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Publication date:
1984

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

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Citation (APA):
Goodstein, L. P., Hedegård, J., Højberg, K. S., & Lind, M. (1984). *The GNP Testbed for Operator Support Evaluation*. Danmarks Tekniske Universitet, Risø Nationallaboratoriet for Bæredygtig Energi. Risø-M No. 2460

RISØ-M-2460

THE GNP TESTBED FOR OPERATOR SUPPORT EVALUATION

L.P. Goodstein, J. Hedegård, K. Søe Højberg, M. Lind

Abstract. The GNP project is an outgrowth of our work over the past few years in the area of man-machine system representation and modelling - particularly with an eye towards studying the activities of diagnosis and decision making in connection with complex technical systems. Previous publications have dealt with the conceptual basis for this work (refs. (4), (5), (6), (8), (9)). However, there was felt to be a need for a realistic test bed of a reasonable (and variable) complexity for evaluating the concepts by means of a suitably designed experimental program. This paper will thus describe the so-called GNP

(continued)

INIS Descriptors. COMPUTER GRAPHICS; COMPUTERIZED SIMULATION; DIAGNOSIS; EDUCATION; FLOW MODELS; FUNCTIONAL ANALYSIS; HUMAN FACTORS; MAN-MACHINE SYSTEMS; MONTORING; NUCLEAR POWER PLANTS; REACTOR OPERATORS; REACTOR SIMULATORS.

UDC 007.51 : 621.039.564

November 1984
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project and the associated activity to date. The following points will be covered:

- GNP as a prototypical process
- GNP as a simulation
- The current GNP experimental setup at Risø
- Initial GNP
- Experiments at Risø
- Planning
- Experience to date

ISBN 87-550-1050-4
ISSN 0418-6435

Risø repro 1984

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GNP AS A PROTOTYPICAL PROCESS

The most important requirement regarding the choice of a testbed system was that it had to reflect the different aspects of system complexity met in modern production systems such as power plants or chemical processing units. The following aspects contribute to system complexity and are accordingly important to consider in diagnosis and control (ref. (6)).

- a component or a subsystem may have several purposes or goals
- plant and subsystem goals may be multiple and partially conflicting
- a plant function may have several alternative physical implementations
- the functional structure changes with the operating mode

The system did not necessarily have to represent all these aspects in a given application during the experiments. However, it had to be flexible and allow easy modification and extension. Thus the power plant presented here and called Generic Nuclear Plant should be considered as a basis for the generation of a whole collection of plants with different degrees of complexity, ref. (7).

The type of fidelity required of the test bed system is related to functional diversity which is an important characteristic of highly reliable production plants. Good agreement of test bed response to disturbances with some existing plant is not important. This implies that the component models chosen need not necessarily be very accurate models of actual existing components but rather describe behavioural characteristics or prototypical functional properties. The number of functional levels in the selected system should be at least three and preferably five. The number of levels can be identified by using the multi-level flow modelling (MFM) approach to systems representation, ref. (6). Three levels are required in order to allow the consideration of the "why-what and how" of system function. Five are necessary in order to study problem solving where system function should be evaluated on three consecutive levels (corresponding to why-what and how).

The requirements described above do not by themselves lead to the choice of a power plant model appropriate for the experiments. More pragmatic aspects as, e.g., the availability of a rich base of information for the type of system chosen was also important.

The power plant selected is shown in Fig. 1. The plant is a very simplified nuclear power station on the PWR type. Fig. 1 should only be considered as the basic layout of the system as modifications and extensions will be necessary when required by the experiments. Note that the basic system does not include a pressurizer.

The control systems include a steam pressure, steam generator level and a turbine-generator control system. Protection systems are not included in the basic system; they may be added later.

GNP AS A SIMULATOR

The system shown in Fig. 1 was used as the basis for generation of a simulator program implemented in PASCAL and executable either on the Apple III or PDP11/34 under RT-11. The initial version treats the secondary amount in detail while the primary is restricted to serving as an instantaneous energy producer.

