UNITED STATES
NUCLEAR REGULATORY COMMISSION
TECHNICAL TRAINING CENTER
OSBORNE OFFICE CENTER
5746 MARLIN ROAD, SUITE 200
CHATTANOOGA, TN 37411-5677

May 14, 2008

MEMORANDUM TO: James F. McDermott, Director
Office of Human Resources

THRU: Kathy Halvey Gibson, Associate Director
for Training and Development
Office of Human Resources

FROM: Mark S. Miller, Chief, Technical Training Support Branch
Office of Human Resources

SUBJECT: FOREIGN TRAVEL TRIP REPORT

From February 26 - 29, 2008, I led a group of NRC staff in a visit to the OECD Halden Reactor Project in Halden, Norway. The group was comprised of myself, James Griffin, Senior Simulator Engineer, TTSB, Michael Junge, Chief of the Operator Licensing and Human Performance Branch, Division of Construction Inspection and Operational Programs, Office of New Reactors, and Daniel Santos, Senior Level Advisor for Digital Instrumentation and Control, Division of Engineering, Office of Nuclear Regulatory Research.

Meetings conducted at Halden were aimed principally at developing a greater understanding of the Halden Man-Machine Laboratory (HAMMLAB) and its hardware and software infrastructure. Meetings also focused on the work Halden is pursuing in the area of digital instrumentation and control, future plans for Halden-developed software currently licensed to NRC, Halden's work in virtual reality training, and human reliability studies being performed at Halden. The information we received, combined with the demonstrations performed for our benefit by Halden staff has informed our thinking on how best to proceed with next-generation training simulators.

The content of this report is not likely to be of interest to the Commission.

Approved: James F. McDermott

Enclosure: Trip Report to HAMMLAB in Halden, Norway

cc: James P. Griffin, HR
Michael A. Junge, NRO
Daniel J. Santos, RES
Leonard J. Reidinger, FR
Vonna L. Ordaz, OEDO
Margaret M. Doane, IP
Trip Rothschild - OGC
ONSIR/INFOSEC

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NRC FOREIGN TRIP REPORT

Subject

Visit to Halden Reactor Project, Halden, Norway, by representatives of the Technical Training Center and the Offices of Research and New Reactors

Dates of Travel and Countries/Organizations Visited

February 25 through March 1, 2008. Business was conducted exclusively at the Halden reactor Project, Halden, Norway.

Author, Title, and Agency Affiliation

Mark S. Miller
Chief, Technical Training Support Branch
Human Resources Training and Development
Office of Human Resources

James P. Griffin, Senior Simulator Engineer
Technical Training Support Branch
Human Resources Training and Development
Office of Human Resources

Michael A. Junge, Branch Chief,
Operator Licensing & Human Performance
Division of Construction Inspection Program
Office of New Reactors

Daniel J. Santos, Senior Level Technical Advisor
Division of Engineering
Office of Nuclear Regulatory Research

Sensitivity

Not applicable

Background/Purpose

The purpose for the trip was to meet with Halden Reactor Project personnel to discuss:

- uses of the Halden Man-Machine Laboratory (HAMMLAB) simulator research facility and its correlation to new reactor training simulators
- HAMMLAB hardware and software configurations
- uses of Virtual and Augmented reality for training, particularly online
- advances made and future plans for ProcSee, a graphics software system designed by Halden and used by NRC in the design and implementation of the Nuclear Engineering Workstation Simulator (NEWS), the upgraded B&W and BWR/4 Simulator Process Computer Systems, the planned Westinghouse Simulator Process Computer System replacement, and the planned TTC simulator instructor station replacements.

Abstract: Summary of Pertinent Points/Issues

The stated purposes for the visit were accomplished. NRC left Halden with a more detailed understanding of the HAMMLAB approach to multi-model simulator construction and development, Halden's development work in virtual reality for training multiple on-line students, and in changes made and planned for ProcSee and how these changes impact existing and planned training applications. Additional topics of discussion were added while at the site, including:

- Results of experiments performed at HAMMLAB in the area of work practices and team behavior in computer-based control rooms
- Results of work performed to date by Halden on human reliability assessment method comparisons
- Work performed by Halden in the area of digital instrumentation and control.

In sum, there was a fruitful exchange of information. Many of the insights gained (e.g., hardware and software infrastructure, development toolkits and middleware) will inform decisions impacting both the maintenance of existing TTC simulators and the selection and design of future training simulators. Further, HAMMLAB personnel will represent a valuable resource as NRC considers in-house development of fully digital simulators and modes of virtual-reality training. Continued cooperation and information exchanges are recommended. No policy issues were identified which need to be brought to Commission attention.

Discussion

The bulk of the visit to Halden revolved around the ongoing question of how NRC plans to approach training in the near-term future. In terms of simulator training for new reactors, NRC is considering options ranging from limited-scope augmentation of existing simulator training to the purchase of design-specific simulators. One of the options under consideration involves the development of generic digital simulators into which multiple reactor plant models can be loaded. HAMMLAB is comprised of just such a simulator, currently configured to simulate both boiling water and pressurized water reactors. In addition to providing simulation capability, HAMMLAB also provides an environment for the development and testing of various schemes for human-machine interface.

The agenda for our visit included the following topic areas:

- Introduction to HAMMLAB Hardware and Software
- Virtual and Augmented reality
- Computerized Operator Support System
- Use of HAMMLAB
- ProcSee Development Environment

Following arrival and initial meetings, the agenda for our activities was modified to include additional discussions, including digital instrumentation and control (I&C) work being performed at Halden and human reliability assessment studies performed by the project. The broad areas of discussion are discussed below. Presentation materials and business cards of contacts at the facility are presented as attachments to this document.

Introduction to HAMMLAB/Hardware and Software

NRC personnel (all) were given a tour of the HAMMLAB facility, the centerpiece of which being the HAMMLAB Integration Platform, a digital plant simulator (see Attachment 2 for details of integration platform architecture). The simulator consisted of three principle work stations, the digital equivalent of a domestic nuclear facility control room with workstations for two reactor operators and a senior reactor operator (see Figure 1). Each reactor operator station consisted of up to 10 flat-panel monitors, a mouse and a keyboard (see Figure 2). Summary plant information, including key performance and safety parameters, was projected on a large wall viewable by all operators (see Figure 3).

