IMPLEMENTATION OF SAFETY PARAMETER DISPLAY SYSTEM AT VVER-440 NPPS

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To be presented in ENS International Topical Meeting on VVER Instrumentation and Control, Prague 21-24 April 1997

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Abstract

Furnishing VVER-440 nuclear power plant units with a safety parameter display system (SPDS) fulfilling the requirements of internationally recognized standards and guidelines has been ranked high on the lists of proposed safety improvement projects.

Technically such an SPDS system can be implemented either as a separate stand-alone system or as an, more or less closely, integrated part of a process information system of the plant unit. In the paper examples of these approaches are presented. Functionally all these examples include the well proven SPDS concept developed by IVO Power Engineering Ltd, Finland. The functional design basis, the general requirements for the system platform, experience on implementation and expansion possibilities of systems are discussed.

1. INTRODUCTION

Monitoring of the safety state of the large nuclear power plant process is a demanding task in changing process conditions because the necessary information may be widely distributed in different places in the main control room. Modern computer systems can be very effectively utilized in the presentation of this information, but there still exists the risk for wrong judgment of the actions needed in emergency situations. For this reason there has been a great need to develop safety function oriented displays where all the essential safety related process information is presented in a processed and highly visualized form.

The Nuclear Regulatory Commission (NRC) in the USA required that the Safety Parameter Display System (SPDS) described in the NUREG-0696 regulation must be implemented at nuclear power plants. International Electrotechnical Commission has issued a standard (IEC-960) for the functional design criteria of an SPDS implementation.

The IEC-960 standard describes its contents as follows:

" This standard considers the functional design criteria for a Safety Parameter Display System (SPDS) which provides information in a concise manner to aid reactor personnel, particularly under abnormal conditions. Computer based systems are used to display the main parameters associated with critical safety functions of light water reactors such as: reactivity control, reactor coolant system integrity, reactor core cooling and heat removal from primary system, radioactivity control and containment integrity. "

The SPDS developed by IVO International for VVER-440 plants includes critical safety function monitoring algorithms called "LO-CSF" fulfilling NUREG-0696 and IEC-960. The LO-CSF were implemented in 1990 integrated into the process computer systems of the Loviisa NPP in Finland. The algorithms were realized by means of the high level software tools of the plant process computer systems based on ABB PMS software platform.

The main reference for the concept as well as experience discussed here is the SPDS developed for Loviisa NPS. Functionally similar systems will be in operation at NPPs Kozloduy in Bulgaria and Kola in Russia. Kozloduy 3 SPDS has been in operation since 1996, whereas unit 4 system is planned to be taken into operation in the first half of 1997. The Kola 1&2 SPDS systems are in Factory Acceptance Test phase in April 1997. Kola systems will be implemented by the Norwegian institute IFE at Halden in consortium with IVO.

Technical implementations of the above systems are different, but common to all these are ABB PMS platform together with IVO SPDS application.

2. GENERAL REQUIREMENTS

The general design of a SPDS shall be compatible with plant **emergency procedures**. These are the most critical part of the operator instructions in terms of nuclear safety. The SPDS shall be designed according to these procedures and be easy to update upon their development.

Compliance with **international standards** (IEC 960, NRC regulations) is necessary for obtaining approval from the nuclear safety authority. The standards, however, define only the minimum requirements applying for all types of nuclear power plants.

The SPDS should be designed also for **normal plant operation**; not only for abnormal and accident situations. Frequent use of the SPDS keeps the operators better conscious of the information provided by the SPDS. Thus the SPDS should include also functions which provide immediate improvement in the plant safety such as continuous calculation of process parameters and safety margins as well as monitoring of the availability of the safety and auxiliary systems. Due to the importance of the SPDS for safe plant operation it should be included in the training simulator.

The overall system **performance** shall be high enough to provide adequate data acquisition capacity and fast response for the operator during all plant conditions.

There shall be adequate **isolation** in the SPDS process interface: Any fault in the SPDS shall have no effect on the systems important to safety at the plant.

