CERNAVODA CANDU 600 NPP - LATEST IN HOUSE IMPROVEMENTS OF MAIN CONTROL ROOM FUNCTIONALITY BASED ON COMPUTERIZED APPLICATIONS

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***Abstract*— As part of Romania program to adhere at European Union, SNN started the construction of a new Emergency Control Center. It is designed to act as a site coordination center in case of nuclear accident. The communication and information channels requirements of such facility are supplemented with an electronic display for a number of critical process parameters which should briefly characterize the nuclear reactor status during the accident. The authors designed, developed and deployed the system for Cernavoda NPP. After implementation the system started to be evaluated in idea to be used also as an important operator tool in Main Control Room of the plant and also to be replicated in other national level emergency centers. Implementation effort was helped by the Plant Information system previously deployed in MCR.**

Keywords: Critical Safety Parameters, Emergency Control Center, Plant Information;

I. INTRODUCTION

Between improved requirements for emergency response capabilities of nuclear plants after Three Mile Island (see Ref.[4]) a Plant Safety Parameter Console was requested and this was analyzed in conjunction with Inadequate Core Cooling conditions. These new assessments require the licensee to implement a program ensuring the capability to accurately monitor the Reactor Coolant System subcooling margin.

The nuclear industry responded by proving capabilities to monitor Safety Parameters. In Candu type nuclear plant we refer this problem as Critical Safety Parameters (CSP) monitoring. At Cernavoda the CSP parameters are monitored based on Station Process Computers and data acquisition systems attached to the two Special Shutdown Systems of the plant. There are instruments attached to plant computers which are not trustable during the accident. Also there are significant instruments for plant status which are qualified to work during accidents but are not connected to plant computers. The CSP Monitor design must carefully balance between these two types of available instruments to ensure a full picture of nuclear plant status. Also the adequate ergonomics of computer display should be provided in accordance with international standards for Human – Machine Interfaces.

Present interest of such system was raised by the need to implement it in the new Emergency Control Center built on Cernavoda site. This center is part of country commitments to improve nuclear safety capabilities in the concert of European Union standards. It contains high standard communication and decision making support equipments to be used in the case of nuclear emergencies. The future success of using this system will qualify it to be used in Main Control Rooms of both Cernavoda nuclear plants and will improve the quality and effectiveness of Romanian nuclear plants safety monitoring.

II. PELIMINARY ACHIVEMENTS

During last years the plant built its own Gateway and Plant Data Network system, as many Candu plants did, to benefit from digital data produced by existing plant computers. The system was entirely developed with in-house effort and using a new digital interface instead of PDLC card (see Fig 1).

A unique characteristic of the system not present in other CANDU plants is the use of redundant gateways. The concept is named AFRG (Advanced Full Redundant Gateway) and was very proficient for the reliability and functionality of the entire network. By the automatic switch of various data packages between the two data channels, redundancy allowed traffic balancing, reliability of the system and easy maintenance/upgrade of gateways, without interruption of functions.

The associated functions implemented in this network are:

- DCC printing based on network laser printers (the system has one black & white printer for every DCC and one color printer)
- Data Acquisition of all DCCX and DCCY digital and analog information

