several groups within the Electronics Department who are engaged in various areas of basic and applied research. The time period covered is 1975-1977.

Available on request from Risø Library, Risø National Laboratory (Risø Bibliotek, Forsøgsanlæg Risø), DK-4000 Roskilde, Denmark
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FI 25-204

ISBN 87-550-0562-4
ISSN 0418-6435

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INTRODUCTION

The Electronics Department at Risø comprises about 80 people and is made up of essentially two main divisions. One deals with the provision of instrumentation and measurement expertise for the different groups at Risø who conduct basic research or technological R and D. This division employs a group of scientific electronics consultants, a production group, a maintenance facility and a central instrument pool for the complete site.

The other division, whose work is reported here, is engaged in both basic and applied research in topics and areas of direct interest to the department itself. These involve the development and evaluation of methods, for example, in the field of plant reliability and safety as well as in a group engaged in nuclear geophysical activities - including mineral prospecting in Greenland. Another team is working with man-machine problems in highly automated systems and the associated needs for computer support in connection with proper job allocation and design. Finally, a group is active in the field of applied laser physics.

RELIABILITY TECHNIQUES

The general objective of the group's work is development and testing of methods for reliability and safety analysis of technical systems. In addition to work within the field of failure analysis techniques and probabilistic modelling, a major part of the activity has been to study the practical use of these techniques.

For example, the group has recently been invited to participate in a Scandinavian cooperative project - the so-called NORDFORSK project - which aims at practical approaches to the utilization of systematic risk analysis techniques by Scandinavian industry.

Applications (see refs. 1,2,6,7)

In collaboration with the Danish Automation Society and interested chemical industries a number of analyses of design proposals has been carried out to gain experience with the benefits to be gained and the costs involved.

The analyses included, e.g., sodium methylate plant safety, ammonia plant compressed-air system availability, and chlorine evaporator/hypochlorite unit safety. In all cases, the analyses revealed inadequate sub-system designs and provided a basis for making decisions concerning design changes.

An important point which the studies made obvious was that in the design of a large complex system - for which high reliability or safety is needed - a reliability/safety analysis must take place as part of the design; and preferably just after the initial piping and instrumentation diagrams are completed. At this stage, it is possible to make simple and often inexpensive design modifications that will greatly enhance reliability/safety.

However, the analyses were often rather time consuming. In order not to overlook possible significant risk contributions, it was sometimes necessary to analyze at a detailed level. This required large amounts of information about design features and construction details which often took a great deal of time to collect.

The following describes in more detail two of the activities carried out by the group.

Automatic Failure Analysis (see refs. 5,8,9)

The first step in risk analysis of any industrial plant is to identify the ways in which a plant can fail and the kinds of consequences which can follow from failure. Only when this has been done can one begin to calculate the probability of failure.

Finding failure causes and mechanisms is often a large job, requiring a systematic approach such as the fault tree technique, or the cause-consequence method developed at Risø. Nevertheless, for complex installations such as power stations, oil refineries, or chemical plants, a thorough analysis can take many man-years, and there is obviously the possibility that some failure causes may be overlooked. If the risk analyses are to be used in design of safety systems an omission could be serious since the plant might be left unprotected against a particular type of accident.

Automatic failure analysis offers the potential for overcoming these difficulties. The methods developed at Risø involve building up a library of failure models for different kinds of components such as valves, pumps, and motors. The models describe the events which can occur within a component, such as different kinds of failure, and the effects these events have on other components which are directly connected. Using a block diagram of the plant as guide, these component models can be pieced together using a computer. The result shows the way that the effects of failure spread through the plant and the different sequences of events which can lead to accidents such as fire or a release of poison.

Methods for carrying out this kind of automatic failure analysis have been developed at Risø over a number of years, but now appear to be practically useful. A major step forward has been to combine purely event-based (on/off, pressure high/low) models with numerical models of plant components (pressure increases by 10 atmospheres). The methods are in fact half way between simple fault-tree construction methods used in "manual" failure analysis, and full scale simulations, which are generally too time consuming to apply to all parts of an industrial plant.

Fig. 1 shows a general scheme of the method and some of the results. The "production versions" of the programs have now begun to run, but there are still many details to be added. And a major task, that of searching through reports of industrial accidents, and adding new accident mechanisms to the library of component models, is just beginning.

Automatic analysis is not a solution to all problems of industrial risk analysis. But by simplifying and improving one difficult stage, it should help to make risk analysis more widely useful in industry.

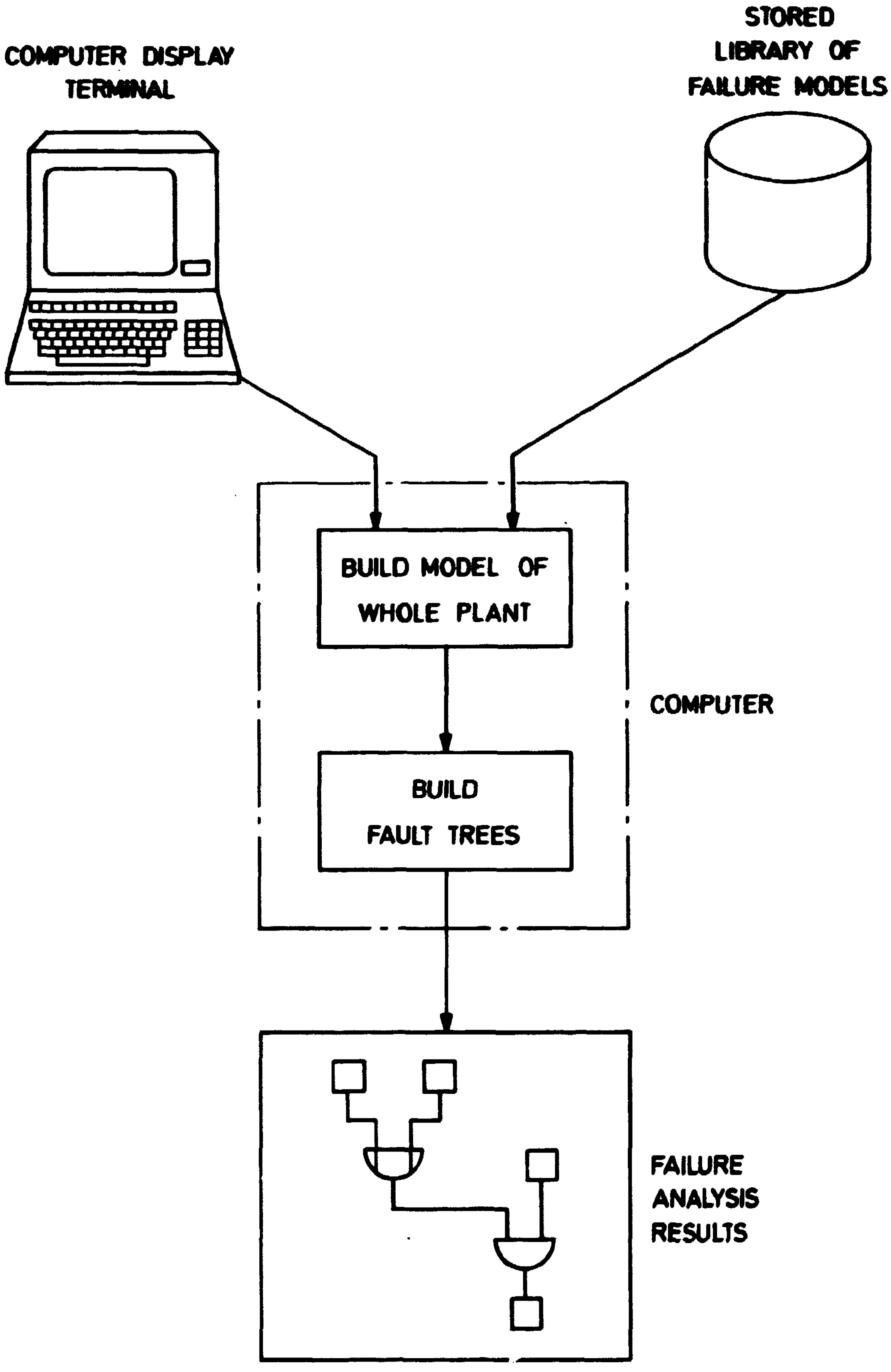

Fig. 1. Scheme for analysis.