The HAMMLAB simulator is capable of providing an operating environment for any simulated facility. Simulation models are run by dedicated off-the-shelf computers which interface to the display and control system through middleware developed by Halden. The facility is currently capable of running both a pressurized water reactor (PWR) and a boiling water reactor simulation (and oil and gas production facilities), and work is progressing on a second PWR model. HAMMLAB personnel estimated that approximately 1 man-year of effort was required to map simulation model parameters to the integration platform's middleware. See Attachment 3 for a description of the architecture of the HAMMLAB Integration Platform.

Operator work stations are built around custom-fabricated desks which can be raised or lowered to support a range of operator preferences from standing to seated. The position of the operators' monitors, relative to the operators' lines of sight, can be independently adjusted. Cable trays and mounting posts for monitors are included in the work stations (see Figure 4).

Individual operator displays and controls are configurable through the use of ProcSee, a display development environment licensed to NRC from Halden. The use of ProcSee allows HAMMLAB to develop innovative human-machine interfaces for use in human factors experimentation conducted at the laboratory.

Of particular interest to NRC staff present was the treatment of alarms within HAMMLAB's digital simulation environment. The HAMMLAB system characterizes alarms as "primary," "secondary," or "consequence," and are color-coded (green, yellow, red, based on urgency) allowing the system and operators to prioritize responses. Plant states are determined by computer through a combination of indications and alarms, with the preponderance of the parameters defining the plant state. Expected component statuses (e.g., valve position, component operation) are subsequently based upon plant state. Components removed from service (e.g., due to tagout) are represented as such and are considered by the system.

Key Observations of Interest to NRC included:

- The hardware environment at HAMMLAB (or a variation on the theme) can be assembled at the Technical Training Center (TTC) as an augmentation to existing simulation capabilities or as a platform for future training and research simulation.

The desirability of such an effort will be discussed further as future (new reactor) training demands are more fully understood).

- Pursuing an approach similar to the HAMMLAB model for a training simulator offers the advantage of flexibility in that multiple models (facilities or portions of facilities) can be used in one simulation environment. Additionally, the ability to apply multiple options for display offers a training advantage, in that presentation complexity can be adjusted, based on the target audience (e.g., students seeking conceptual training can operate a simulation that is less "dense" in plant indications, allowing more of a "big picture" presentation, while students training for inspector/examiner roles can train in a simulation environment displaying all of the parameters typically associated with commercial nuclear facilities).

Uses of HAMMLAB

HAMMLAB has been used for experiments in human-machine interface in which control room operators are exposed to alternative modes of data indication. These studies have extended from individual operator performance to full crew performance in various control room representations (see Attachment 4 for example experiment). Cumulative insights gained at HAMMLAB into individual operator and crew performance was discussed at a separate meeting covering work practices in computer-based control rooms (see Attachment 5 for presentation materials). Key observations from HAMMLAB personnel in the course of these experiments on operator performance included:

- Benefits resulting from computer-based control rooms include the ability to present information not possible in a panel-based control room in ways not possible without significant and possibly frequent hardware modification (e.g., the ability to optimize displays for particular plant evolutions).
- Challenges included:
    - Differences in the nature of and need for communications between operators in the control room. There is a tendency for operators to develop a "key-hole" vision of their respective tasks, focusing intently on individual screens and not communicating their actions to control room supervision.
    - Control room supervision experienced increased difficulty in determining what individual operators are doing. As opposed to panel-based control rooms in which individual or grouped controls are in fixed positions, computer-based control rooms allow for myriad controls to be called on the same, limited, set of screens.
    - Poorly-designed operator interfaces can add complexity to tasks. Closely associated with this observation is HAMMLAB's identification that the definition of "obsolescence" changes in computer-based systems. Unlike panel-based control rooms, in which "obsolete" components are those for which no replacements can be found, computer-based control rooms face obsolescence issues associated with changing methods of data representation on screens, largely as a result of operator preference.

Virtual and Augmented Reality

NRC staff (all) was presented with examples of virtual and augmented reality systems ("mixed reality") developed at Halden to support both training and experimental control room development. In the case of the former, Halden personnel demonstrated virtual environments in which multiple operators engaged in collaborative maintenance training (in this case, moving and changing an ion exchanger resin bed), with each operator working from an individual computer, controlling avatars of themselves coordinating field activities (operating cranes). In the latter case, virtual technology was combined with control room indications and wireless handheld devices to give operators virtual representations of plant conditions (e.g., radiation fields displayed on computer-generated representations of plant environments) and operator locations (see slides 6 and 9 of Attachment 4).

Halden's work in this area began in 1998 and is currently being accomplished with multiple software applications including ProcSee and the Halden VR platform. Halden has also created development tools for training, allowing components developed in computer-aided design (CAD) applications to be animated and joined to procedures describing attributes for the components (e.g., assembly, disassembly, operation).

Studies have been performed by Halden in the use of virtual reality training. Three studies were presented, indicating:

- Active virtual reality training, involving active student participation, is more effective than when students assume a passive role akin to online training.
- Augmented reality, in which students don glasses that superimpose computer-generated graphics on real environments is generally well-received by students
- Experiments performed to determine the effectiveness of virtual representations of radiation fields indicated that both topographical and flat maps of radiation fields were effective in training workers on radiation environments in facilities.

Finally, field operator training was discussed, in which Halden developed a virtual plant model of Forsmark 3 in which major operational components were represented virtually and tied to a process simulation, allowing field operators to navigate within the virtual facility, locate components they were to operate or maintain, and see the consequences of their actions. Halden personnel reported generally positive responses from operators exposed to the training environment.

The examples presented by Halden in this broad category of training were illuminating and germane to current efforts by the TTC to develop a virtual environment for future training of technical personnel. In this regard, Halden represents a resource that TTC will be accessing as development activities progress.

<u>Computerized Operator Support Systems</u>

NRC staff (all) was presented with a summary of activities at Halden in the area of Computerized Operator Support Systems (COSS) which are conceived at the facility, tested in HAMMLAB, and in some cases deployed in both the oil/gas and nuclear industries (see Attachment 6 for presentation materials). The objective of these systems is to provide information to control room operators to support operation and help predict pending problems. Examples included:

- A system for online calibration monitoring and sensor validation of existing instrumentation based on fuzzy neural networks
- An online early detection system and diagnosis system which compares multiple parameters to arrive at decisions on component integrity. An example of this type of

system was installed at V.C. Summer to help predict reactor coolant pump seal failure by comparing data on parameters such as vibration, thermal barrier leakage, etc.