Availability of the system shall be high for the continuous operation of the system in the control room. Availability of the information highly depends on the quality of process instrumentation. An important advantage in SPDS system over the conventional means of information presentation is the **signal validation**, which therefore should be utilized for improving the information quality as far as feasible.

The reliability of the SPDS largely depends on the **software platform** used to build it. The platform shall be proven, and - as much as practicable - independent of the computer hardware to allow later hardware extensions and upgrades. The software shall also include easy and reliable means of building and maintaining the SPDS algorithms, displays, and other functions. The software in general shall be selected and designed to last for the plant life-time.

The **computer hardware** of the system should represent proven industry standard real-time computer technology ensuring easy upgradeability and compatibility with commercially available hardware.

The software and hardware shall allow for easy **expandability** without need of changes in the existing software. There shall be no practical limitations in adding new process signals and functions in the SPDS. The network and graphics software shall make it possible to use standard peripherals and personal computers in the system.

3. SPDS FOR VVER-440 PLANTS

The SPDS developed for VVER-440 plants is described below as to the monitoring of critical safety functions and emergency systems, user interface, and basic software platform.

3.1 Monitoring of critical safety functions (CSF)

A symptom oriented Critical Safety Functions Overview display supports the operators in judging the process in terms of its nuclear safety status. It presents the alarm states of the parameters derived by the CSF monitoring algorithms.

Basically the critical safety functions are as listed below. In SPDS implementations these can be reduced (combined) to 6 or even 5 CSFs to be strictly in accordance with the local emergency procedures.

- Subcriticality
- Core Cooling
- Primary Cooling (Decreasing priority order)
- Mass Balance
- Primary Pressure
- Emergency Cooling
- Containment Integrity

The CSFs are defined so that if they are restored, then the core damage is avoided.

The alarm status of a CSF is defined so that no alarms are activated if the thermohydraulic state of the process does not significantly deviate from the normal state. For example, major transients such as a turbine trip or a reactor trip followed by turbine trip, do not alone activate the CSF alarms.

In order to get a quick overview of the safety of the process state the degree of severity for the status of the critical safety functions is defined. The degrees of severity are given in Table 1.

DEGREE OF SEVERITY	DEFINITION
0 : SAFE	No counteractions for nuclear safety are required
1 : THREATENING	Normal systems are not capable of keeping the safety function in their normal states
2 : SERIOUS	Emergency systems are not capable of fully restoring the safety function
3 : DANGEROUS	Emergency systems lack the capability of restoring the safety functions and core damage may result

Table 1. Degrees of severity of CSF status.

The degree of severity makes it possible to dynamically determine (dependent on the process state) the order of the control actions to be taken to restore the CSFs.

The control strategy used to determine the control actions sequence is as follows:

A First try to restore the CSF having the highest degree of **severity**

B If several CSFs have the same degree of severity, then first try to restore the one ranked highest in **priority**

C If a degraded CSF is supported by the emergency system as designed or it cannot be supported better, then try to support the next one according to the rules A and B above

3.2 *Monitoring of safety systems*

The states of the safety systems are monitored by using connection state algorithms. The connection state algorithms check whether the emergency systems function as designed. If a mismatch is observed, then a first priority alarm is given. These alarms represent a straight-forward guidance level in the Functional Emergency Procedures.

In order to start up pumps or to change the state of a safety system valve, auxiliary information is needed. Therefore, monitoring algorithms for the availability of emergency power and instrument gas are employed. The availability is presented in a separate display.

3.3 User interface

3.3.1 SPDS displays

The status of the CSFs and the safety systems connection states are presented in an overview display (Fig. 1). The design basis of the overview display is to present the whole status of the Critical Safety Functions in a single display picture in the most informative way. No icon-type overview display was seen necessary according to the opinions of experienced Loviisa NPP operators, who preferred an overview combined with complete set of CSF symptoms in a single display at the top of SPDS display hierarchy. This is partly due to their long experience with high resolution computer graphics in the plant control rooms ever since the start-up of the plants in 1977-80.