FAUNET: A Program Package for Fault Tree and Network Calculations (see refs. 3,4)

A program package for fault tree and network calculations has been developed. The package, written in standard FORTRAN, is primarily designed for use on a minicomputer (8k or 16k PDP8 under OS/8). Special efforts were therefore made to minimize storage space requirements.

The package contains programs for checking the fault tree input data for logical consistency and for providing various graphical representations of the tree. Furthermore it contains programs for calculating the minimal cut/path sets of the system from the tree. A special technique modularizes the fault tree before the minimal set calculation. In practice the modularization has proved to considerably reduce computer time and storage space requirements.

The probability programs of the package calculate the unavailability and the failure intensity of the system at various time points from the minimal sets and from failure and repair data of the components. The basic events, component failures, are assumed to be statistically independent. The distribution of time to first system failure taken at a time point t can be bounded from above by the expected number of system failures within the time interval (0,t). This number is obtained as the integral of the failure intensity.

In their present form, the programs accept exponentially distributed failure times and repair times that are either constant or exponentially distributed. They also accept constant failure probabilities for components with a fixed probability of failure per demand. For the purpose of treating components where failures are only detected during testing, the programs furthermore allow the specification of constant test intervals.

For many fault trees the modularization will reduce the number and/or the order of the minimal sets so much that it becomes possible to perform exact probability calculations instead of using bounding techniques. Reference 4 contains a description of a reduction-expansion algorithm developed for that purpose. The program package is also capable of performing calculations for systems undergoing phased missions.

The network program of the package finds all path sets between two selected nodes in a directed or undirected network where both links and nodes may fail. The path sets represent the structure function for node-pair connectivity. The minimal cut sets are found by subjecting the structure function to the minimal set programs. The availability and the reliability for node-pair connectivity can then be calculated by using the probability programs. The network program is described in detail in reference 3.

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PLANT PROTECTION

Introduction

This group is concerned with design and operational problems with safety and reliability in modern process plant. Relevant issues in this field include the distribution of tasks related to system protection between operations personnel and the plant instrumentation and control system as well as means for including the effects of human actions in systematic risk assessment analyses. As is well known, the human is an adaptive, flexible creature who often can step in and save an unforeseen situation. At the same time, however, these characteristics make him a potential error source of considerable complexity and dubious predictability. This is a contributing factor to the current trend toward a greater use of automation - but, contrary to many designers' wishes, this will not result in an elimination of the operator but rather shifts upwards and/or downwards in the competence and capabilities required.

In order to build a better foundation for dealing with these problems in the design and analysis of man-machine systems the group at Risø is studying the process operator's total work situation. Elements within this situation include the tasks involved, the strategies, mental representations and failure characteristics of the operator and the support provided in the form of training, displays, procedures, etc. A scenario approach is preferred where ever possible as a means for obtaining a picture of the dynamics of the control room environment which can be especially helpful in the identification of error-friendly conditions and interactions.

In practice, this work has been carried out as a combination of local studies - often in cooperation with Danish power stations - and participation in international projects. Besides being potential sources of data, the latter serve also as "test beds" for the evaluation and verification of the more theoretical work. This approach has become more prevalent in recent years - particularly as the result of the unfortunate reassignment of personnel from the group to other functions at Risø. This has made it necessary to constrain the scope of the work.

Risø studies

A previous progress report (1) described briefly a set of models - based mainly on information processing concepts - to represent the functioning of the human operator in conjunction with a physical system. These models were an attempt to explain, at a level usable by system engineers, human behaviour in "real life" tasks and to structure the confrontation between the operator and the system - particularly in diagnostic situations.

In the period being reported here, this frame of reference has been further used and tested in several application areas. These consisted of (a) conventional power station control rooms, and (b) a minicomputer system troubleshooting task. In addition, earlier analyses from an electronic instrument maintenance facility (2) were incorporated in order to permit, among other things, a comparison to be made of the results obtainable from the use of verbal protocols to reflect the relevant human activity. The three situations were different in various ways and this was evident from the contents of the tape recordings. The following attempts to summarize the main points.

Characteristics of the situations

Levels of proficiency

Control room - operators were well trained in a practical way - usually as ships' engineers - and also had considerable power plant experience.

Computer troubleshooting - performed by engineers who also were directly involved in the hardware and software design of instrumentation systems.

Instrument troubleshooting - technicians highly experienced in handling a wide spectrum of general-purpose and special instruments.

General task features

Control room - operators were responsible for safety and economy which, more concretely, involved continuous monitoring, supervision and, depending on the specific plant, a certain amount of manual control and coordinating. Thus, the "pacing" of the operator by the process or vice-versa varied considerably.

Computer troubleshooting - the man paced the activity. He required suitable (possibly sophisticated) aids in order to control and interpret the machine's operation.

Instrument troubleshooting - generally the same. However, the aids were simpler, in line with the repertoire of "tricks of the trade" which usually were effective.

Goal in a diagnostic situation

Control room - dependent on the circumstances - typically can be plant protection where cause is less vital than determining from system state whether shutdown is required or
compensation where cause is less vital than finding a suitable countermeasure or
restoration, the physical locating of the failed component for repair or adjustment.

Computer troubleshooting - find the defect for repair or readjustment as quickly as possible.

Instrument troubleshooting - the same.

Results from the protocols

Protocols of instrument troubleshooting reflected directly the higher level characteristics of the task itself - i.e., a long sequence of relatively simple locate-measure-evaluate subroutines. Analysis of many of these protocols has led to an identification of several general-purpose search strategies which seem to be used over and over in different combinations. For example, the successful service technician has relatively little need for a detailed functional model of the particular unit but instead relies greatly on a function-independent topographical representation of signal flow routes through the system with convenient measuring points and normal/reference values. This permits simple yes/no judgements to be made which serve to close in on the defective location. Other strategies fall under the heading of symptomatic search procedures and include pattern recognition (= a direct associative clue from the state of the unit), lookup (= a clue from a sequential search through a library of states) or hypothesis and test which can be based on a somewhat fuzzy recognition of something or other combined perhaps with knowledge of the past history of the unit.

It is characteristic for the protocols that while these various strategies usually are consciously monitored and verbalized, the mechanisms for chaining them, i.e., for switching suddenly from one to the other or, for example, stopping completely to seek inspiration elsewhere, do not appear to be consciously controlled. Thus the aggregate set of protocols give a picture of what the man can do but not what he will do in any given situation.

Protocols from computer system troubleshooting also gave a rather complete structure of the particular diagnostic sequence. The complexity of the system coupled with the novelty of each situation led to the need for the engineer to start his search at a rather high level. Indeed it seems that he first would test his own understanding of a rational designer's intentions with such a system and thus compare its actual external performance with his conception of how a well-designed configuration should function in order to get a clue as to where a more concentrated effort should be directed. An extension of this line of analysis led to the identification and categorization of several levels, areas or domains in which human data processing could take place. The following table illustrates such a set which has been found to be useful.