In addition to methodologies, several software tools were described that are used in HAMMLAB and which might be considered generically for computer-based control rooms or simulators, including:

- COAST – an alarm toolbox
- COPMA – for integrating computerized procedures in control rooms
- SCORPIO – software for comparing in-core instrumentation to a simulated core

ProcSee Development Environment

Principal attendees for the ProcSee discussion were James Griffin and Mark Miller (NRC) and Hakon Jokstad. The purpose of the discussion was to determine the direction the ProcSee developers were taking to provide for greater interoperability with other software products.

ProcSee is a software system used to develop human-machine interfaces. It provides a graphical environment around which one can build highly expandable displays of real-time data, as well as providing a mechanism for sending user actions to another software system. It is the graphics engine behind the displays used on the Hammlab simulator, several oil and gas process systems, and a variety of other European industrial applications. ProcSee is used at the TTC as the basis of the TTC-designed Nuclear Engineering Workstation (NEWS), and as the process computer and SPDS simulations for the BWR and Westinghouse simulators.

TTC intends to use ProcSee to replace the instructor stations on several of the existing simulators, and, as a major project, to replace the process computer system that is part of the current Westinghouse simulator. It is also likely that ProcSee will be used in initial efforts at advanced control room simulation.

It was learned that the next generation of ProcSee will be able to import and use Java applets, developed with the NetBeans Java development system. This will allow the user to expand the native functionality of ProcSee to include customized functions that may be necessitated by the application, in a platform-independent environment. Previous customization was generally not transportable across platform environments.

It was also learned that the ProcSee graphical editor GED was being redesigned as a Java application. Again, this fosters cross-platform operability and helps to ensure that all platforms will have the same capabilities.

As a new development, IFE has developed and is testing a way to run ProcSee displays on portable devices and demonstrated a display on a Windows Mobile device. In essence, the device (which could be any palm-sized device running the Windows Mobile OS with suitable resources) runs a version of VNC (Virtual Network Computer) that connects wirelessly to a workstation serving as a VNC host. ProcSee actually runs on the host; the display is on the mobile device. Citrix is an example of such a technique used within the Agency. The key to making this work is that the displays developed for use on a mobile device must be designed for the small screen.

One possible immediate application for these mobile displays would be their use as simulator remote instructor stations.

Digital I&C

During the visit, RES (Santos) and HRP personnel discussed HRP ongoing and proposed research in the area of risk and dependability of digital instrumentation and control (I&C) systems. In the area of digital I&C, Halden projects are primarily focused on vendor support and most of the products are Halden Work Products which are proprietary with limited distribution. However, there are few programs that complement some current NRC digital I&C research programs. (e.g., develop review guidance for fault detection in advanced reactor I&C systems). HRP has started to work more proactively with other I&C regulatory research groups (for example GRS/ISTec) and is committed to improve support of NRC regulatory efforts. Continuous interaction with HRP is needed to ensure research results will be useful in supporting NRC work.

Regarding proposed research in the area of digital I&C, HRP personnel provided an overview of proposed research activities under Chapter 5 (Software Systems Dependability) of the Safety-MTO HRP Program Proposal for 2009-2011. Based on this proposal, RES considers that there are two specific topics in the area of digital instrumentation and controls that may warrant continued interaction with HRP. These are: (1) dependable requirements engineering (i.e., develop guidance on how to assess safety system requirements, and develop methods to include requirement engineering in risk assessments) and (2) assessment of common cause failures. These topics would be further evaluated as part of our current efforts to update the NRC 5-year Digital Research Plan.

Human Reliability Assessment Methodologies

NRC staff (Miller, Junge, Griffin) was presented with the results of an International HRA Empirical Pilot Study. The purpose of the study was to address an SRM for the ACRS to work with the staff and external stakeholders to address the issue of the differences in HRA models. The study assessed different Human Reliability Assessment methods to determine their strengths and weaknesses.

This was the first study that compared HRA analyses with crew performance observations. It provided the opportunity to see, in detail, how methods are applied. The results identified that in general, the methods/analysts were doing a good job. The uncomplicated scenarios do not provide significant insights about how the methods are applied, but the more challenging scenarios tested methods' limits and hence, help in identifying the limitations of methods.

The study is expected to continue with more analysis of Human Reliability Methods and will be completed in 2010.

Pending Actions/Planned Next Steps for NRC

There are no specific follow up actions planned as a result of this trip. TTC intends to:

- Maintain a close association with Halden in the continued development and use of ProcSee.

- Consider the development of a HAMMLAB-style simulator at the TTC for training and potential use by the Office of Research
- Evaluate Halden-developed virtual and augmented reality tools for use as plans for virtual training mature

Points for Commission Consideration/Items of Interest

No points for Commission consideration were identified as a result of this trip.

Attachments

Attachment 1 – Business Cards of Key Halden Contacts
Attachment 2 – HAMMLAB Overview Presentation
Attachment 3 – HAMMLAB Integration Platform Presentation
Attachment 4 – Extended Teamwork 2004 Experiment Presentation
Attachment 5 – Work Practices in Computer-Based Control Rooms Presentation
Attachment 6 – Computerized Operation Support Systems Presentation
Figures 1-4 – Photographs of HAMMLAB

"On the Margins"

While not a specific objective of the trip, the information provided by Halden on challenges associated with computer-based control rooms represents a potential resource both in the training of inspectors for the operational phase of new reactors and in the review of control room designs and communications standards for operator licensing.