The overview display includes a lined rectangular area for each CSF. In that area, the status of the CSF is presented by displaying the degree of severity for each symptom related to the CSF. In the rectangular area, information is also provided on the connection states of the relating safety systems. At the bottom of the display the states of the diesel fed busbars and the instrument gas supply are presented. Alarming values are indicated by color.

Typical supporting displays on the next level of display hierarchy are (Fig. 2) Primary circuit, boiling margin & cold stress, and emergency feedwater systems displays. The amount of process diagram displays varies according to the process data available.

The CSF activated alarms are presented in the chronological alarm and event list displays, also.

The dynamic logic diagrams of the CSF and safety system connection algorithms are presented on request. The logic is color coded to indicate whether the state is true or false.

The CSF algorithms and displays are realized by using the standard calculations, logic, and graphic tools of the PMS software platform. The dynamic logic diagrams are automatically generated from these logic definitions when the logic diagrams are called on the display screen.

This feature supports the verification of the definitions. It also provides the operators with a possibility to see how the alarms are generated.

3.3.2 Retrieving of displays

The CSF overview display appears automatically on the shift supervisor's screen overwriting the whole screen when any CSF activates an alarm. The next automatic appearance is allowed only if all CSF alarms have been inactive for a certain time period. The idea is to prevent a frequent automatic appearance of the CSF overview display in the case of reappearing alarms.

The CSF overview display can be called by the operator on any display screen.

Each display of the SPDS continuously indicates the general status of the CSFs by special symbols in the corner of the display.

At the bottom of the displays there are soft-key fields for direct display calls and for user defined sequences.

The dynamic logic diagram displays of both the CSF algorithms and the connection state algorithms can be directly called by pointing the cursor on the respective text.

Generic feature in the PMS is that any dynamic information on the screen can be used as a reference for further details by means of cursor pointing.

3.4 Basic software platform

The SPDS is implemented by using the standard data acquisition, preprocessing, calculations, alarm monitoring, and user interface functions provided by the Process Information Management Software (PMS) of ABB.

PMS is a software product intended for demanding real time process monitoring and supervisory control applications. ABB has used PMS to build over 100 real time systems, of which more than half are power plant process information systems. PMS based process information systems have been delivered to six nuclear power plants. Most of these systems include a safety parameter system as an integral part.

PMS runs on Digital's Alpha AXP or VAX computers under the Open VMS operating system.

PMS supports workstations, PCs, and X-terminals as user interface output devices. Standard keyboards, mouse or trackball, and a proprietary function keyboard are used as user interface input devices.

PMS provides as its integral part effective tools for building and maintaining applications. PMS tools are available for example for defining data base variables and their attributes, creating static parts of displays and reports and defining their dynamic information, and defining calculations on values of database variables. By using these tools, applications such as safety parameter display systems can be created without any computer programming. If, however, computer programming is needed to implement a particular application, PMS provides a standard application program interface through which custom or user developed application programs can be interfaced to it.

The displays and reports of the user interface can be implemented by using a set of standard predefined PMS displays supplemented, if needed, by custom displays and reports. The standard predefined PMS displays include 300 different types of displays for presenting any data in the PMS database.

The calculation tools of PMS provide means for performing arithmetic and logic calculations on measured variables at regular time intervals, typically in the range of 1... 10 seconds. The results of the calculations are stored into the PMS database as values of composed variables and can be further handled in the same way as the values of measured varies. The proposed SPDS for VVER-440 plants is built on PMS by using solely its software development tools.

The design of PMS is based on distribution of both software and data to a network of computers on an Ethernet or FDDI local area network. The PMS database is a network database, such that all areas in the network are available to all software irrespective of where in the network the software resides. The proposed SPDS for VVER-440 plants utilizes the distributed design of PMS such that the user interface is distributed to all workstations in the system.