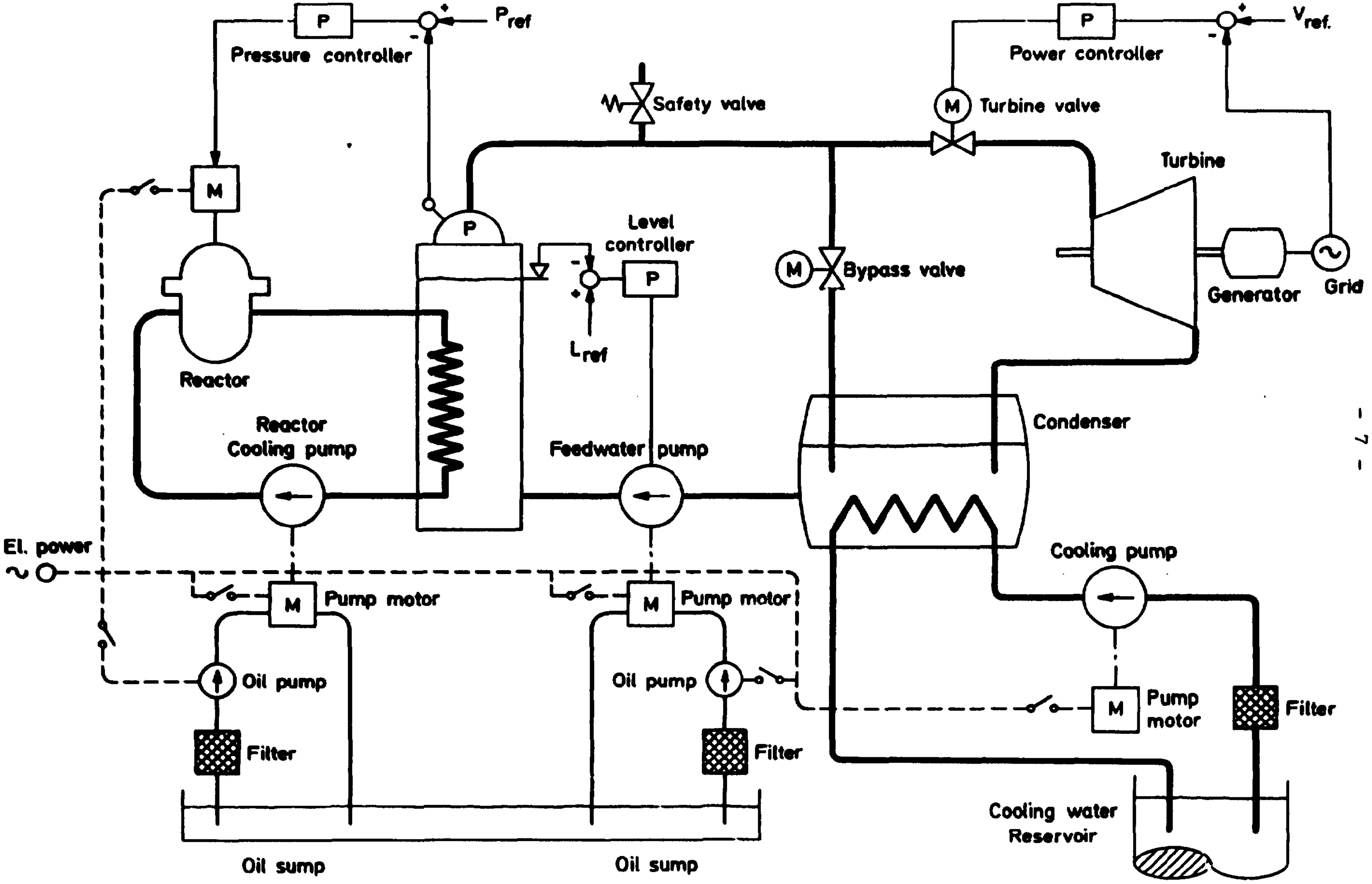


Fig. 1 GNP - Generic Nuclear Plant (Initial Version)

It was necessary to give some consideration to the modelling approach adopted. The component models were formulated using fundamental physical laws. However, in order to reduce model complexity, only the basic principles of the component function are modelled. This means that the models will not provide accurate predictions of the behaviour of some actual existing components but rather produce responses which are typical for the class of component in question. An advantage of using basic physical laws is that the resulting models will be applicable for a wider range of disturbances than will be the case for models which are accurate for certain selected inputs. Another advantage of using basic principles is that disturbances of component function such as leaks can readily be incorporated. However, properly speaking, not all of the models describe the function of components. Some describe the properties of more abstract functions (such as a leakage, and the turbine-generator). It is a well known problem in systems modelling that it is not possible to base modelling on a decomposition into physical components. It is necessary to take into account interaction between components and to decompose in a way which does not violate these functional interdependences. Improper decomposition will result in inconsistent or incorrect models.

Most of the data was based on information from real plants. The rest were estimated. The size of the program is about 500 lines of PASCAL-code - equivalent to approx. 13,5 K bytes on the Apple III. See ref. (3) for further details.

The use of the GNP simulating program in generating data for the first set of experiments is described later.