Attachment 1

Business Cards of Key Halden Contacts

Institutt for energiteknikk
OECD Halden Reactor Project

JON KVALEM
Division Head
Operation Centres

P.O. Box 173, NO-1751 Halden, Norway
Tel. + 47 69 21 22 00 • Dir. + 47 69 21 22 25 • Fax + 47 69 21 24 90
jon.kvalem@hrp.no
www.ife.no/hrp

Institutt for energiteknikk
OECD Halden Reactor Project

ØIVIND BERG
Division Head
Computerised Operation Support Systems

P.O. Box 173, NO-1751 Halden, Norway
Tel. + 47 69 21 22 00 • Dir. + 47 69 21 22 71
Fax + 47 69 21 24 60
oivind.berg@hrp.no
www.ife.no/hrp

Institutt for energiteknikk
OECD Halden Reactor Project

ANDREAS BYE
Division Head
Industrial Psychology

P.O. Box 173, NO-1751 Halden, Norway
Tel. + 47 69 21 22 00 • Dir. + 47 69 21 22 76
Fax + 47 69 21 24 90
andreas.bye@hrp.no
www.ife.no/

Institutt for energiteknikk
OECD Halden Reactor Project

FRIDTJOV ØWRE
Research Director - Sector Safety - MTO
Deputy Project Manager

Post Box 173, NO-1751 Halden, Norway
Tel.: + 47 69 21 22 00 • Dir.: + 47 69 21 23 54
Fax: + 47 69 21 24 60
fridtjov.owre@hrp.no
www.ife.no/hrp

Institutt for energiteknikk
OECD Halden Reactor Project

TERJE JOHNSEN
Division Head - Visual Interface Technologies
Halden Virtual Reality Centre

P.O. Box 173, NO-1751 Halden, Norway
Tel. + 47 69 21 22 00 • Dir. + 47 69 21 22 47
Fax + 47 69 21 24 90
terje.johnsen@hrp.no
www.ife.no/vr/

Institutt for energiteknikk
OECD Halden Reactor Project

HÅKON JOKSTAD
Section Head - Visual Interface Technologies
Halden Virtual Reality Centre

P.O.Box 173, NO-1751 Halden, Norway
PHONE +47 69 21 22 00 • DIR. +47 69 21 22 46 • FAX +47 69 21 24 90
hakon.jokstad@hrp.no
http://www.ife.no/picasso/

Institutt for energiteknikk
OECD Halden Reactor Project

CHRISTER NIHLWING
Section Head - Operation Centres

P.O.Box 173, NO-1751 Halden, Norway
PHONE +47 69 21 22 00 • DIR. +47 69 21 22 58 • FAX +47 69 21 24 90
cni@hrp.no
www.ife.no/hrp

Attachment 2

HAMMLAB
Halden Man-Machine Laboratory

29.02.2008 Håkon Jokstad, Seksjonsleder Visualiseringsteknologi 1

IFE

What is HAMMLAB?

- HAMMLAB is an international research centre within human-system interaction, human performance and integrated operations of complex systems
- HAMMLAB provides experimental conditions for performing studies that extends knowledge of human performance in complex process environments
  - to adapt new technology to the needs of the human operator
- HAMMLAB is a simulator-based, flexible and adaptable operation centre whose equipment and functionality can be easily manipulated to produce different experimental conditions

29.02.2008 2

IFE

HAMMLAB Characteristics

- Simulator-based experimental facility
  - 3 full-scope simulators: PWR, BWR, oil & gas production
    - Typically 7-10.000 variables pr simulator extracted to HSI
- Main control room
  - 3 operator desks, 25-30 operator screens in total
    - Updated 3 times pr second
  - Front-projected large overview screen (6 x 1.5m)
- Experimenter's gallery
  - Simulator/scenario control
  - Process experts' online scoring of operator performance
  - Audio & video recordings, including head-mounted cameras
  - Database recordings of process events, operator actions, experimenters' actions and selected simulator variables

HW & SW

- HW
  - Simulators: various types (PC, Unix workstations)
  - Middleware: standard PCs, Microsoft Windows
  - Operator workstations: standard PCs, Windows XP
    - up to 8 screens pr PC
- SW
  - Simulators: various (depending on simulator vendor)
  - Middleware: HAMMLAB Integration Platform (in-house developed)
  - Operator interfaces: ProcSee (IFE product)

Middleware

- HAMMLAB Integration Platform provide flexible and efficient methods for integration of HSI and COSSes with simulators
  - Robust and efficient data distribution
  - Data structuring
    - Simulator variables combined into structures for pumps, valves, etc (specified pr simulator)
    - Makes configuration of HSI and COSSes easier
  - COSSes may add their own data to the IP
    - COSSes updates data in IP, IP distributes simulator data + COSS data
  - Routing operator actions back to simulator
- Re-used in all HAMMLAB simulators
  - + monitoring system for Halden Reactor (control room, offices, and handheld)

Operator Interfaces

- Implemented using ProcSee (IFE-product)
  - Unique flexibility in building customised operator interfaces
    - Crucial for HSI research
    - Highly configurable HSI-setup
    - Objects can be added/removed online (e.g. annotations by external system)
    - Screen sizes: from large-screen to small handheld devices
  - Highly configurable trend-system for logging and visualising historic data
  - Easily connected to process data
  - Optimised to handle large amounts of data and frequent display updates
- Product info at www.ife.no/procsee

Logging System

- Two types of logging
  - Events
    - Associated data pr type of event
    - Time-stamped: simTime, realTime, elapsed simTime, elapsed realTime
  - Variable values
    - Values logged regularly (each second)
- Data stored in an SQL-server database
  - Size of database for typical experiment: 1.2 Gb
- Web-interface to extract data from the database for post-scenario analysis
  - Export function to Excel for further treatment of data
  - Access control pr experiment and user

Logging System (cont)

- Operator actions
  - Navigation
  - Process commands
- Instructor actions
  - All actions to manipulate the simulator
- Scenario events
  - Run/freeze
  - Start/stop scenario
- Process events
  - Pumps starting/stopping
  - Valves opening/closing
  - ...
- Alarm events
  - On/off
  - Acknowledge
  - Suppression
- Other types of events can easily be added
- Variables are selected for logging prior to experiment
  - Values logged in database every second

Operator Performance Assessment

- Performance criteria defined prior to experiment
  - May be altered if operators' strategy differs from expected
- Manual assessment
  - Process expert rates performance during scoring
  - Extraction of data from logging system and audio/video for post-scenario analysis
- Automatic assessment
  - Criteria evaluated using data from logging system during/after scenario
    - Visible for process expert during scenario

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HAMMLAB Integration Platform