The design of PMS also provides for building high availability system such that desired software functions are executed in two or three computing nodes of the network, fully active in one node and in shadow mode in the other nodes, and that the shadow node automatically turns to a fully active node when the fully active node fails. In this way double or triple redundancy can be provided.

3.5 Process interface

The process interface is of crucial importance for the reliable operation of a CSF monitoring system. Therefore, the state and specifications of the existing instrumentation, transducer signals and data acquisition systems shall be thoroughly assessed prior to the final specification of the set of input signals to be used in the SPDS system.

The most economic solution, moreover minimizing disturbances to the plant instrumentation and control systems, is a gateway or bridge connection to the data acquisition system of existing process computer system. Provided that safety related signals need not to be touched, SPDS process interface can be built using industry standard components.

3.6 Specification of application software

The functional specification of the application software consists of two parts:

- General design principles
- Definition of CSFs
- Design principles of CSF algorithms
- Severity classification
- List of symptoms for each CSF
- Safety system monitoring principles
- Display principles
- Algorithms for monitoring the status and degree of severity of each CSF parameters
- Examples of logic diagrams for monitoring the functioning of emergency systems
- Examples of display pictures at various hierarchical levels

Information needed from the client

- Results of safety analyses for design basis and other accidents
- Plant protection and reactor trip system documentation
- Design data and analyses of safety systems
- Emergency operation guidelines
- Process and instrumentation diagrams

4. REFERENCE INSTALLATIONS

4.1 Integrated systems

The present process information systems at Imatran Voima Oy's (IVO) Loviisa NPS in Finland (two-unit VVER-440) have been in operation since the computer replacement in 1990. Upon the replacement an SPDS was added to the systems as a new function.

A duplicate of the SPDS is also implemented at the full-scope training simulator of the plant.

The SPDS has met the functional requirements and its reliability has been extremely high. The simulator has provided good means for validating the SPDS, as well as for training of the operators in utilizing SPDS for various plant incidents and accidents. The role of plant operators and other staff has been important in the design and validation phases.

The SPDS has been approved by the Finnish Nuclear Safety Authority (STUK).

Recent enhancements to the SPDS include addition of guidance information to applicable emergency procedures and a display hierarchy level for presentation of emergency procedure information in dynamic display formats.

The Loviisa process information system includes several operator support functions, which are available for incorporation also into the stand-alone SPDS. The support functions are discussed in Section 5.3 below.

4.2 Stand-alone systems

The SPDS described in Section 3 above has been supplied as a stand-alone system to unit 3 of the **Kozloduy** VVER-440 NPP in 1996 and will be taken into operation at unit 4 during the second quarter of 1997.

Nearly similar system will be delivered to **Kola** NPP, units 1 and 2. This system is in factory acceptance test phase in April 1997 at IFE/Halden, Norway.

In both Kozloduy and Kola systems the definitions of safety functions are essentially identical. The number of safety functions is reduced to five by combining some of the functions of Loviisa system. The main differences in respect to SPDS implementation are as follows:

- older type of reactor ("230") and the plant processes in general
- lacking of containment
- shortage of measurement signals (especially qualified ones)

Due to these differences some redesign has been necessary in SPDS algorithms as compared to those in Loviisa SPDS.

The control room operator interface of each plant unit is implemented by using one computer workstation (Fig. 3). A similar workstation is used to provide separate plant shift supervisor SPDS interface for the two plant units. At Kozloduy a personal computer based SPDS user interface, with access to both plant unit SPDSs, is provided for the plant Emergency Support Center.

The process interface of the SPDSs, including in the first phase about 300 input signals (analog and binary), is implemented at Kozloduy by using the G2/RTP data acquisition system of Computer Products, Inc. At Kola, the SPDS system will receive information from the existing process information system MSKU via a gateway between system LANs.

A fiber optic Ethernet local area network is used to interconnect the subsystems of each SPDS, and to connect the emergency support center SPDS terminal to both of the SPDSs.

The whole software of the SPDS resides, for redundancy reasons, in the control room operator interface workstation and in the common workstation(s).