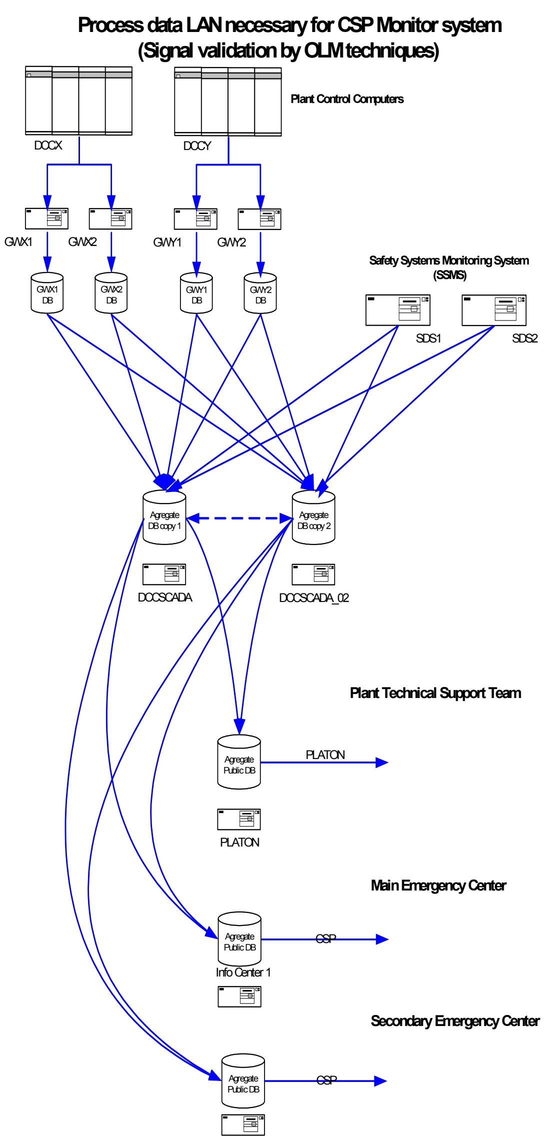

Figure 1

- Alarm processing
- On-line Software Maintenance Services

Adequate software tools lead to implementation of subsystems like Alarms Data Base Interrogation (Fig.2), Hardcopy Save and Retrieval (Fig.3) Fast Operating Manual Retrieval, Graphic Process Data Trending or Gateway for Alarming on Mobile Phones.

III. SCOPE OF SYSTEM

CSP Monitor system is a digital system for electronic data collection, remote communications and appropriate visualization. This system is built in top of other digital systems which handle data from sensors identified as relevant for CSP parameters.