File: \\tommy\usrife\projects\h2k\ip\design\topLevelSpec\IP_Cerns.ppt

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2

Purpose

- Provide flexible and efficient methods for integration of MMI and COSSs with the simulators
  - Simulator-independent layer ⇨ increased reuse of client code across simulators
  - Data structuring according to client needs
  - Robust and efficient data distribution

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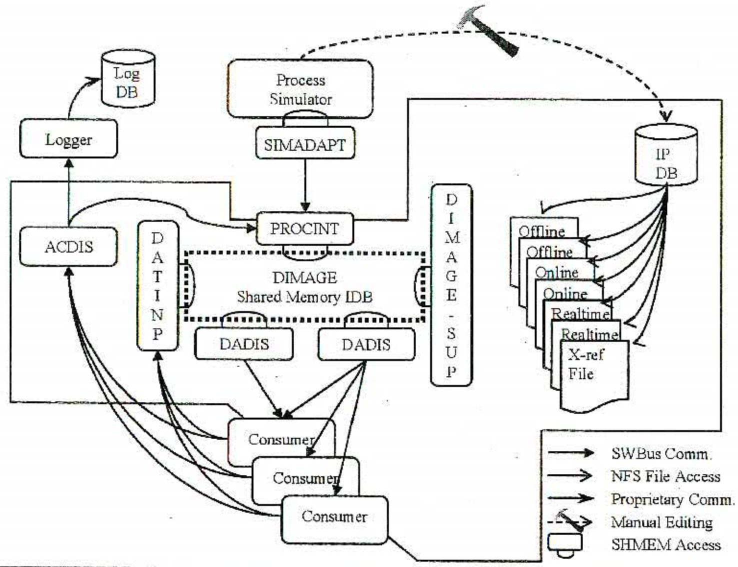
3

System Architecture



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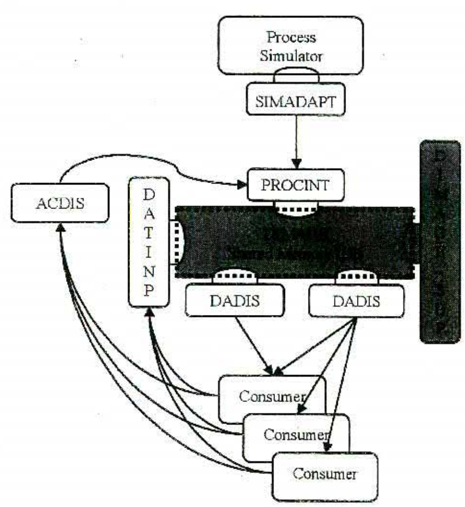
4

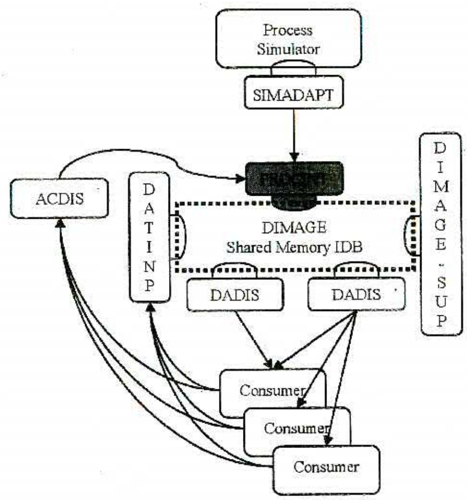
Data Image — DIMAGE

- Shared memory containing all variables
- Structured according to consumer needs
- Specified by a set of configuration files
- Created at start-up time
- Synchronised by DIMAGE_SUP



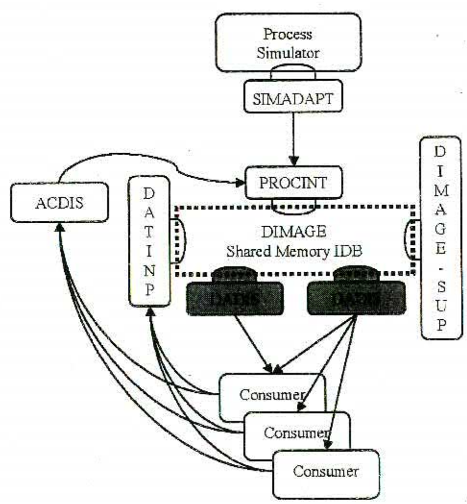
Process Interface — PROCINT

- Interface between IP and simulator
- Receive data from simulator. Dead band for value-updates
- Restructure data to IP data format
- Send commands to simulator



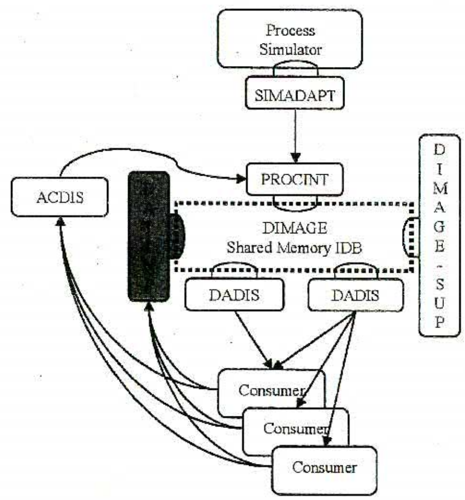
Data Distributor — DADIS

- Distribute DIMAGE data to CONSUMERS based on subscriptions
- Only updated variables are distributed
- Broadcast simulator events
- Fault-tolerant for failing consumers



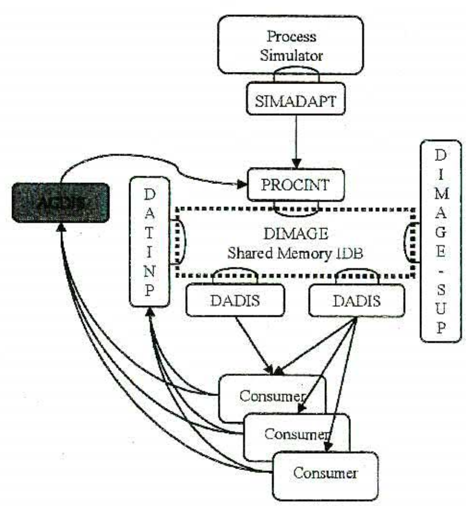
Derived Data Input — DATINP

- Insert derived data from CONSUMERs into DIMAGE
- DIMAGE access synchronised by DIMAGE_SUP