5. EXPANSION POSSIBILITIES

5.1 General

The described SPDS can be expanded in two ways:

1) By expanding the functionality of the system to encompass more functions of a plant process information system and by increasing the amount of acquired input data.

2) By adding new operator support functions to the systems

5.2 Expansion to process information system

The distributed structure of the PMS software platform of the proposed SPDS provides a flexible and cost effective path for expansion. PMS includes the full functionality required from software platforms of advanced nuclear power plant process information systems. Thus, the SPDS for example already includes an operator interface which can be retained upon its expansion up to plant process information system. This ensures that after the expansion a unified operator interface is achieved instead of different interfaces for different subsystems that would be the result of the expansion if the SPDS would be built on a software platform not including such capabilities.

The expansion of the SPDS towards a full plant process information system may be performed in several phases. The phases could be based for example on plant subsystems. Such a phase could encompass for example the turbine plant or the reactor plant. The functionality of the system can also be increased in phases. The optimal expansion path depends on such things as the operational condition of the plant, and the available personnel and other resources for implementing the expansion.

5.3 Support functions

Computerized operator support functions generally include software applications and functions designed for supporting control room operators in identifying plant function, system and component states, and to identify faults and diagnose them. In the case of Loviisa NPP such functions have been integrated into the process information system. They can as well be integrated into a stand-alone SPDS built on the PMS software platform.

In the case of the Loviisa process information system support functions have been implemented by using the calculation and logic tools of the PMS software as far as feasible. Only in some special cases or in very extensive calculations computer programs have been developed. Verification and validation have been made in most cases at the plant on-site simulator.

Available operator support functions and their main features are the following:

Plant performance related functions

- Monitoring the efficiency and optimum operation of plant components
- Determination of the reactor thermal power
- Determination of the plant thermal balance
- Calculation of leakages and flow balance of the primary circuit
- Continuous supervision of operation economy

- Performance monitoring of main plant components

Reactor performance related functions
- Input: mainly in-core analog measurements
- 3D-power distribution automatically and on request
- Local thermal margins (pinwise power distribution)
- Automatic detection and filtering of defective measurements
- Fuel burn-up distribution and loading pattern calculation

Task oriented displays
- To support operators in specific tasks such as start-up, shut down and other transients by optimizing information presentation

Intelligent alarm handling
- Logical reduction and masking of irrelevant alarms
- Dynamic prioritization based on the process state
- Alarm state of subsystems and functional groups

Logic displays
- For monitoring of I&C system interlockings and control sequences
- Automatic graphical display of logic algorithms

Early Fault Detection
- Model-based fault detection for high-pressure preheaters

Materials stress monitoring
- For prediction of cracks and lifetime of pipes, tanks etc.
- Based on strain-gauge and temperature measurements

Forecasting reactivity effects
- Calculation of xenon poisoning

Long-term history
- Plant life time history of selected parameters

Computerised operational procedures presentation

After the experience gained in testing and using the Loviisa SPDS, as the next step towards computer aided guidance of the operator a project for developing computerized operational procedures has been commenced. The tasks of this function are:
- Guiding the operator to the relevant procedure
- Presentation of procedures dynamically and interactively on displays
- Follow-up monitoring of actions required in the procedures

The function is implemented by using the PMS tools. In the first phase the guidance is limited to procedures associated to critical safety functions.

6. CONCLUSION

The presented SPDS concept has been designed together with VVER plant operators having a long experience with computerized operator support systems. The system has been tested thoroughly in a full scope full replica simulator and used both in plant operation as well as in operator training for 6 years.

The main function of SPDS is continuous monitoring and display of the critical parameters of NPP processes to provide the operators with adequate and reliable information on the safety status of the plant. This information supports the operator in abnormal situations to take correct actions.

Introducing SPDS into the control room does not affect the role of the operator or the need of written emergency procedures.