EXPERIMENTAL FACILITY

At present, the experimental setup utilizes an Apple III microcomputer (with 256 K byte store and three mini-discette stations) supplemented with a raster color display. Additional computing resources for off-line processing consist of a PDP11/34. The Apple was chosen originally because of an (optimistic) desire to use equipment which was compatible with that of colleagues in Europe and the U.S. in order to facilitate the interchange of programs and data. The other reason was the (at that time) unavailability of a larger machine for long enough periods of time in which to prepare or conduct the experiments. The choice has forced us to make certain compromises in the implementation which we now are planning to overcome by making more use of the PDP 11 as an on-line host machine.

At present, the Apple is used to make available to the operator /subject a given set of displays which reflect the current state of the simulated GNP. The present version is static in the sense that no actions can be taken by the subject on the GNP process, which is pre-programmed to the situation which is selected to be displayed. The present version is dynamic in the sense that the set of displays reflects the evolution in time of the selected event/failure. The subject's interaction with the system is thus restricted to selecting a given display from the available set as well as stepping time forward.

Fig. 2 illustrates a simplified flow diagram of the procedure involved in generating a set of displays for a given experiment.

Picture generation is done by means of the graphics package GRACE on a PDP 11 minicomputer. Variable and component names are converted to array oriented numbers in the GRAPE system due to accessing speed considerations in the on-line program G. Static/background pictures (so-called photos) which are based on Apple PASCAL raster graphics, are produced by the CAM program for the G program. The structure (including location, symbol type) and symbol library for the dynamic elements of all the pictures is generated via the MUL program.