OPERATOR'S MODELS

DATA DOMAIN	TYPICAL OPERATION
- Stored spatial-temporal patterns of surface behaviour	Imagery, visual thinking Sensory-motor skills
- Stored data patterns labelled in states, events. Heuristic rules	Perception, recognition, associative reasoning
FUNCTIONAL DOMAIN	
Models structured according to:	Deduction, Abduction, Induction and Search
Purposes of system Teleological models	
External functions and effects Relations between actions, events, states	by Common sense, natural language, reasoning
Abstract relations and functions in terms of Energy, Information, etc.	or
Formal structure, relations between physical variables	Formal data processing following procedural conventions
Internal physical structure, interacting parts and components	
PHYSICAL DOMAIN	
Maps of spatial location of objects and components	Find things, execute cookbook recipes

Leaps back and forth between these domains in a way similar to that mentioned previously for the utilized search strategies were quite common.

Protocols from the control room were completely different from the above mentioned. Both continuity and the level of detail were sporadic and uneven with little information on strategies or data handling. The operator typically had several tasks running concurrently. Each of these involved different forms for processing within the different domains mentioned earlier in order to best fit the demands of the particular diagnostic phase for each task (observe, identify, plan, control.....). As a result, the protocols consisted mainly of shorter or longer statements about the operator's state-of-knowledge regarding the plant, the task, his actions, etc. It seems also clear that the remarks reflected the presence of an underlying model of the plant which supported a continuously updated "feel" or expectation about the plant and its behaviour and which had led to a corresponding set of routines for dealing with it - routines which apparently did not lend themselves to verbalizing. The relationship between the operator and the plant is very close - actually, the operator rarely talked for any length of time about the plant per se but instead in terms of his own interaction with it - for example, his proposed action in response to plant behaviour as the result of a command from the automatic control system. In general, operators also have tendencies to assign properties to system functions and objects and to verbalize in these terms instead of using the more formal scientific concepts of variables and relations. Thus reasoning about system behaviour occurred via an associative chaining of events caused by changes in the state of one object influencing the states of other objects (á la Rube Goldberg). The potential lack of precision in this form for communication was compensated for by the control room environment itself with its shared pool of knowledge and experience as well as by the presence of some type of feedback mechanism. However, this view of the plant can lead to conflicts with automated or protective interlock systems when their goals and functions cannot be assimilated by the operator in a similar way.

Another source of useful information are the event report systems associated with the nuclear power installations in the different countries. Of these, the American "Licensee Event Reports" are probably the most directly accessible. These cover a wide range of incidents and events including those involving operator/technician errors. While not directly useful for statistical treatment, they illustrate the great variety of situations which can arise in a plant and lead to and/or result from human errors. Particular use of these reports has been made in connection with the test and calibration task as part of the CSNI project which is mentioned later.

Cooperative activities

One of the international cooperative ventures of which the Risø group is a part is a Scandinavian project under the Nordic Council of Ministers. This so-called NKA/KRU project, running from 1977 to 1981 with participants from Denmark, Finland, Norway and Sweden, will be looking into the control room in nuclear power plants and will be paying particular attention to ergonomic factors, human reliability and operator selection and training - areas which are particularly important from the point of view of plant safety and availability. This project will build on the various national activities and interests in the man-machine area and, in Risø's case, will provide an opportunity to test experimentally on simulator equipment the concepts developed on operator models, data types, strategies, etc. in diagnostic situations. In addition, it should be possible to gain more insight into the total work situation in operating nuclear power stations in Scandinavia.

Another cooperative effort which has been a useful supplement to the group's own work has been organized by the Committee on the Safety of Nuclear Installations (CSNI) under NEA/OECD to look into the problems connected with rare events in the reliability analysis of nuclear power plants. This total task was divided among several international working groups among which was one on human error analysis and quantification in which Risø participated. This group was to assess the extent to which existing quantitative analytic methods could be used to predict human reliability or, put another way, to determine the criteria to be met by task requirements and system design in order to permit such an analysis to be performed by existing methods. In addition, the requirements for supporting field data were to be examined. Cooperation with French colleagues was to make it ultimately possible to study the test and calibration task at one of the French reactors as a concrete example for attempting a systematic analysis. However, time, coordination and other resource constraints have not permitted any form for detailed consideration but instead have limited the effort so far to a general evaluation and consensus-taking of available methods, data, criteria in addition to some preliminary comments on the specific reactor test specification. A first summary report has been issued (3). The work will continue in 1978.

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REACTOR INSTRUMENTATION

Relations between power reactor instrumentation, risk analysis and regulations and standards.

The department's normal interest in the general trends in reactor instrumentation has within the past year or so been redirected toward the study of some special topics of interest to the Danish nuclear regulating authorities. These included present practises in the employment of redundancy, separation, etc. in protection systems. This work and also the earlier studies have given insight into an instrumentation field characterized 1) by rigorous requirements regarding to the reliability of the functions and design bases of the systems and 2) by the working out of these requirements in technical rules such as regulations and industrial standards. In different countries with highly developed nuclear technology these rules have different degrees of systematic nomenclature, structure, coverage, etc. Some effort has been given to the study of these rules, and this will also be necessary in the future, as a part of the nuclear preparedness at Risø. Thus, sufficiently correct and detailed interpretations of rules will be possible even in the event that the Danish authorities only issue general rules.

In addition to this, the study of technical rules has another aim: A growing interest can be noticed for the use of systematic risk analysis, i.e. quantitative analytical methods, as design tools for the identification and evaluation of risks in industrial production plants, including the risk of failure of systems for prevention and limitation of accidents (the NORDFORSK risk analysis project is an example of this trend). The technical rules in the nuclear power field can in their present shape be considered to be counterparts to the analytical methods, i.e. can be considered as empirical methods to obtain extremely reliable systems. As an example: The rules as a basic principle require redundancy. Further requirements then state certain combinations of specific failures and events which should leave the system unaffected. Thus relatively simple combinatorial reasoning enables the designer to determine the degree of redundancy and other detail characteristics of the system, e.g. 2-out-of-4 configuration. Quantitative methods for analysis and prediction are not yet accepted as substitutes for this simple reasoning; still they are often accepted as a means for establishing arguments for the exclusion of some types of failures/events. In future, technical rules, regarded as empirical design methods, and analytical methods are expected to develop in a mutually supplementing way:

- Empirical solutions can often be utilized in the first stages of solving even non-traditional problems or in the decomposition of such problems, while analytical methods have to be used when experience and thus the empirical solutions are missing.

- The analytical method has limitations and preconditions: Taking account of these is necessary for giving meaning to the results of the analysis. Technical rules could ensure, for example, that systems were given a basic layout compatible with the limitations and preconditions of analytical methods.

In this foreseen adaptation between methods it is expected that the insight obtained in technical rules can be utilized in cooperation with analytical specialists.

Finally, growing efforts can be noticed in the direction of utilizing technical rules within the individual countries and also at an international level. The interface between laws (general level, great permanence) and technical rules (detailed level, specific, more frequent updating due to technological evolution) is expected to require the growing involvement of technical specialists with knowledge of technical rule problems.

APPLICATIONS OF NUCLEAR TECHNIQUES TO MINERAL EXPLORATION

Survey of activities 1975-77

The Department's co-operation with the Geological Survey of Greenland included regional reconnaissance for uranium in both eastern and western Greenland. An airborne gamma-ray survey in the East, carried out in the summers of 1973 and 1974, was followed by detailed radiometric field investigations and geochemical prospecting. The airborne work was continued in the West for two summer seasons. Spectrometric data were acquired over a total flying distance of 22.000 km. Geo-magnetic data were recorded at night using an airborne proton-magnetometer. A ground investigation of radioactive anomalies near the town of Sukkertoppen was commenced in the summer of 1977. These activities, apart from the geo-magnetic surveys, have resulted in a large amount of data on the uranium potential of Greenland. The Department is presently undertaken the computer-processing of the data and is also strongly engaged in the interpretation of the latter. A brief account of the geochemical investigations in northern East Greenland is given later.