These systems deploy following

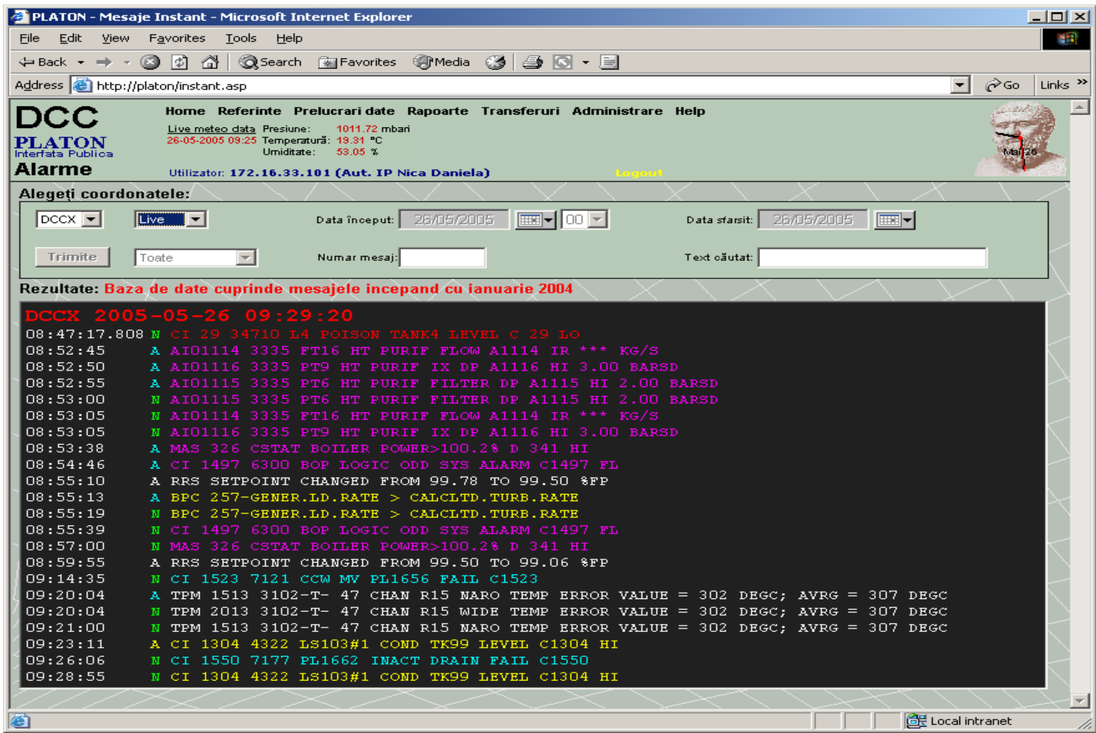

Fig. 2 - Alarms Interoggation

The system was extended with fast DAQ computers connected to SDS1 and SDS2 (the SSMS system).

This process network topology and Plant Information functions implemented allowed data transmit to ECC center and implementation of CSP Monitor.

elements of the related CSP instrumentation:

- Sensing device,
- Transmission device,
- Displaying device.

When instrument loops belonging to CSP are included in the Post-Accident system, these are referred as information chains for covering specific qualification topics.

The CSP Monitor is built at interface with these systems and contains requirements for data processing in interface computers, digital data transport through dedicated LAN and appropriate HMI on dedicated computer terminals. Examples of interface computers are DAS1 and DAS2. These are connected with SDS1 and SDS2 and in the mean time provide the monitoring functions for MCR (these functions are covered by the requirements of SSMS system). The main function will be completed with relay functionalities useful for CSP Monitor. Only these parts are relevant for CSP Monitor but from case to case, adding the last requirement will need a revision of the whole interface program. These considerations explain why some parts of the SSMS programs will be repeated in CSPM specifications.

The data transport through dedicated LAN, due to real-time and reliability constraints, must avoid superposition or crossover with ordinary corporate business LAN.

IV. FUNCTIONAL REQUIREMENTS

Critical Safety Parameters are used in plant control room and by consequence in Emergency Response Centre control room. Critical Safety Parameters are used in plant control room during two main circumstances: in post accident events or in normal operation.

In Post accident status the CSP information assists the operator in assessing the post accident plant conditions and in determining the nature and course of the accident. Specifically the dedicated instrumentation used for post accident monitoring and the corresponding CSPs shall assist the operator in carrying out the following functions:

a) Verification of:

1) Reactor shutdown,
2) Reactor fuel heat removal,
3) The provision of a physical barrier to the release of radioactivity to the environment (containment).

b) Monitoring of plant characteristics required to follow the effects of the accident.

Table 1-Operator actions during accident

#	Operator Actions
1	Start EPS and EWS after LOCA/SDE or DBE
2	Establish Heat Sink (ECC, SG, Moderator)
3	Open MSSVs after DBE
4	Limit instrument air to ‘essential users’
5	Start Shutdown Cooling System
6	Start D2O Recovery System Dryers
7	Control Depressurization of Containment
8	Use HPECC to Break Rupture ECC Discs or EWS after DBE
9	Initiate Controlled SG Cooldown
10	Terminate EWS Make-up Mode and Initiate ECC Recirculation Mode if necessary
11	Maintain SG Level Manually
12	Provide EWS Flow to ECCS Heat Exchangers for LOCA/SDE When in EWS Mode

Actions of the plant crew are summarized briefly in the Table 1. These actions are related with specific plant systems designed to mitigate and eliminate effects of accident. These are listed here only for illustration of plant crew role during accident.

A requirement for CSPM system is to allow visualization in plant MCR and in ECC control room of all parameters important in Post Accident events.

During normal operation there are much more other not qualified instruments which provide CSP information. These instruments complete the whole picture of the plant from safety point of view. The operators are able to predict eventually abnormal behaviors. In ECC control room the crew could be mobilized before a real event start developing. Remote data received here could keep the crew informed. Remote assistance for MCR could come from the other MCR or from ad-hoc or regular Technical Support Center mobilized for crisis management.