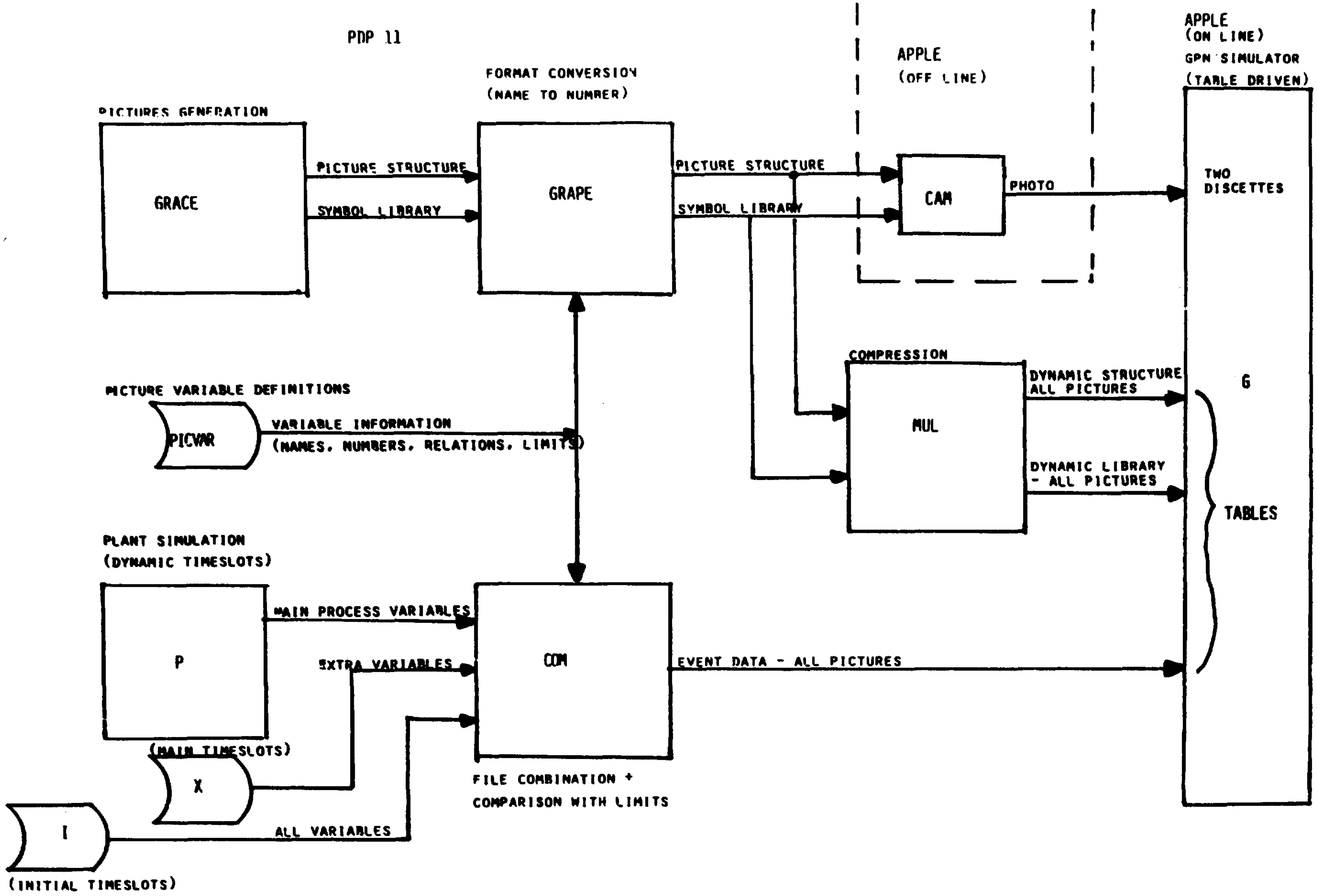


Fig. 2 Block Diagram for Display Generation

Events are composed by means of the COM program system. The program I (the GNP model) generates essentially state-variable values and names. For each sampling time, the variable list is repeated together with the current values. Each complete variable list is called a time slot and one typical event file has 35 time slots. The file contains extra variables such as set points, alarm limits etc. which are not supplied by the P program. Initial operating data, which precedes a typical event for some initial time periods are supplied from the I file. The model-based event data are converted to an all-picture oriented file with a list of picture-variable data for each time slot. These data include state (high/low/normal etc.), dynamic type and value. The states are based on comparing variables with limits as specified by the PICVAR file.

The program P simulates a given event by stepping manually or automatically through the time periods. The object picture is updated bby G according to state and the given rules each time a step is made or a new picture selected.

In addition to the Apple/PDP11 arrangement, the experimental facility includes audio/visual apparatus for use in recording for later analysis the interaction between the subject and the system. Fig. 3 illustrates this. As in our previous work, use is made of verbal protocols to obtain "thinking aloud" material which reflects in some way each subject's mental speculations about the presented situation on the color screen. A simultaneous recording is made - both of the screen and the subject's face - together with a time-of-day indication and thus captures completely the visible elements of each run. See Fig. 4 for a typical computer video frame. Use of this technique permits the experimenter, e.g., to confront the subject immediately after an experiment with the playback of certain particular segments of special interest in order to attempt to obtain a more deep-going discussion of the subject's thinking at that time.

Figure 3.

Figure 4.

THE FIRST EXPERIMENTS

The first experiment was planned as an exploratory investigation into the ability of experimental subjects with a technical background to identify GNP state on the basis of functional information presented on a color display and expressed in terms of abstract flow symbols. More specifically, there was a desire to

- evaluate the cognitive strategies and problem solving methods used by the subjects.
- evaluate the impact of the fault finding training course in general and diagnostic principles in particular.
- Investigate the value of using an abstraction capability test procedure as an explanative background for the qualitative results attained by the subjects in the experiments.
- evaluate experimental methods, data collection procedures and data evaluation techniques used in the experiments.

Display set

The display set utilized in the first experiments is based on a functional analysis of GNP. The result is shown in Fig. 5 with an enlarged section in Fig. 6 and is an example of the application of Lind's multi-level-flow modelling (MFM) concept to GNP in order to arrive at a functional representation of the process. The approach has been described previously, refs. (4), (5), (6) and produces in diagrammatic form the result of a top-down goal-directed functional identification and description in terms of mass and energy flows. Thus the top goals of safety and production give rise to a multi-level arrangement of functional entities - each with its own sub-goals, targets, conditions, etc., and conformed and constrained so as to