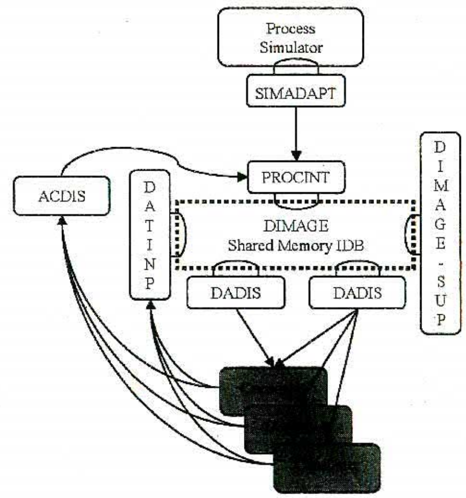
Action Distributor — ACDIS

- Retrieve simulator commands from all CONSUMERs
- Forward commands to PROCINT and other interested modules (e.g. Logger)



CONSUMER

- Subscribe for variables from DADIS
- Send actions to ACDIS
- Send derived data to DATINP



Configuration

- All modules configured by SWBus-readable config files (data definitions)
- PROCINT additionally configured by cross-reference file
- Modules may use subsets of data
- All config files generated from central database

Attachment 4

The Extended Teamwork 2004 Experiment

Teamwork & New Technology

Stine Strand

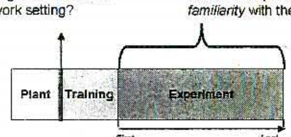
Overall purpose of the 2004 experiment

To generate ideas on how advanced control room solutions influence the quality of teamwork and performance

→ *(indication of human performance aspects important for design and operation of future NPPs*

Specific purpose of the 2004 experiment

1. How do operators handle the *transition* from operating in a conventional control room to operating in an Extended Teamwork setting?
2. Which implications do operating in such a setting have over time? (after increased *exposure* to and *familiarity* with the design)



Properties of the design solution

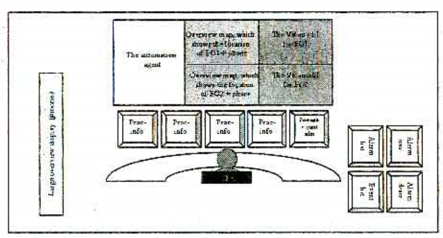
Represents a possible future design solution

- High levels of automation (turbine)
- Explisit representation of the automatic system
- Explicit representation of team member activities

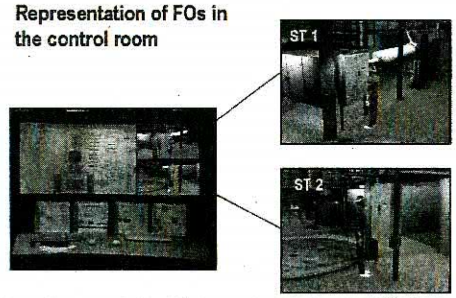
Redefinition of traditional NPP team composition:

- 1 Control room operator (RO)
- 2 "Field operators" (SS + FO)

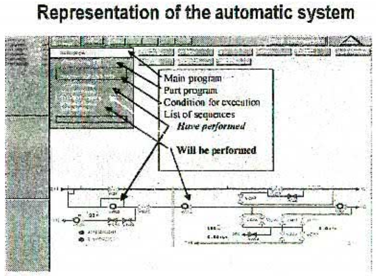
HAMMLAB Control room set-up



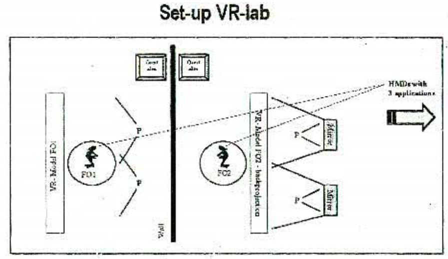
Representation of FOs in the control room



Representation of the automatic system

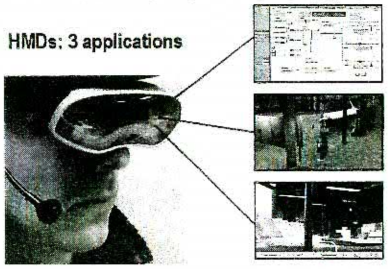


Set-up VR-lab



Operations performed directly in the VR model – connected to simulator

HMDs: 3 applications



+ Communication system

IFE

Sum

- The Extended Teamwork experiment is an example of how new technology can be applied to support teamwork between operators with diffferent locations
- New technology can be utilized for...
  - Improvement of the within-team communication
  - To establish a mutual understanding of the process
  - Improve the possibilities for continouos update on the situation/activities/problems/challenges of other team members
    → Improve the basis for teamwork and performance
- Continuation...
  - What type of teamwork related information should be presented to the different members? Different information to the different actors?
  - Amount of information
  - How to present such information

IFE

Data collection techniques

- **Field Study** (Interview + observation on the plant)
- **Background questionnaire** (age, gender, experience +++)
- **Semi-structured interviews** (After training, after experiment)
- **Transition related (after training)**
  - Norms of reciprocity
  - Role comfortability
- **Online scoring of observable teamwork activities**
  - Psychologist (communication, ideas, task allocation etc.)
  - Process expert
- **Self-evaluation**
  - How the team handled the scenarios
- **Simulator Logging**
  - Communication, performed actions, events, use of the displays
- **Questionnaires** (after scenarios)
  - Trust, Cooperation Quality, SA, Workload/complexity

IFE

Attachment 5

Work Practices in Computer-Based control rooms

M. Kaarstad, IFE, HRP
E-mail: magnhild@hrp.no

1

Introduction of computer-based systems

- Potential benefits:
  - Give information not possible with panel-based systems
  - Present information in ways much better suited to personnel tasks and information processing needs
- Potential challenges:
  - Changed need for communication
  - Difficult to know what team-member is working on (physical location)
  - Operator tasks/ roles
  - Altering roles, responsibilities
  - Information
  - Poor design may add overall complexity
    - Data overload
    - Organisation of information
    - Interface management demands
  - Difficult to get a whole picture: "Key-hole effect"