In 1977 a drilling programme, economically supported by the EEC, was carried into effect and successfully completed at Kvanefjeld, the only uranium deposit in Greenland known up to now. About 5,000 metres of drill core from 27 holes were recovered. More than 2,000 crushed core samples were analysed for uranium in the Department's laboratory gamma-ray spectrometer, and the results were used to calculate the tonnage of uranium in the drilling area. A Canadian company provided spectrometric gamma-ray logs of most of the drill holes, and the Department made a detailed spectrometric survey of the terrain surface.

The most significant progress on the instrumentation side is an advanced neutron-activation facility installed at the reactor DR3 in 1975-76. The facility makes it possible to determine very small concentrations of uranium in geochemical samples. A sample is typically irradiated for 20 seconds in a thermal flux of 2.5 x 10^{13} neutrons/cm^2/sec., after which the sample is automatically delivered to a sensitive neutron detector. The latter registers the delayed neutron emission resulting from fission of uranium-235 in the sample material. The equipment can be loaded with up to 24 samples at a time, and the whole measuring sequence is controlled by a PDP11 mini-computer.

Research has been done to obtain a better interpretation of ground and airborne gamma-ray surveys. It was discovered that the Department's uranium gamma-ray standard - a large concrete pad doped with a uraniferous mineral - produces a fluctuating radiation output due to the presence of mobile radon-222 in the porespaces. Calibration errors arising from this effect can now be prevented through a simple experimental procedure in which two similar pads, doped with potassium and thorium respectively, serve as reference standards. For airborne spectrometers, it is necessary to correct the measured calibration constants for gamma-ray attenuation in the air. Height-dependent correction factors have been determined from gamma-ray transport calculations in 2π, semi-infinite geometry.

Geochemical exploration in northern East Greenland

As a result of decomposition processes in nature, mineral deposits may be traced far from their exposure site by anomalous metal concentrations in the weathering products. Geochemical exploration is based on the systematic analysis of weathering products. Analytical targets are rocks, stream sediments, soil and water. Anomalous metal concentrations in the weathering products, compared to barren rocks, may indicate the presence of buried or outcropping mineralisation.

A study to evaluate geochemical exploration techniques for the arctic environment was initiated in 1974 in northern East Greenland by the Geological Survey of Greenland. Regional sampling of stream sediments and water,based on the collection of 1-5 samples per km^2, was carried out in an area of about 5.000 km^2 with the help of a helicopter, whereas detailed sampling was undertaken by small field teams. Our group has actively participated in the latter sampling. Most of the sampling activity followed geophysical investigations including airborne gamma-ray spectrometry (1).

Samples collected in the field were characterised by an area code, a sample kind, sample number, parameters describing the fractional composition of the sample (e.g. content of gravel, sand, silt or organic material), pH-value, air and water temperatures, radiation level, altitude and coordinates of the sampling site, code for the geological environment, and the date of the sample collection. These data were coded in the field on specially designed field-geochemistry cards, converted into punched paper cards and tabulated by means of a computer programme. A statistical treatment of selected parameters of the samples was then possible.

Generally, the -80 mesh fraction of the samples was used for analysis. Two analytical facilities exist for the analysis of geological samples:

1. The delayed-neutron counting facility installed at the reactor DR3 for the analysis of U.

2. Radioisotope energy-dispersive X-ray fluorescence instrumentation for the determination of K, Ca, Ti, V, Cr, Mu, Fe, Ni, Cu, Zu, Ga, Sr, and Pb.

Capacities of 100 and 40 samples per day, respectively, are characteristic for these instruments. Detection limits for both analytical tools are below or adequate to the contents expected in normal igneous rocks. All analytical data are available in the form of tables generated by the B6700 computer and as files stored in the disk system. The storage is necessary for statistical evaluation and interpretational work. A general analysis-data base is under construction.

To support geologic interpretation of the analytical data, small statistical procedures, and several tabulation and plotter programmes were developed. All the data collected in northern East Greenland are currently under investigation and will be published in the form of reports and open-file information during 1978.

An example of the application of geochemical exploration is the Randbøldal area, located within the mentioned area. Uranium min-

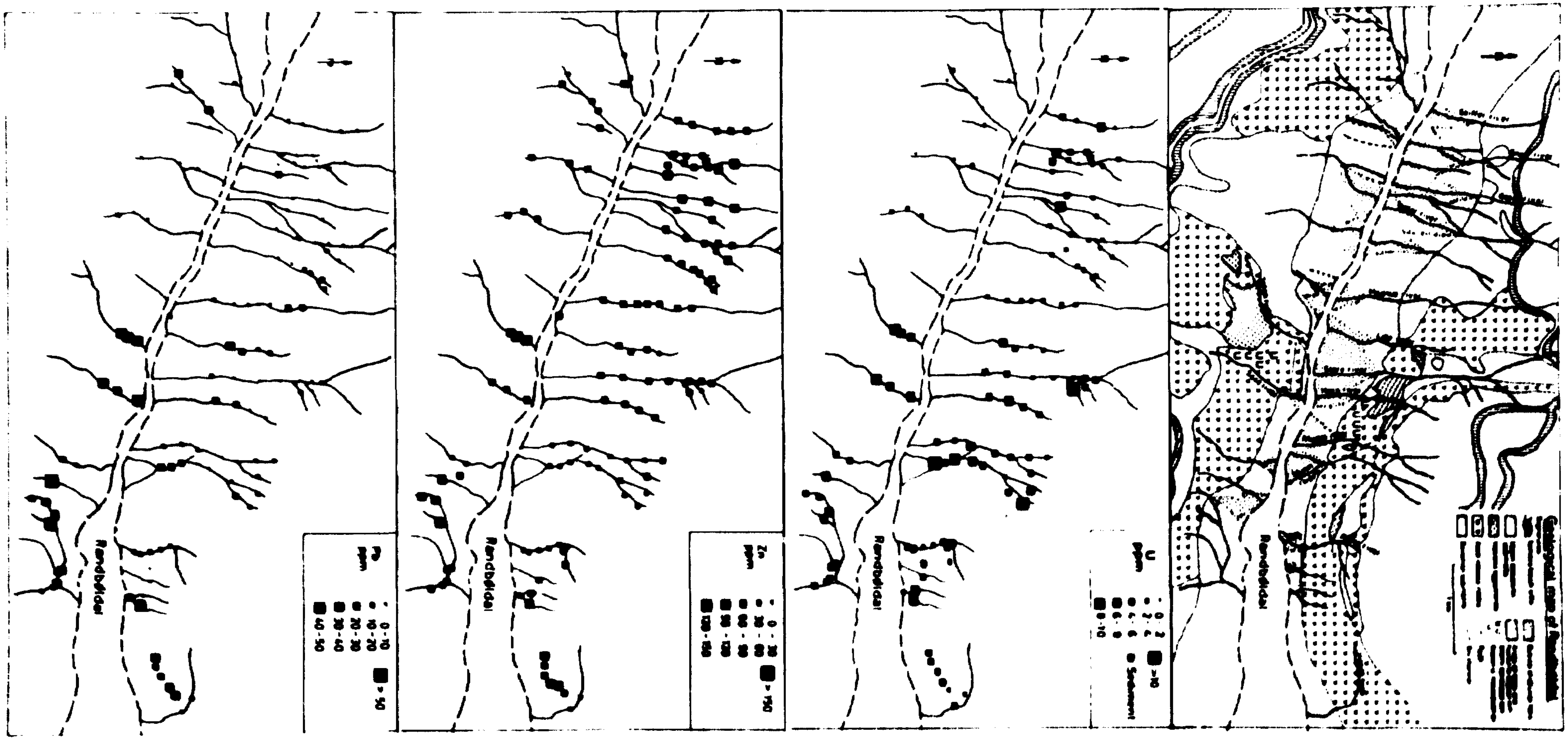

Fig. 1. Geological map and analytical results for U, Zu and Pb in stream sediments of Randbøldal, northern east Greenland.