GNP FUNCTIONAL SPECIFICATION

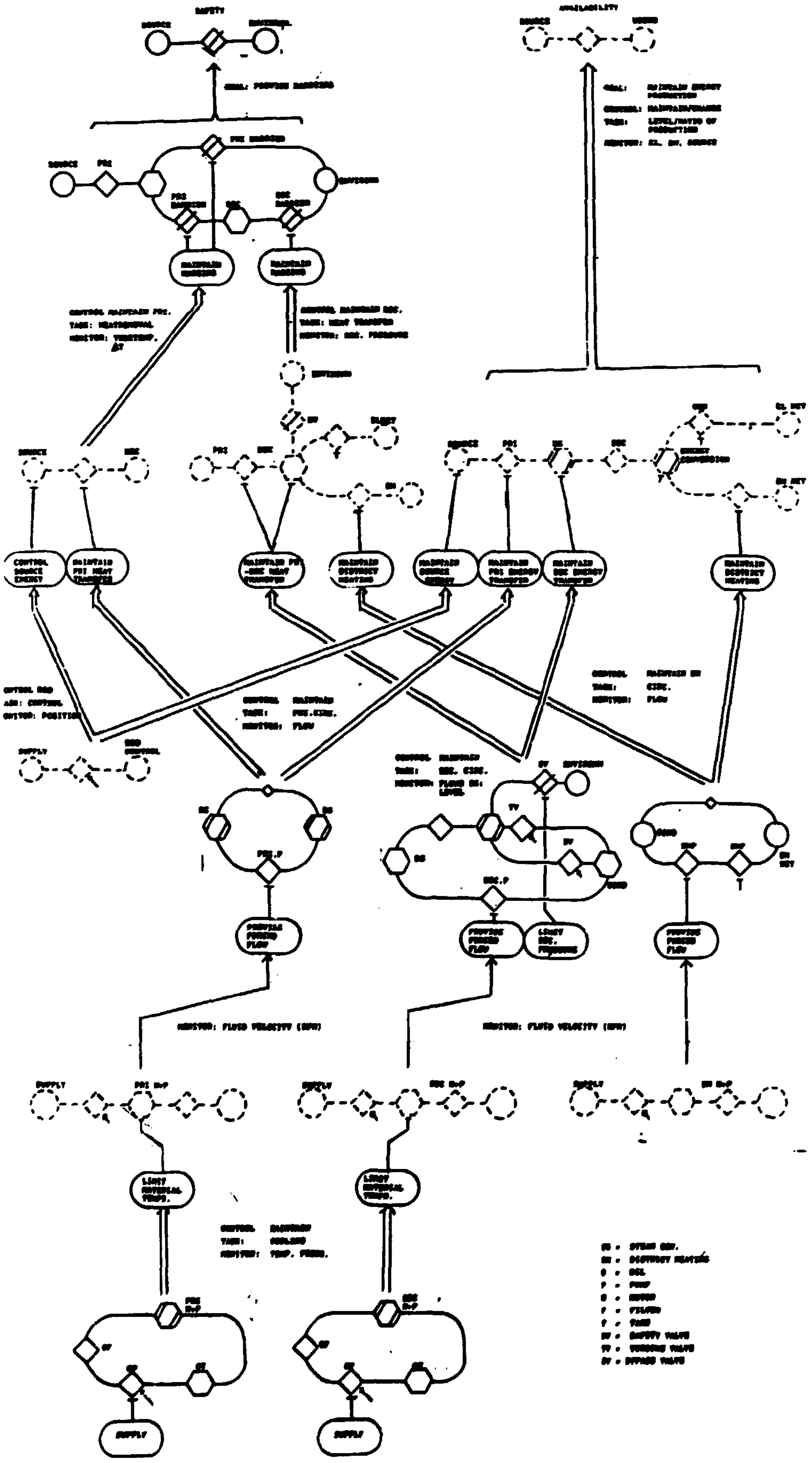


Fig. 5

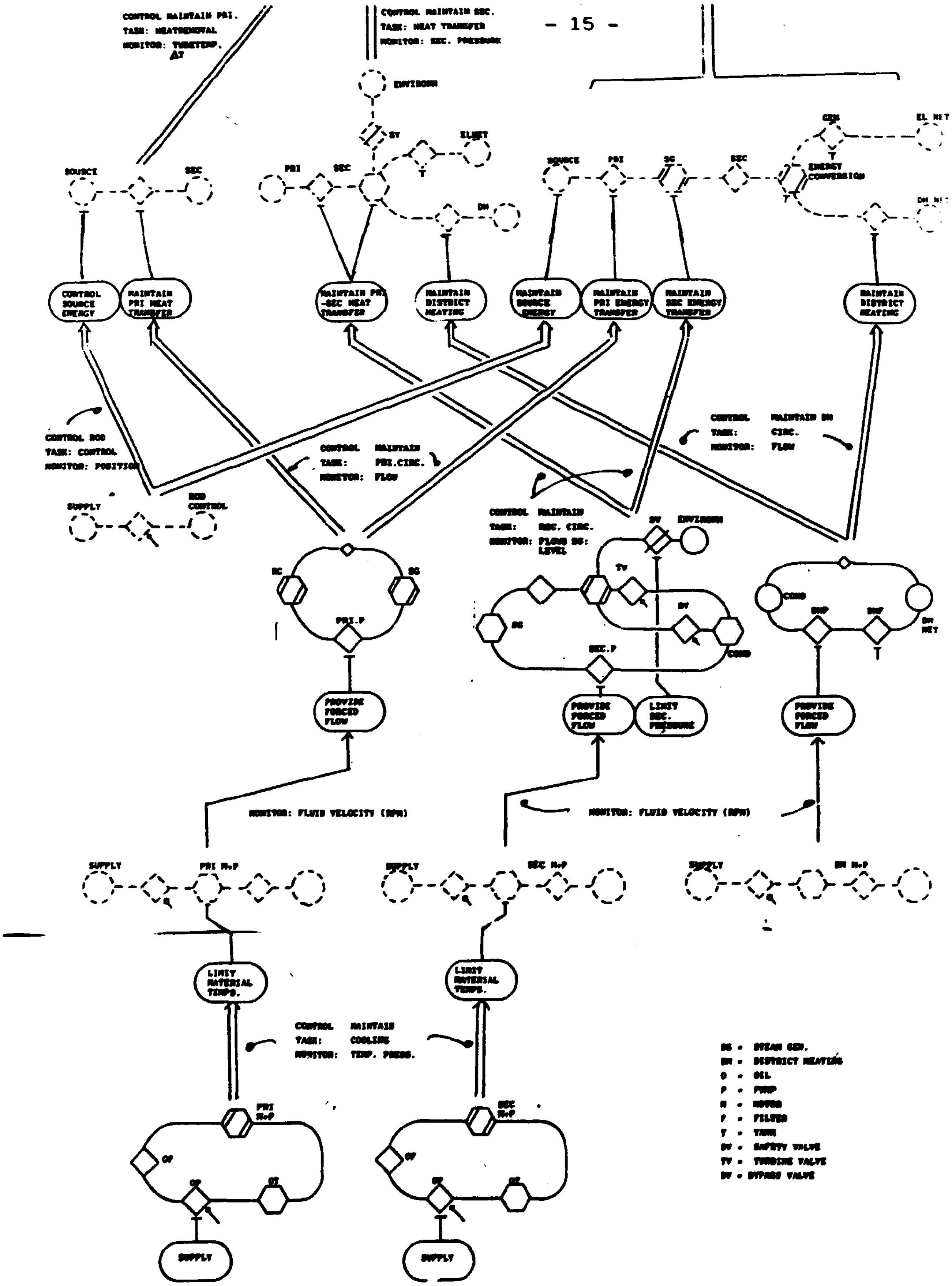


Fig. 6 Part of GNP Functional Specification

satisfy the requirements of the connected "user" functions at the higher levels.

For each function can be identified a goal, set by the user function(s), the control task to be performed and a set of critical variables the state of which reflect whether the requirements are being met. In turn, each function is conditioned by/sets goals for other functions at a lower level. The diagram can be seen to reflect this.

For the first experiments - aimed at testing the applicability of flow models as a directly visual representational form - this functional array was used as the basis for the design of the display set. The generic layout for each display is shown on Fig. 7 and a typical picture (in black and white) is shown in Fig. 8.

Each display thus consists of two parts; (a) the functional array, common to all pictures, and (b) the flow structure together with relevant state and condition-related information for the particular function. The functional array fulfills two purposes - it indicates the current choice of display and it indicates the overall status of each functional entity. This is made possible by assigning a letter for each function and connecting the letters together in accordance with the structure of Fig. 5. Thus the functional array is a miniaturized and greatly simplified version of Fig. 5.

The rest of the display comprises the flow structure for the given function - colour coded according to whether the function deals with mass or energy. Information about the function takes on the following forms:

- States of the critical variables which define (non)normal functional performance. This information is given in digital and analogue format - including a trend indication.

- State of the flow network - dynamic indications of too high/too low flow (with respect to normal/target), indi-