2

Work practices - Motivation

- Upgrades and new, computer-based designs may change the control room operators' way of operating the plant from what is normal in panel-based control rooms
  - Introducing new computer-based systems: New style of operation, changed need for information and communication between crew members
    (Roth & O'Hara 2002, Rogers 1992)
- Upgrades and new, computer-based designs affect the observability of what other team members are working on

3

1

Work practices - Objectives

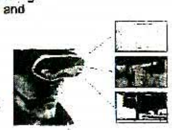
1. Prepare Human Factors community for potential challenges
   - Collect and provide knowledge on how work practices may change
     - Relevant findings in literature (theoretical, practical, methodological)
     - Practical experience (workshops, interviews, field studies)
2. Support work practices through increased transparency of team member activities
   - Suggest solutions to maintain safe work practices, through e.g.
     - Design,
     - Control room layout and/ or
     - Teamwork skills

- Focus
  - Near future, within control room, practical solutions
  - Communication, Operator tasks, Information

4

International Workshop 2006

- Joint effort: CSNI SEGHOF (WGHOF) and HRP
  - Future Control Station Designs and Human Performance Issues in Nuclear Power Plants
- Plants are upgraded and new plants are being built
- Efficient and safe performance: dependent on effective teamworking and work practices
- Teamwork and work practices may need to change to accommodate developments in upgrades and advanced plants:
  - Introduction of new designs
  - Staffing levels
  - Multireactor control
  - Remote operation
- Need to be addressed by nuclear operators, regulators and researchers



5

Workshop Objectives

- Overall objective:
  - Identify human and organisational issues associated with upgrades and new control station concepts
- SEGHOF (WGHOF) objective:
  - Follow up on a prior workshop in cooperation with HRP (1999), entitled: "Approaches for the integration of human factors into the upgrading and refurbishment of control rooms"
  - Determine whether additional international CSNI activities are required in this area
- HRP objective:
  - Obtain recommendations and research ideas to our research in general, and in particular to the two projects "Work practices" and "Extended teamwork"
  - Establish a resource group consisting of people who are interested in these topics
    - Give input to what is the most useful areas to focus on
    - Ensure that the research will be practical for the community

6

Workshop arrangement

- Workshop time and place:
  Halden, 8-10 May. 2006
- Keynote Speaker
  - Dr. Eduardo Salas, teamwork expert
- Chairman
  - Dr. J. Persensky, USNRC
- Participants
  - Utilities
  - Operators
  - Vendors
  - Research bodies
  - Regulators
  - Oil industry
- Workshop content
  - Paper presentations
  - Panels
  - Group discussions
  - Plenary sessions
  - HAMMLAB illustration
- Session topics
  - Teamwork
  - Control room Design Concepts
  - Petroleum Experience
  - Control Room Evaluation Methods and Measures
  - Concepts of Operation
  - Regulatory Requirements

7

8

Teamwork

- The nature of teamwork and concepts of operation are likely to change for new control rooms and advanced reactors and research should be based on this knowledge. The changes are likely to include:
  - Integrated remote and local operations
    - Distributed decision making
    - Cooperation across physical distances
    - Different cooperation tools
  - Teams made up of agents – people, machines, intelligent systems
  - Multiunit control from a single control station
  - Resultant changes in the staffing, training, and qualifications of personnel

9

3

Control room design concepts

- Computer-based (digital) control stations and the associated human-system interfaces will become obsolete faster than has been experienced in analogue control rooms, therefore
  - New human factors technologies, such as, performance modelling and virtual environments need to be developed and validated for regulatory and design use
  - Research is needed on how to balance between technology-focused design and human-driven design so that people and automation can be integrated effectively to maintain a safe operating environment
  - Clear acceptance criteria for human factors elements of design need to be developed and promulgated

10

Petroleum experience

- The Human Factors of control station design in the nuclear sector is being outpaced by other sectors, e.g., the petroleum sector, therefore:
  - The nuclear sector must learn from others that already have on-and off-site modular operations
  - Multi-disciplinary design and review teams need to be established
  - An international and cross-industry knowledge sharing and experience information base is necessary

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Evaluation methods and measurement

- Many issues are still unclear with respect to how to identify, collect, and interpret operational experience, therefore:
  - International operating and design experience databases need to be developed
  - Experience data for old designs to new designs should be utilized
  - Operational experience from other industries are relevant for a number of human factors issues, as many human design elements cut across industrial settings

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Concepts of operation

Advanced reactors are expected to be based on concepts of operation that are different from today's light water reactors. There are several unresolved human factors challenges associated with the design of control rooms for advanced plants, therefore:

- Methods of assessment and evaluation methods and tools may have to be modified to keep pace with these changes
- Thorough analyses are required as well as simulation for validation and verification
- Experience from the petroleum sector can provide valuable insight
- Research applied to advanced settings is needed to take advantage of intelligent HSI functions

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Regulatory requirements, concerns and approaches

Regulatory agencies need to prepare for advanced reactors and new designs, therefore:

- There is a need for determine what new regulatory review guidance may be needed to address the review of modernised and advanced plants
- There is a need to develop regulatory review and approval processes that are flexible and able to adapt to these rapid technological changes
- There is a need for guidance on how to recruit new plant personnel, guidance on teamwork aspects, including role-changes, the role of automation as an agent in the team, and how teamwork issues might be addressed by the regulator

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On the verge of a new beginning...

- Paradigm shift
- Multi-disciplinary cooperation is needed
  - Balance technology driven and human driven design processes
  - Forums for sharing results
- Teamwork will always be integral to nuclear power operations
  - Design will be different
  - New technology may change the nature of teamwork
- Impact on research
  - New approaches to how operators interact
  - New ways to measure operator performance
  - New methodological approaches to research
  - A lot of research is going on. We need to make use of it
- Experience
  - Learn from control room modernisation programmes
  - Learn from other domains - integrated operations in the oil industry
- Relevance of existing guidelines and methods need to be considered
- New regulatory concepts may be needed

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5

Written feedback

- The workshop was successful for sharing information and experiences
- Key messages participants wanted to take away:
  - Important to integrate Human Factors early in the design process for new reactors
  - The Human Factors community needs to develop and apply acceptance criteria for the human factors design elements of new reactors
  - Technological change should be driven by what is needed by the user for safe and productive operation
- Suggestions for further work:
  - Operator roles
  - Measures and indicators of teamwork
  - Staffing issues
  - Training needs
  - Establishing a mechanism for exchanging information regularly

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Workshop outcome

- Reporting
  - Workshop proceedings [NEA/CSNI/R(2007)1] *in prep.*
  - Paper - EHPG 07
- SEGHOF (WGHOF)
  - Teamwork issues could be a more salient part of the WGHOF work programme
  - No immediate actions on this topic
- HRP
  - Initiate work on the project "Work Practices"
  - Input to the continuation of the work on the project "Extended Teamwork" and other, related projects
  - Resource group established – sub-group of HEPA

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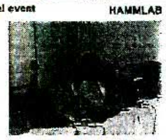
Workshop atmosphere

Conference room

Social event

HAMMLAB illustration

Fun ....