V. DESIGN PRINCIPLE FOR CSP MONITOR

A display system for CSP Monitor could be created using conventional display devices which include meters, light indicators, numeric readout displays, and plotters. Modern approach use computer-based display device including CRTs, flat panel devices, and large-screen devices. Many advantages of displaying a lot of data on large screens recommend the modern approach.

NUREG-700 issued (Ref.[3]) the numerous criteria for modern display design. Some of main criteria for information display design are the following:

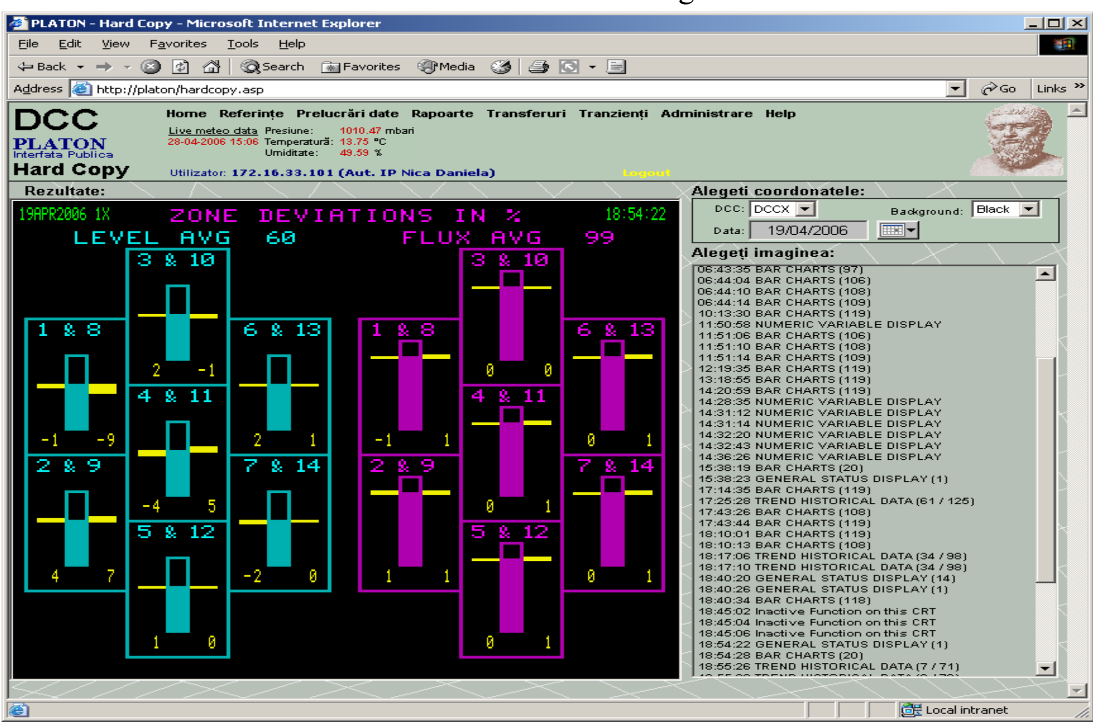

Fig.3 – Hardcopy Storage and Retrieval

– Information display should have safety parameters convenient displayed and readily accessible;

-Parameter selection and the way they are displayed should help target users evaluate safety status of plant. The selection of these parameters are specific to every plant and guided by *control/cool/contain* (3C) rule which means provide information about the following critical safety functions: reactivity control, reactor core cooling and heat removal from the primary system, reactor coolant system integrity, radioactivity control, and containment conditions;