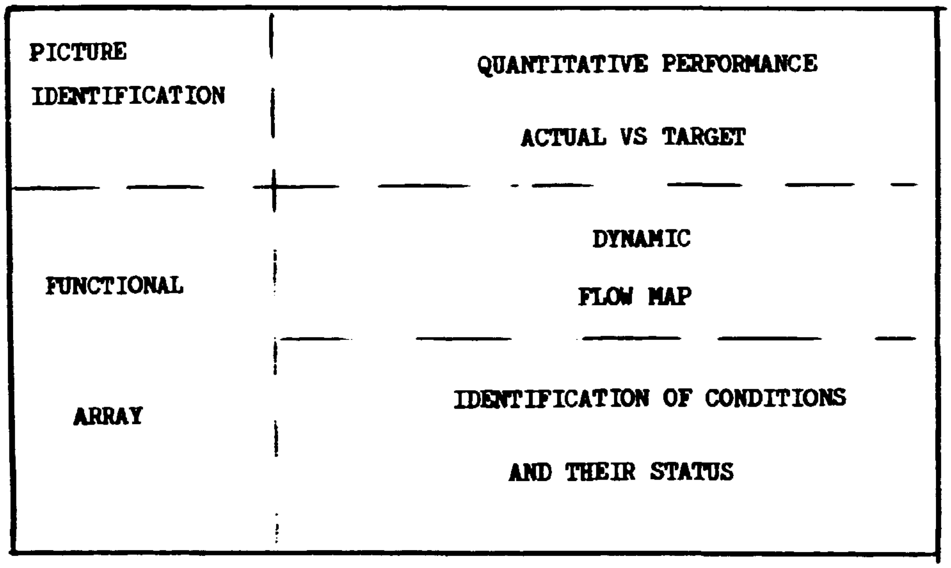


Fig. 7 Generic Display Layout

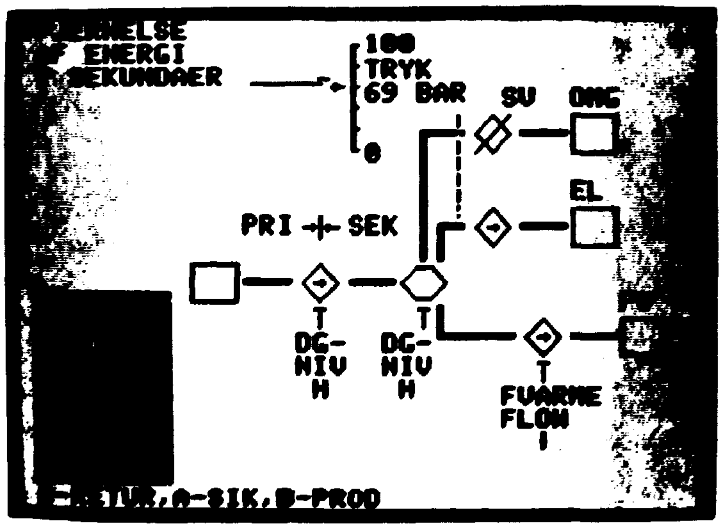


Fig. 8 Sample Display - Removal of Heat from Secondary

cations of availability/nonavailability of the individual flow elements, changes in the type of flow function, e.g., from barrier to transport.

- Identification of and state indications for the conditions necessary to maintain the given function. These are identical with an abbreviated name together with the letter corresponding to the function (and also display) which "supplies" the condition. This facilitates an orderly movement from picture to picture in searching for relevant information.

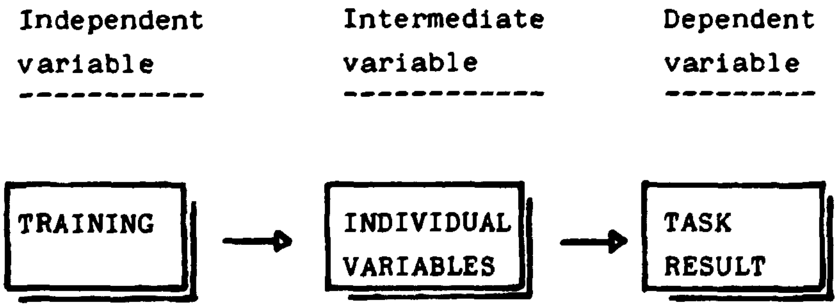
A combination of blink and colour change are used sometimes together with symbol charges - to denote deviations.

The interface to the operator is quite simple. To select a display, the appropriate letter is typed followed by a carriage return. The letter appears on the screen as a check on typing accuracy. Every carriage return steps one time slot through the event evolution.

Experiment Variables

As mentioned before in this paper the experiment purposes include dealing with experiment methods, cognitive structures and individual variables concerning human performance, etc.

The experimental paradigm can in a simple way be stated as follows:



The impact of the individual variables is of importance when evaluating the data collected from the experiment. In practice one has to prioritize the different individual variables involved in this kind of experiments. As the Multilevel Flow Modelling (MFM) is based on the notion of abstraction hierarchy, the human capability of abstract thinking comes into focus.

Since the abstraction capability is considered to have a large proportion of the variance caused by human variability efforts have been made in the GNP experiment to cover this variable by means of two abstration tests.

Experiment Procedure

The experiment has been carried out as follows:

a. Preparation of training and experiment equipment, etc.
b. Selection of and contact with subjects.
c. Preparation of experiment and test instructions, etc.
d. Training session for five hours.
e. Written background description from each subject.
f. Oral "exam" in order to state the subject's knowledge of the training content.
g. Experiment data collection.
h. Debriefing session with each subject individually with the purpose of getting information and personal points of view from the subjects about the experiment.
i. Abstract capability testing (The Brunner Board and Phrase Cards).
j. Data analysis.

This experiment, which is part of a series of experiments, will be followed by others in which the variables will be altered in order to investigate different aspects of operator support systems.

The Subjects

All six subjects are employees at the Risø Electronics Department. As a consequence all subjects have a more or less advanced technical background ranging from technical high school and specialized elektronics training to civil engineers. There were only males involved between 23 and 49 year of age. The participation in the experiment was of course on a voluntary basis and the subjects were briefed in advance of the general parts and purpose of the experiment.