eralisation detected by the airborne gamma-ray spectrometer was observed during follow-up work in Devonion rhyolites (2). Anomalous contents of U in stream sediments, soils and water were registered in the close vicinity of the mineralised areas (3), (4). The results for U, Zn and Pb in stream sediments together with a geological map are given in Fig. 1. Zu and Pb anomalies close to the southern U mineralisation were observed. Several conclusions can be drawn from the investigations in Randbøldal:

1. Analytical data on stream sediments indicate predominantly mechanical transport of the weathering products. The dispersion halos are generally small and dense sampling must be applied, therefore.

2. Soil sampling was advantageous in areas with large distances between drainage channels.

3. Water sampling was effective for U in Randbøldal. Generally, geochemical sampling was a useful and effective supplement to the geological and geophysical prospecting methods.

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COMPUTER LABORATORY

Introduction

The laboratory contains a hybrid computer EAI680-PDP8/I, FPP12, a minicomputer PDP8 and a graphic processor PDS1. Connections can be made to the central computer Burroughs B6700. The laboratory computers are run as open-shop facilities for general purpose simulation and production and maintenance of programs for minicomputer experimental facilities. Five staff members are connected to the laboratory. They develop software and hardware tools for users (refs. 1 to 7) and take care of software and hardware maintenance. In addition they work with new areas of computer technology (refs. 5 to 10) for simulation and handling of problems related to nuclear and industrial safety.

The main application areas for the hybrid computer are simulation of nuclear power plants, modelling of laser measuring systems, man-machine communication experiments and simulation of superconductor oscillators. In addition the equipment has been used a great deal for quantization of recorded analog signals.

In the software field, the development of a semiautomatic programming system HAPS (ref. 1) for the analogue computer EAI680 was finished. HAPS enables programming of differential equations given in symbolic form for solution on EAI680. The equations are used as input to HAPS. A patching list, a potentiometer table and a set of static test data are given as output.

Preliminary work was made in the field of structured programming (ref. 4) to obtain more easy programming and maintenance of programs. A language FORSC with special instructions was defined and implemented by means of a precompiler which accepts programs written in FORSC and produces FORTRAN object code.

In the new technology field a microprocessor was employed in the hybrid computer (refs. 5, 6). Software (ref. 7) and hardware (refs. 8, 10) problems in connection with parallel digital simulation were considered. A multicomputer MUMI1, for which the structure is outlined in ref. 8, was implemented in a two computer version to be described below. The aim is to explore the use of multicomputers for parallel system simulation and on-line error detection. An obvious advantage by this method as compared with analogue technique is that patching and scaling can be avoided.

Multimicrocomputer system

Figure 1 illustrates different aspects of the multicomputer MUMI1. Figure 1a depicts the structure. A processor P_1 may communicate with its own memory M_1 by means of a local bus or P_1 may address a memory, say M_3, by means of a global bus. A high efficiency is obtained if all processors use their own memories most of the time and only rarely exchange data by global transmission. I is a processor-bus interface. B is a bus controller (arbiter) which is required by processors which want to use the global bus. B issues only one grant at a time. In this way conflicts are avoided when more than one processor requests the bus.

The physical layout of the multicomputer is shown in figure 2. Each computer consists of one processor, one memory and one memory extension card. An essential problem in a multicomputer is current consumption. Only 90 mA was required in a 4k word 12 bit CMOS memory as compared to 9A in a corresponding core memory. Note that a multicomputer with 100 units would require 9A and 900A respectively. The IM6100 processor was selected due to its CMOS technology and due to software compatibility with Digital Equipment Corporation PDP8 software.

The structure of the two-port computer is shown in figure 1b. The processor IM6100 with memory extension facility has 15 bit address corresponding to a 32k word address space. 3 bits are used as pointers. They point out a 12 bit field address which specifies 1 of 8 computers to be addressed by standard PDP8 instructions. By using special input/output instructions, the 8 addresses can be exchanged for addressing up to 4096, 4k word, memories. Similar techniques are used for data fields and instruction fields. Thus the processor may exchange data with a global memory or execute a program stored in a global memory.

Memory transmission takes place in an asynchronous way by a handshake procedure. The following addressing principle is applied. The field address issued by the processor is compared with the field address assigned to the processors local memory. If equality is obtained the bus is switched to local position and the field address is connected to the memory port comparator. Otherwise the address is connected to the global bus. At the memory the field address is compared with the address assigned to the given memory and used for setting the memory bus switch into the correct position. If field address agreement is obtained the switch allows the attached 12 bit word address to be applied directly to the memory.

An essential feature in the computer is the memory hold system. It allows a processor to lock an addressed memory during several instructions to avoid interaction by other processors during synchronisation. An I/O instruction is used for memory hold purpose and another I/O instruction is dedicated to memory release application.