Additional safety enhancement can be achieved by developing advanced operator support applications for the control room operators as well as for the Technical Support Centre and Emergency Operation Facility The main attention shall, however, be paid on such principal requirements for safe operation as skills, and training, of the operational personal as well as reliability of the process information in the main control room of NPP.

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Fig. 1. LAY-OUT OF SPS OVERVIEW DISPLAY

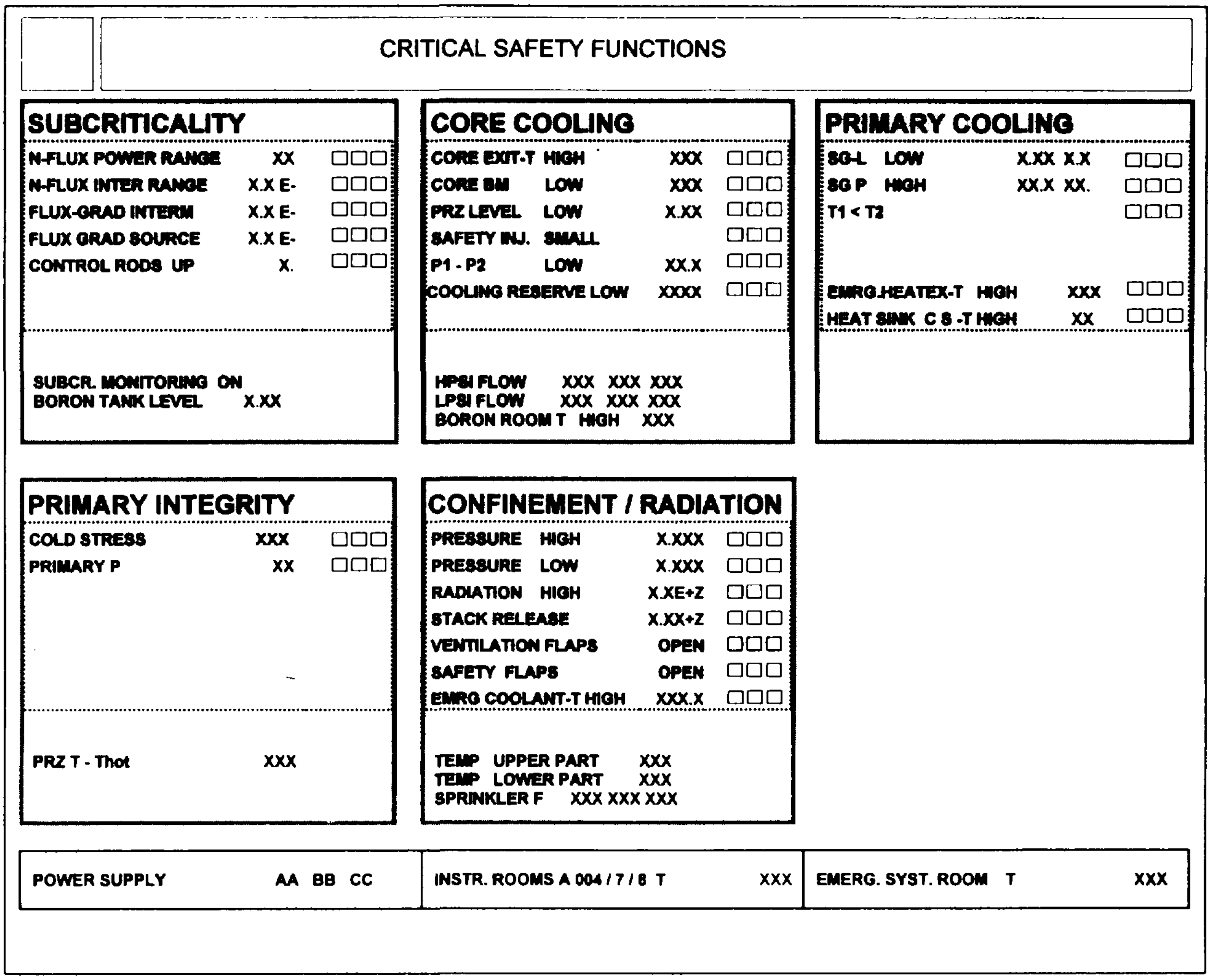
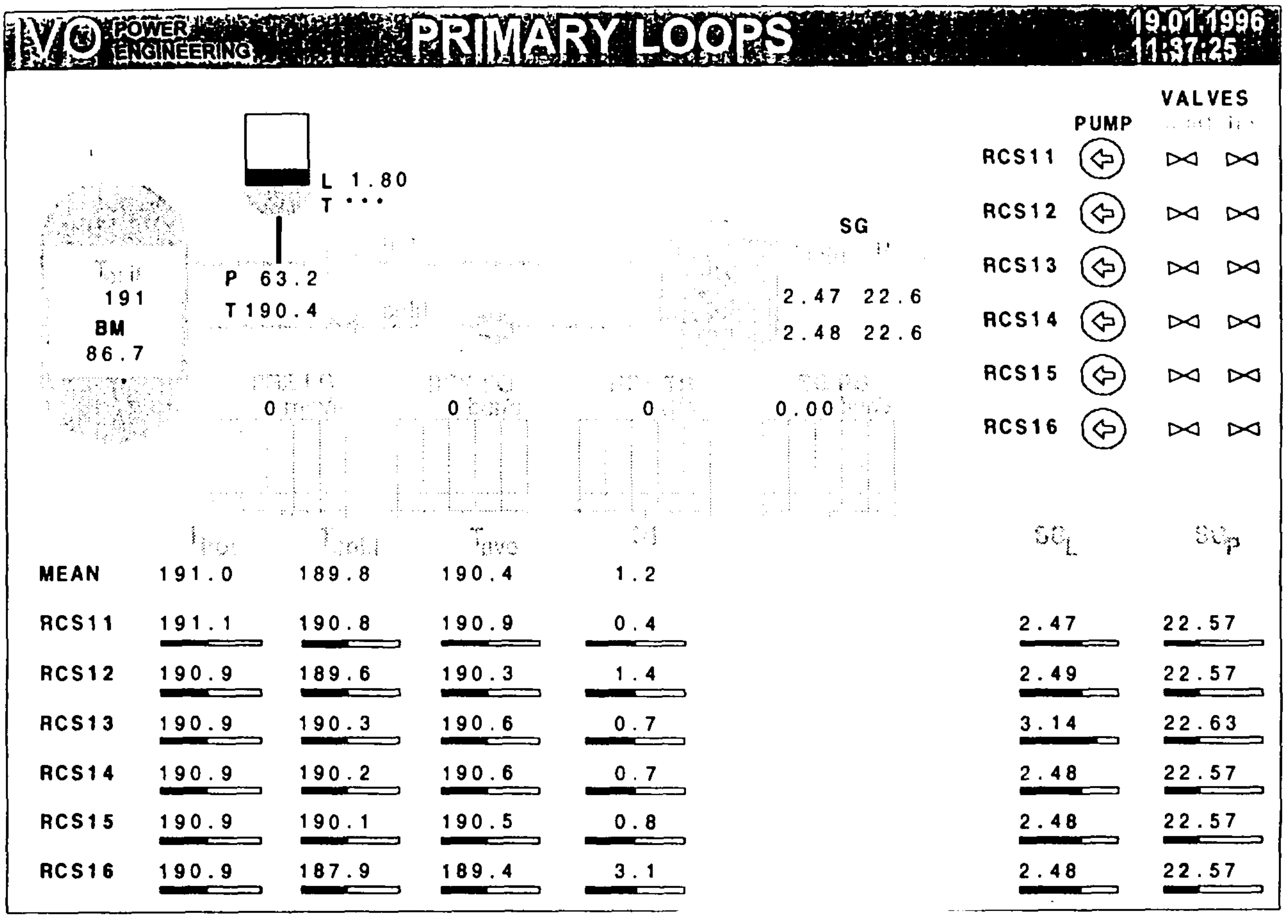