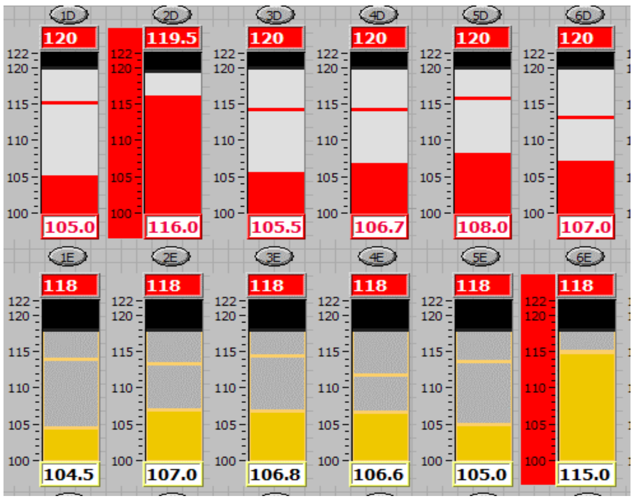

Figure 4 - Modern parameter display

The display system should display information about severe accident symptoms associated with the plant safety parameters and functions. (e.g. fuel subcooling margin).

Critical parameters should be displayed in a concise format. The display format should support users in comparing data from across related plant functions and assessing the safety status of the plant. A concise format might be achieved by presenting a group of critical variables on a single mimic display or by multiplexing a set of displays easy to switch.

Display response to transients and accident sequences should keep operator informed of the real plant status. They should comprehend a change in safety status in a matter of seconds. The sampling rate should be tuned accordingly;

Typical modes of plant operation are full or plateau power operation, startup, hot standby, and hot shutdown. For each mode, the displays should be separate and contain at least the minimum set of data needed to assess the safety status of the plant;

Because safety parameter and function monitoring systems are used to support operators during abnormal or emergency conditions, it is important that user-system interaction tasks comply with the skills and workload capabilities of the users under these conditions.

The display system should contain dynamic objects that help the user in monitoring critical safety parameters. Interest concerned those fast/slow changing parameters, by visually alerting the user when values are out of normal operation range. The user may not be able to keep attention on the slow changing display due to many parallel task demands and, thus, may not be aware that the parameter is out of range. In the case of fast changing parameters, the out of normal range might be reached before the user is able to switch attention to that parameter. For both cases, as in control room practices, setpoints used provide enough time to respond appropriately.

Abnormal Conditions should be alerted with audible and/or visual signs which will request corrective action from operator/user of system. When using of system in Emergency Control Center the alarm should indicate to Emergency Response Team the appropriate action to be started.

TABLE 2 – CSP Monitor summary

Nr.	Type	CSP Parameter
1	Control	- Reactor Power - Rate of Reactor Power
2	Cool	Core Heat Removal - RIH Temperature - ROH Temperature - ROH Pressure - RIH Pressure - Pressurizer Level Primary Heat Sink Inventory Supply - RWS Tank Level - RCW Flow - D2O Storage Tank Level Boilers as Heat Sink - Boiler Pressure - Boiler Level - Boiler Cold Leg Temperature - Boiler Hot Leg Temperature - Feedwater Flow - Deaerator Level - MSSV Status Shutdown Cooling as Heat Sink - SDC Temperature - SDC HX Inlet Temperature - SDC HX Outlet Temperature - SDC Pump State (On/Off can be inferred by Pressures or flows) Moderator as Heat Sink - Moderator Temperature - Moderator Level - Emergency Core Cooling - LOCA Signal Status - ECC HX Inlet Temperature - ECC HX Outlet Temperature
3	Contain	- RB Pressure - RB Sump Level - Reactor Building Activity Level - FW/SW Activity Level

When multi-level display is used a notification from higher level display will indicate that attention should be put to parameters in that display.

An example of display used at Cernavoda NPP is shown in Fig.4 where bar graph display is used to show value, setpoint, margin to trip and alarm.