References

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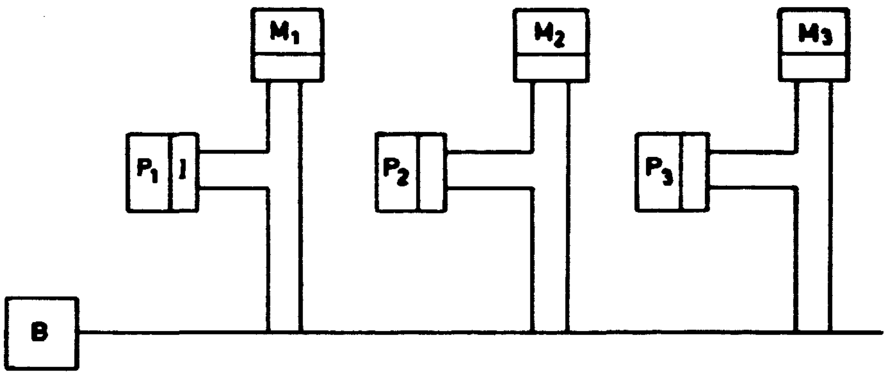
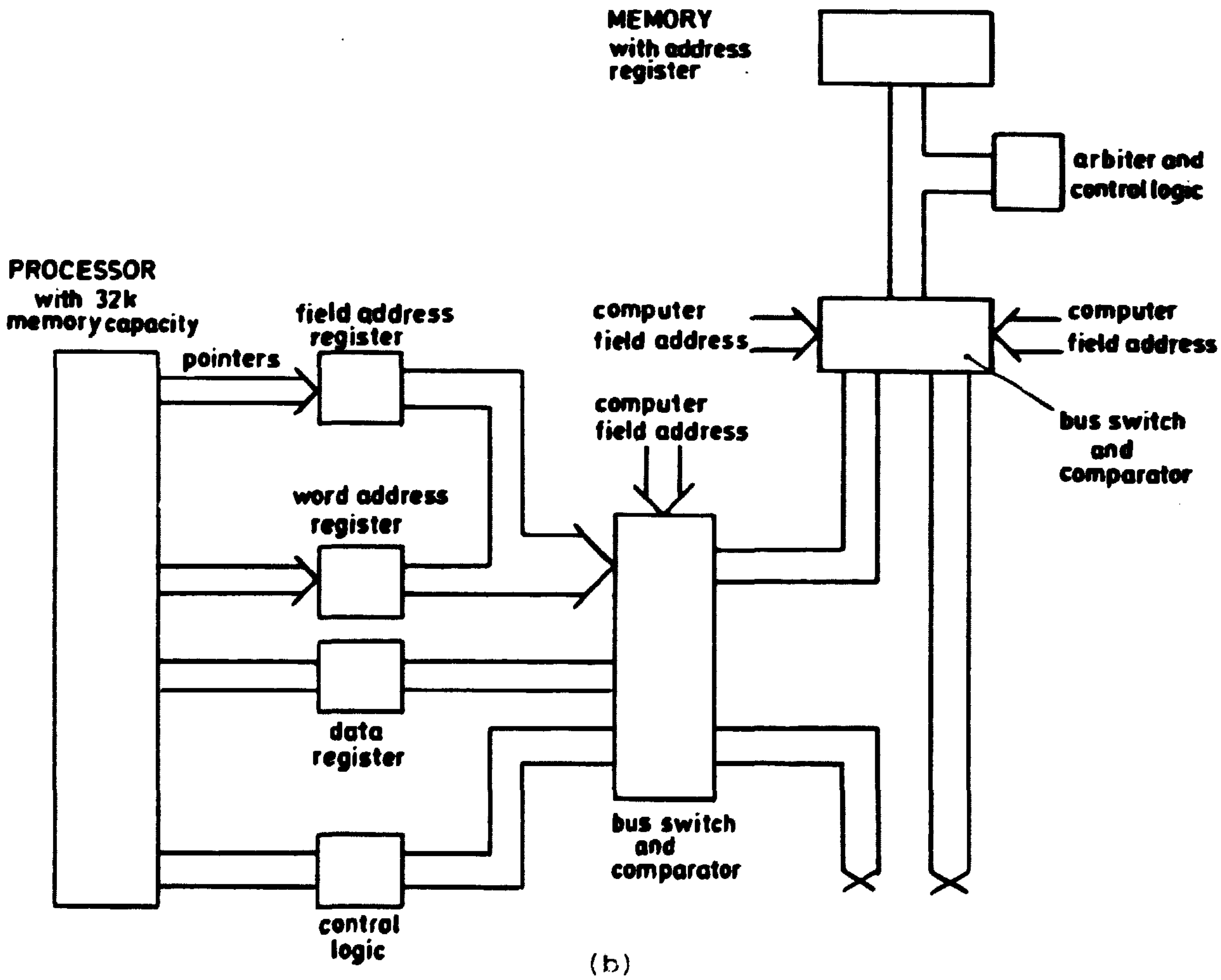


(a)



(b)

Figure 1. Multimicrocomputer MUMI1

a. Structure. P: processor, M: memory, B: buscontroller, I: interface.

b. Two-port computer with IM6100 microprocessor.

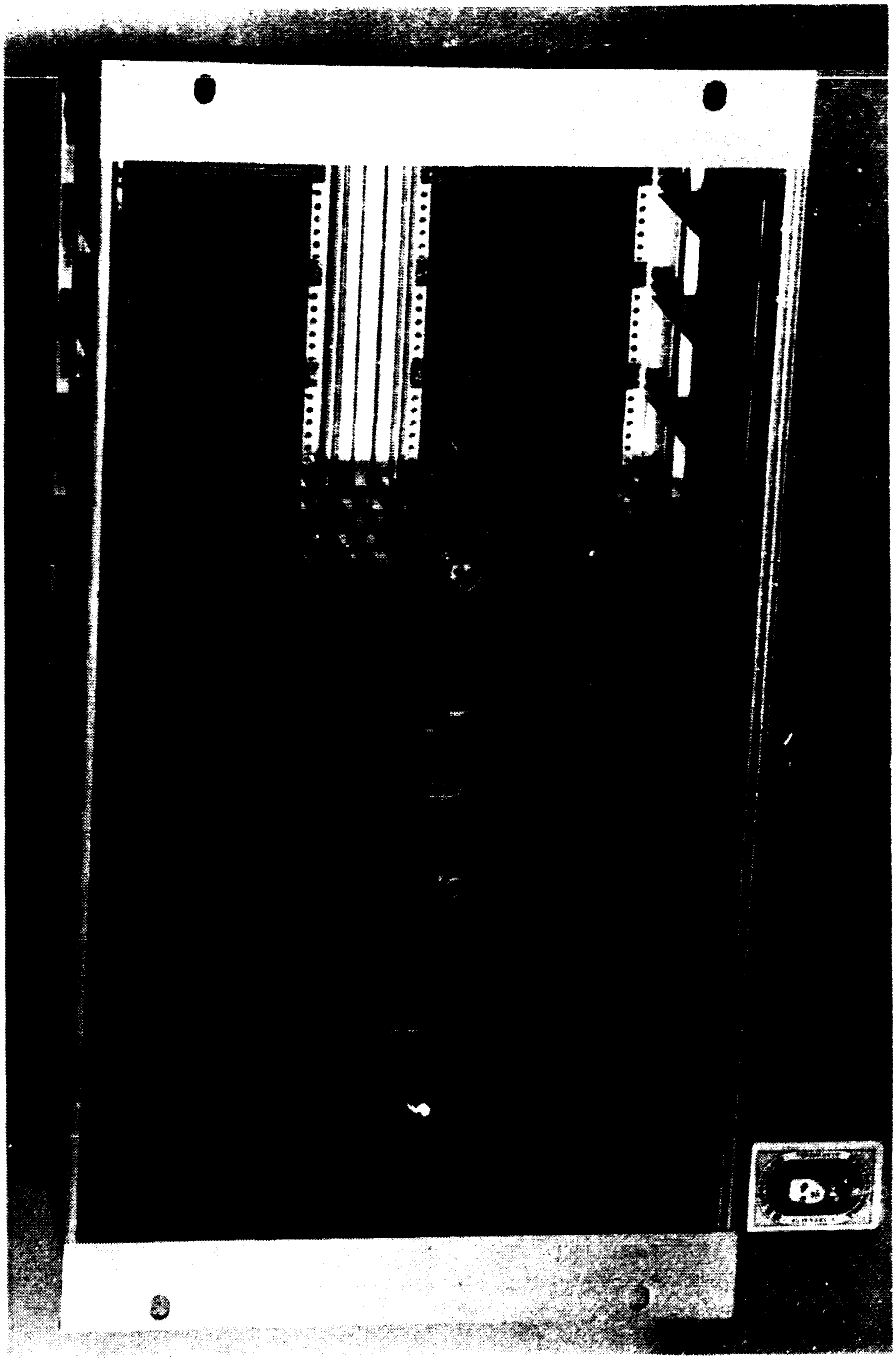


Fig. 2. Multicomputer with 2 computers inserted.

APPLIED LASER PHYSICS

The work of this group concentrates on the application of laser light to physical measurements, especially in fluids, and ranges from rather basic investigations to very specific applications such as two-phase flow measurements and measurements of wind velocity. A considerable part of the work is concentrated on stochastic processes relating to the systems investigated. This report describes a few of the projects on applications.

Measurement of the wind-speed in the atmosphere by a cross-wind anemometer

In cooperation with the Meteorology Section at Risø, a cross-wind anemometer (CWA) has been tested. The (CWA) consists of a transmitter and a receiver separated a distance which typically is of the order of one kilometer. The transmitter is a 2 mW helium-neon laser. The receiver consists of two photodetectors separated by about 1 cm. A disturbance in the air between the transmitter and receiver will cause scintillations in the laser beam. By correlating the signals from the two photodetectors, one can measure a quantity which is proportional to the mean integrated path cross wind. The CWA is useful only when the turbulence intensity is weak; i.e., when the intensity of the scintillations is proportional to the turbulence intensity. When the turbulence intensity becomes high, the scintillations become saturated. In connection with the use of the CWA, we have done a theoretical investigation of light propagation through turbulent media.