The Training

The training session consisted of the following parts:

a. A brief overall description of the research project of which this particular experiment is a part.
b. Fault finding strategies and the MFM principles.
c. The GNP simulator system and working principles.
d. Familiarization with the GNP simulator in practice.
e. Experiment details and information in general.

The training was carried out in one day with all subjects sitting together in a traditional class room teaching situation. The different training parts were first explained by the instructor (Jan Hedegård) and thereafter discussed by the subjects.

The Experiment Session

After having had the oral "exam" mentioned above, the subject was given information about the purpose and procedure of the experiment, etc. The first event (called 00 dealing with a feedwater pump failure in the secondary loop) was started. The subject had three time slots to observe and tell about the normal fluctuations within the process. The transient then started and the subject was asked to continuously "think aloud" describing his intentions and actions. Emphasis was put on the subject's understanding of the content and processes of the progress of the event. When the subject had explained in a clear way the transient and its consequences, the event was concluded.

In case of some uncertainty about the subject's intentions and conclusions, the video tape was played back confronting the subject to the situation which had to be further explained. The experimenter was thus given another opportunity to get more details to the notes taken during the session, (Fig. 9).

The second event (called 01),consisting of two combined transients, circulation pump failure in the circulation system and failure in the automatic rod control system), was then introduced and carried out in the same way as for the first event.

The experiment session was terminated by giving the subject information on the data handling and reporting of results.

Proceedings after the Experiment Session

Two days after the experiment, the subjects individually participated in a debriefing session consisting of questioning about the training and the experiment itself. The purpose was to get information from the subjects in order to improve the training content and instructing methods as well as instructions and display arrangement during the experiment.

This debriefing session was concluded by testing the subjects problem solving style and abstraction capability. Two sets were used - phrase cards and the Brunner Board, (Fig. 10 and 11).

Figure 9.

Figure 10.

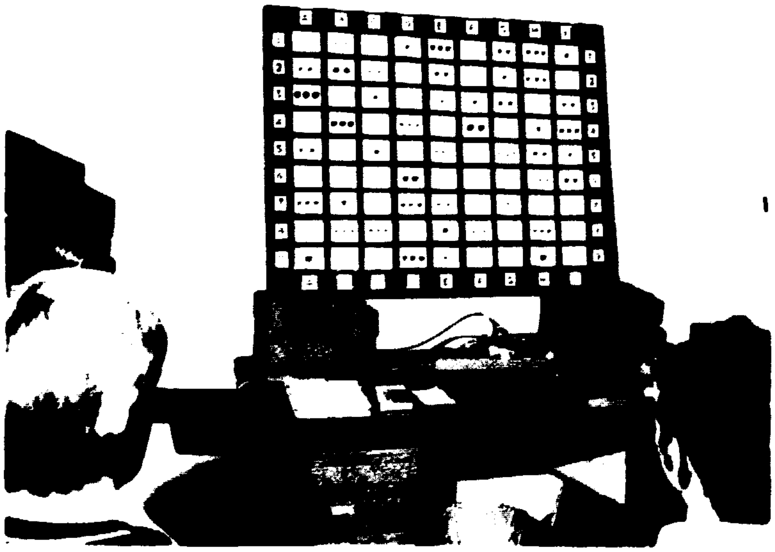


Figure 11.

Results

At the present time only trends and "face validity" results can be given.

It appears that small but significant differences between the subjects are present as far as problem solving strategies and fault diagnosis methods are concerned. This trend is not particular pronounced in this experiment due to the fact that the effects and origins of the transients are fairly simple to detect and explain.

In event 00 all subjects had a clear picture of the transient and its consequences after ten time steps were presented, i.e. seven minutes after the transient had begun and alarms began to appear on the display. The more complicated event 01 gave more variation in time used before the subjects were able to explain the event. The subjects used between 17 and 29 time steps before the event was finished. A not very astonishing result is that the subject gave a more clear and qualitatively better description of the event when the subject's background included a more thorough knowledge of technical processes in general and nuclear power plants in particular.

Finally, it seems that the subjects were more clear in their explanations and made less mistakes when using the fault finding strategies presented during the training session. Some subjects used these strategies through the whole event while others started their diagnosis according to the strategies but later on used a less coordinated and "common sense" tactic as they became more used to the programme. This latter behaviour resulted in a more confused and less constructive fault diagnosis proceeding.

Acknowledgement

This work has been partially supported by the Nordic Council of Ministers.

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pages + tables + illustrations

Date November 1984

Department or group

Electronics

Group's own registration number(s)

R-5-84
LPG-JH-
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However, there was felt to be a need for a realistic test bed of a reasonable (and variable) complexity for evaluating the concepts by means of a suitably designed experimental program. This paper will thus describe the so-called GNP project and the associated activity to date. The following points will be covered:

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