VI. CRITICAL SAFETY PARAMETERS MONITOR DISPLAY DESIGN

The extension of use of CSP Monitoring multi-display suite outside Emergency Control Center is intended to support the monitoring of Critical Safety Parameters by the Senior Control Room Operator (SCRO) or the Shift Supervisor (SS) following an upset. In this condition the displays will be designed to be used in conjunction with Abnormal Plant Operation Procedures/Emergency Operation Procedures (APOP/EOP), a set of procedures associated with major safety related functions failures. The design has been based on prototype design and simulation evaluations of the CSP monitor developed and evaluated. The multi-display suite includes four CSPM displays, one for each of the four primary heat sinks. The key information to be displayed includes primary CSPs as well as support CSPs and related supporting information as required. These parameters are listed in TABLE 1. Groups of these parameters are concentrated in following 3 displays which show plant heat removal with different plant systems configurations as resulting from display names:

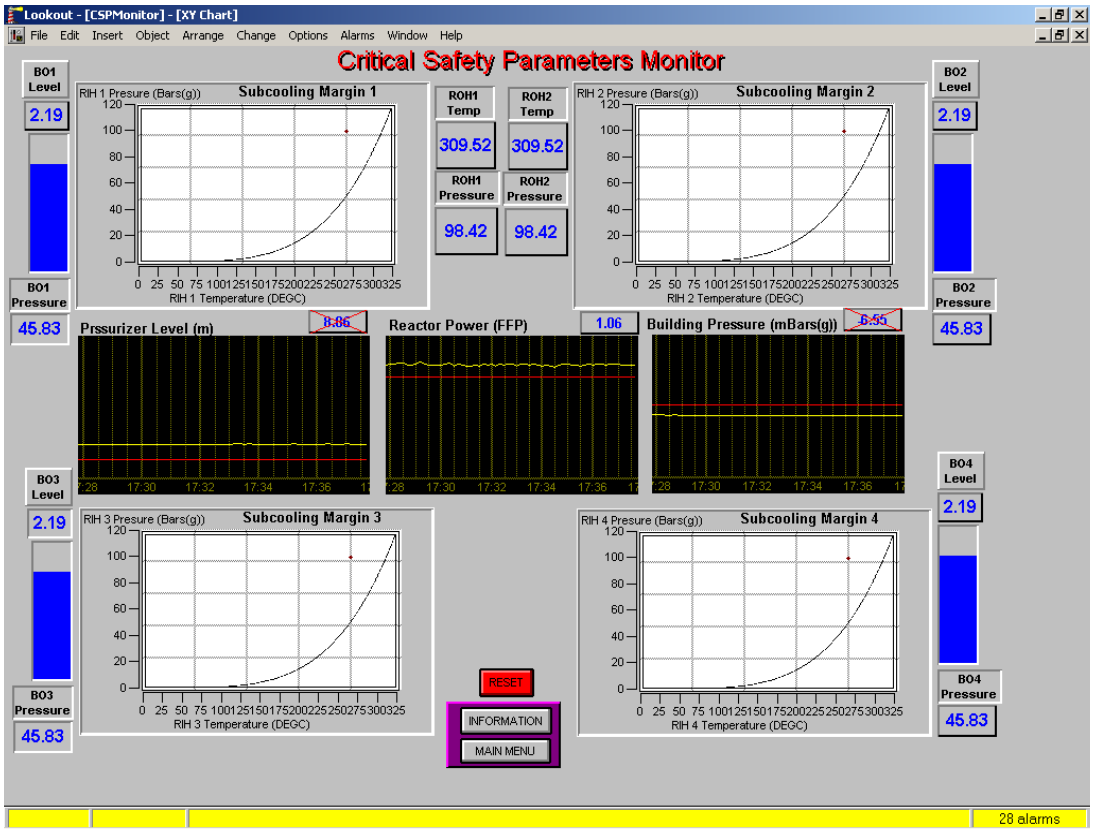

Figure 5 View of sample CSP Monitor display

1. Boiler Heat Sink (Figure 5)
2. ECC Heat Sink
3. Shutdown Cooling Heat Sink

The system is supplied with data from the two control computers and from the two acquisition computers connected to SDS system. As seen in Fig.5 a graphical combination of charts, bar graphs and trends show appropriate group of variables. Abnormal safety values are easily shown and also colored blinking alarms animate appropriate part of display during such events.