Measurement of wind velocity

A signal processing system based on correlation of photon counts has been constructed and used for measurements of wind velocity by means of the Doppler technique. Another setup using the time-of-flight method has been constructed. As the latter principle has proved the superior of the two, emphasis has concentrated on this method which is described in the following. (See also (1).

Measurements of atmospheric wind velocities by the time-of-flight method

The time-of-flight laser anemometer (TFLA) is based on measuring the time of flight between two small volumes in space. This anemometer can provide the same information as a laser Doppler anomometer. We shall here describe a backscattering system aimed at localized wind velocity measurements at fairly long ranges.

The design targets have been:

1. A range of up to 100 m with a 1W cw argon-ion laser.
2. A good spatial and possibly temporal resolution (of the order of mm and 10-100 ms).
3. A range adjustment that can be aligned at one range and that will stay aligned independent of range.
4. The measuring direction can be changed without rotating the whole instrument.
5. There must be no ambiguity in the sign of the measured velocity.
6. The size must be minimal - especially the major optical components.

It has been assumed that a single particle timing will be preferable to a timing of particle patterns. (This has been confirmed experimentally). The many (small) particles will then essentially only cause noise.

The layout of the system is shown in Fig. 1. By means of a birefringent element W1 (a Wollaston prism) and a lens system L1, a laser beam is focused in two narrow volumes 1-10 mm from each other at a distance of 10-100 m from the equipment. The receiving system has been constructed as an optical copy of the transmitting system and thus has its highest sensitivity in exactly the same small volumes in the atmosphere as those where the transmitting system generates the highest light intensity.

The velocity is given by the ratio of the distance between the two focal volumes and the time of flight for a particle from one to the other. The latter is measured as follows:

When a particle passes the two focused beams, the backscattered light is collected by the optical receiving system and detected by two photo-multiplier tubes (PMT), one for each of the two focal volumes.

Just by rotating the Wollaston prisms W1 and W2 and the $\lambda/2$-plate it is possible the rotate the plane of the axes of the two beams without having to touch any of the larger components (lenses or PMT's).

A number of measurements have been made both under "controlled" conditions and in the real atmosphere under various weather conditions. Initial tests with a low-power (10 mW) argon laser and an inexpensive single element 15 cm diameter lens common to both beams gave quite good results at ranges up to 6 m.

The results of the measurements with a 1 W laser, a 15 cm collecting aperture, and a 5 cm transmitter aperture can be summarised as follows:

Measurements have been made at ranges up to 70 m in the atmosphere. The measurements were performed in what is considered to be a clean rural atmosphere. Below 30 m the number of spurious counts was generally negligible (see Fig. 3). The number of detected particles was typically of the order of 50 per sec. for a mean velocity of roughly 10 m/sec. The instrument could operate even under moderate rainfall. A window discriminator instead of just a threshold would probably improve the performance in rain.

The principles of the signal processing as presently used are shown in Fig. 2. The PMT outputs are amplified and filtered. The outputs of the discriminators are fed to a time-to-pulse height converter, which again provides for input to a multichannel analyser (MCA). The analyser will then as output give a histogram of the times of flight between the two focal volumes.

The first implementation, as shown in Fig. 2, is not an optimum processor - except from an availability point of view; it is more or less put together from standard NIM-modules.

A mobile, optimized system is under construction. The system is mounted on the support for a cannon. Each channel contains two matched, adaptive, tapped-delay-line filters (see Fig. 4) operating in parallel; one with a Gaussian impulse transfer function (followed by a window detector) determines whether a particle has been detected by the channel, the other having an S-shaped transfer function (Hilbert transformed Gaussian) generates a well-defined zero cross-over (timewise it is easier to determine a zero cross-over than the maximum). Thus the time difference between the zero crossings in the two channels equals the wanted flight time between to two remote focused volumes.

This time difference, in turn, is monitored by a coincidence tracker in which a voltage-to-frequency converter clocks a shift register at a speed making half the length of the shift register equal the flight time. If the flight time differs from its previously detected (or preset) value, an error function is integrated and the clock frequency is updated. Thus, at any time, a number proportional to the clock frequency can be used as estimate for the wind velocity.

Comparable measurements have been made with a differential Doppler set-up with a "single-burst" photon-count correlator/spectrum analyzer. Even though the Doppler set-up suffered from problems both with the optics and the processor, we feel it is safe to conclude that, under the present conditions, the TFLA with single-particle timing is superior to the differential Doppler system.

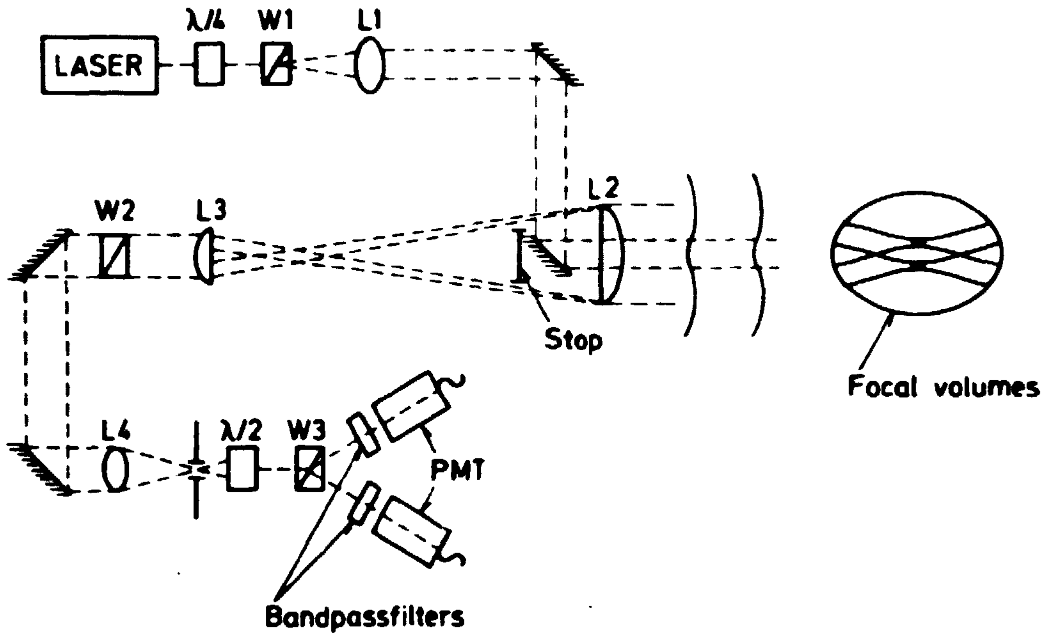


Fig. 1 Lay-out of the optical-system.