Fig 2. EXAMPLES OF SUPPORTING DISPLAYS



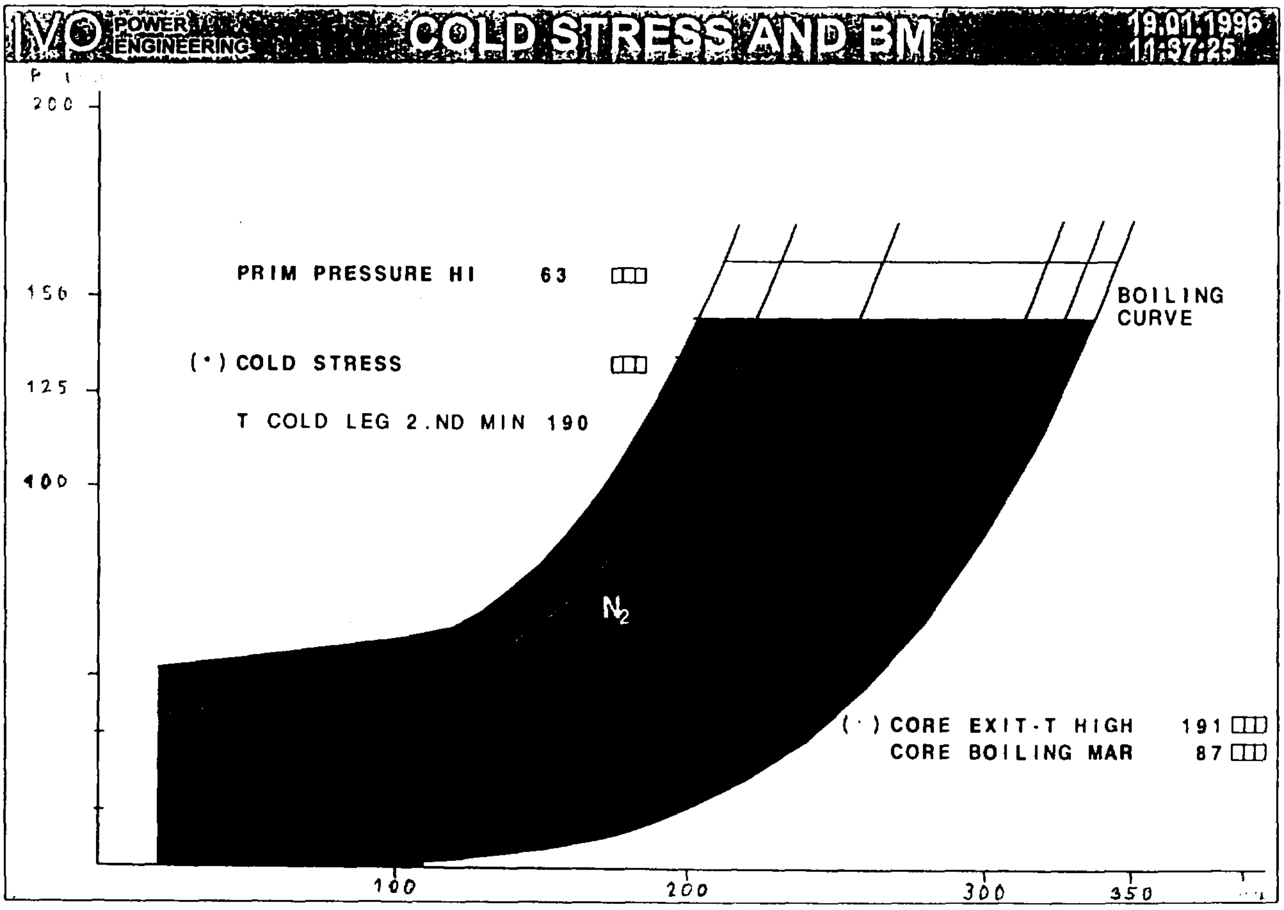


Fig 3. SPDS SYSTEM CONFIGURATIONS