For the time been the system is deployed in the Emergency Control Center to allow nuclear emergencies exercises which will tune team response. It is expected that feedbacks during such exercises will be used to build final version of system. After that the software package could be used in the Main Control Room as part of the extended future expansion of Station SCADA System which will improve Operator Panel.

VII. SELECTION OF PARAMETERS

The parameter selection is done based on several instruments. Some times the application has up to 9 instruments showing the same physical variable.(Channels A, B, C are from Control Computers, channels D,E,F are from SDS#1 and channels G,H,J are from SDS#2). A spread check is done against all 9 instruments. When a certain instrument is qualified as post accident instrument, it is used as base value for spread check. Otherwise average value is used. Good values after spread check are averaged to determine parameter value.

Same rules apply to instruments of subcooling margin monitor in every reactor header. The reactor header subcooling margin is the key critical safety parameter used by operators to ensure that fuel cooling is not jeopardized. It is also an important monitoring parameter for thermosyphoning. Thermosyphoning is that natural circulation of the cooling agent in Primary Heat Transport system when Main Pumps are shutdown. Because this natural circulation without pumps could reverse the sense, calculation of margin to saturation is done also for outlet headers.

The saturation temperature, **TsatN**, is determined by doing a table lookup of two saturation temperatures that correspond to the selected header pressures, and by interpolating between these two values. The subcooling margin (margin to saturation temperature) is then calculated by subtracting the header temperature, **ThdrN**, from the saturation temperature, **TsatN**. The header pressures are limited to 0 -11.999 MPa(g) (or 0 - 119.99 bar(g)).

VIII. ACTUAL OPERATIONAL ASSESMENT STATUS AND FUTURE DEVELOPMENT

After full implementation in ECC the focuses will be oriented on the operational impacts of CSP monitor display introduction, from plant perspective. These impacts are multiple and major. Careful assessment need to be performed. Examples are:

· The performance of MCR crews in detecting CSP challenges when using the new multi-display;

- Potential display use conflicts given the CSP monitor display is one of three monitoring applications sharing a common CRT display,

-The operational integrity of CSP monitor display information will asses the availability of the computing platform on which the CSP display application operates in comparison to the existing Main Control Room Control Computers and conventional panel indications.

The assessment program will include:

·Participation of MCR crew members in CSP monitoring (during ECC exercises and recovery refresher training sessions);

·Analysis of the operational contexts in which CSP and other Data Trending Display applications indicate potential conflict of display use;

·An assessment of Data Extraction System (DIGMA) and CSP monitor display failure modes. This will allow future development of system.

IX. CONCLUSIONS

Modern digital data production and transport in/between plant control centers allow increase performance in nuclear safety functions monitoring. Critical Safety Parameters Monitor is a typical attempt which proved that digital equipment allows full monitoring at big distances from source of data and modern display systems allow improved ergonomics. Even created for ECC center the investment returned in MCR for improvement of plant operation. After system was deployed, new requirements and functions are still necessary to be implemented to evolve it as a Plant Control Room tool which will help adequate operation of nuclear plant.

Other national level emergency centers today are interested by this system due to its already proved capabilities to provide remote real time critical information.

X. ACRONYMS AND ABBREVIATIONS

CSP - Critical Safety Parameters
MCR- Main Control Room
CRT - Control Room Terminal
DCC - Digital Control Computer
ECC - Emergency Core Cooling or Emergency Control Center
HMI - Human Machine Interface
PHT - Primary Heat Transport
RIH - Reactor Inlet Header
ROH - Reactor Outlet Header
SDC - Shutdown Cooling
SDS1 - Shutdown System #1
SDS2 - Shutdown System #2
SSMS - Shutdown Systems Monitoring System
DIGMA – Plant Engineering Data Extraction System

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