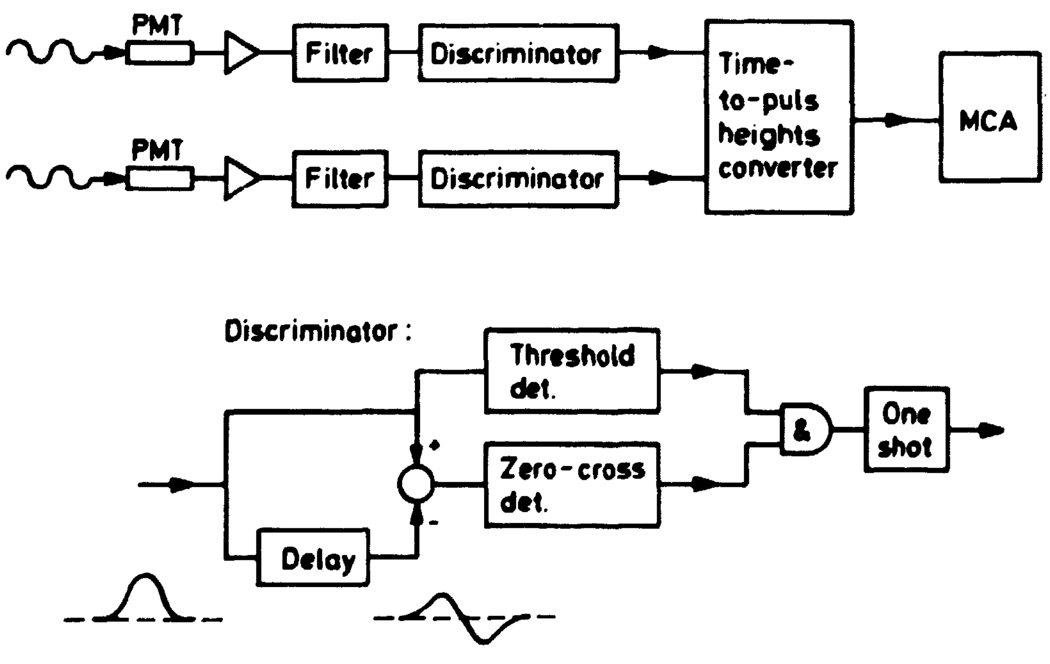
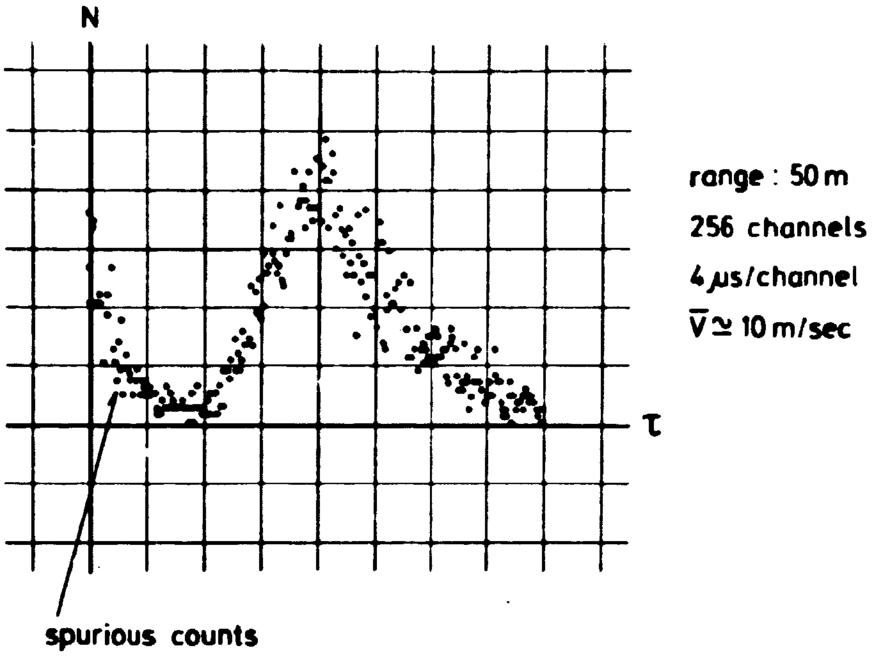


Fig. 2 The principles of the signal processing.



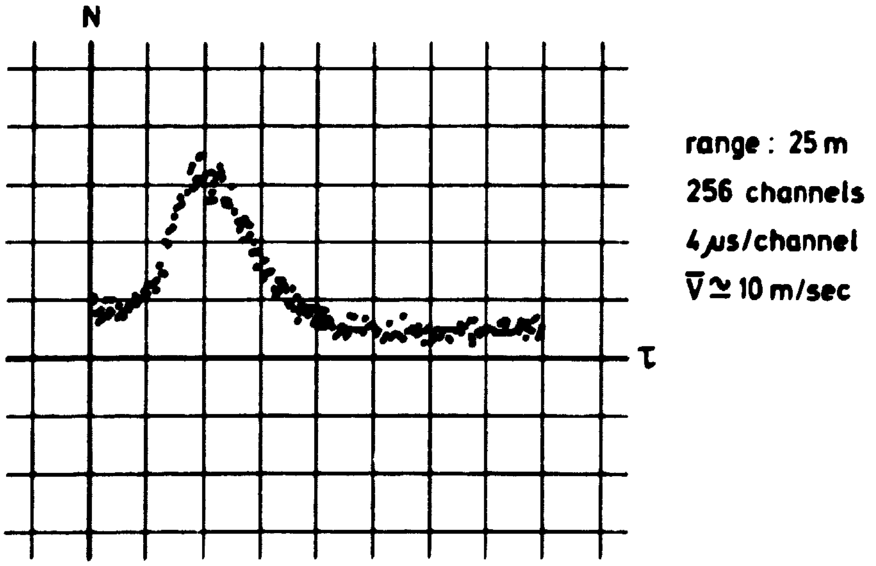


Fig. 3 Examples of time-of-flight histograms obtained with a MCA.

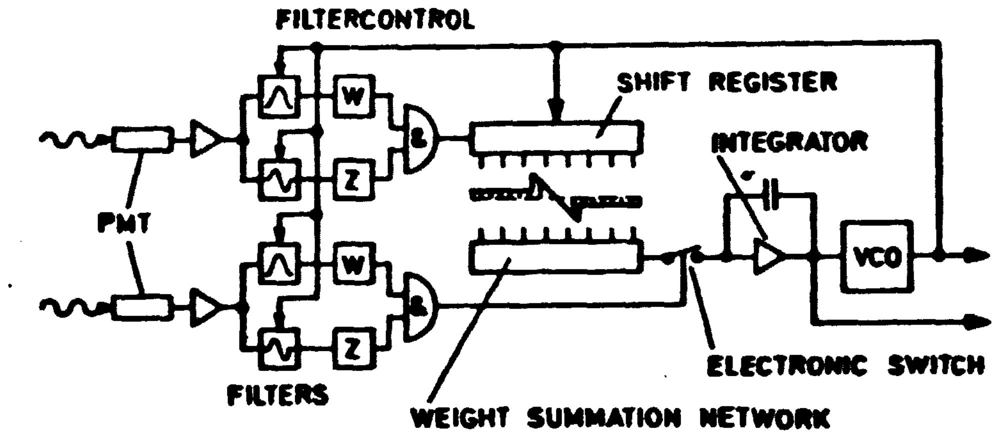


Fig. 4 A coincidence tracker.

Other activities

Pollution measurements

A fluorescence set-up has been developed for "Miljøstyrelsen" (Dept. of Environmental Affairs). The equipment is used for measuring the contents of polyoromates in the exhaust gas of an automobile engine.

Measurement of thermal noise

Experiments have been made for measurements of temperatures inside a nuclear reactor. By measuring Johnson noise and resistance (quantities which both can be measured currently from outside the hostile environment) in an ohmic resistor placed inside reactor the temperature can be calculated. At present the bottleneck in the project is the choice of proper heat and radiation resistant conducting and isolation materials rather than the electronic system.

Optical filtering

Methods for performing optical (spatial) filtering instead of electronic filtering are developed. A patent application has been filed.

Computer designed optical components

A ray-tracing program for computer design of lenses has been developed. The program was applied in connection with the specification of a lens system for the time-of-flight laser anemometer (see above).

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