... and hard work!

18

6

Review of previous HRP work

- Determine how previous work performed at HRP is relevant for the Work practice programme
  - Theoretical and practical input
  - Confirm initial ideas
  - Generate new ideas
  - Not overlap previous research
- Seven different research programmes identified
- 15 reports reviewed based on the following characteristics
  - Type of work
  - Purpose of work
  - Relevant theoretical basis
  - Relevant variables
  - Outcome of work
  - Identified needs for further work

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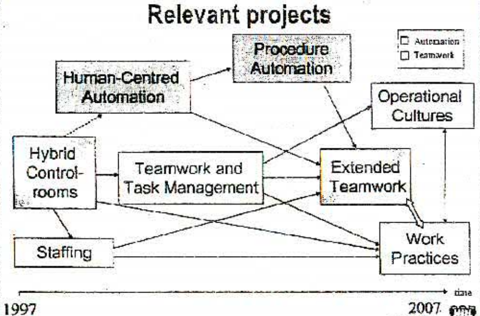
Relevant projects



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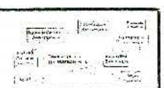
Outcome of work



- Specific topics discussed
  – relevant for work practices
- Communication
  - Large screen aid communication and improve teamwork
  - Loss of visibility - changes in the nature of workload
- Operator tasks/ roles
  - Possible changes in the responsibilities, functions and tasks of the crew members (operation to supervision)
  - Possible effects on staffing, teamwork skills and interpersonal dynamics
- Information
  - Information about the system and process status
  - Information about crew member
  - Shared situation understanding

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7

Identified needs for further work

- Communication
  - Analyse communication and communication patterns
  - Investigate new communication strategies with the use of new technology
- Operator tasks/ roles
  - Investigate measurement and analysis tools for work style quality
  - Perform analyses of function allocation, automation, and plant specific characteristics in order to decide CR staffing levels
- Information
  - Find ways to present information (audible + visual) to better support the operators' need to supervise plant systems
  - Investigate how to provide for inter-personal operator support across physical distance

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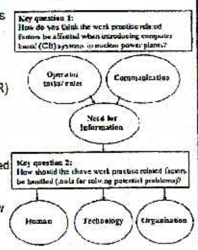
Workshop sessions in HAMMLAB

- Purpose: To observe operators/ discuss with operators
  - How work practices may change
  - Possible tools to solve potential problems
- Workshop sessionx2 (conv. + comp CR)
  - Four operators
  - Three scenarios
- Initial observation of problems
  - Communication
  - More need for communication: increased workload
  - Operator tasks/ roles
  - Need for one operator to keep overview
  - Information
  - Specific problems: loose overview



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Status and further plans

- 2006
  - International workshop
- 2007
  - Workshop with operators from conventional and computer-based NPP control room
  - Review of previous HRP work (HWR-848)
- 2008
  - Fieldstudies/ interviews with operators from computer-based NPP control rooms
  - Review of relevant literature
  - Suggest a possible solution for increased observability in computer-based control room
  - Test solution

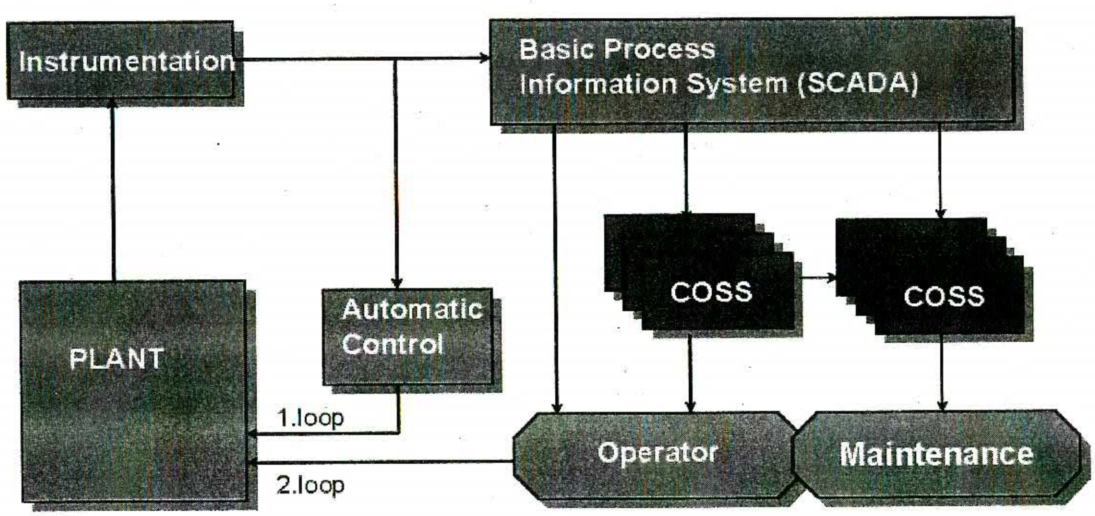
24

Computerised Operation Support Systems (COSS)
and
On-Line-Monitoring (OLM)-Applications

Øivind Berg
oivind.berg@hrp.no

Institutt for energiteknikk
OECD Halden Reactor Project

Role of Computerised Operation Support Systems, COSS



HRP activities on operator support systems

Objectives:

- Explore potential of computer-based operation support

Method:

- Develop **prototype** Computerised Operator Support Systems (COSS)
- **Evaluate** COSSes in realistic experiments in HAMMLAB (Halden Man Machine LABoratory)
- **Implement** specific COSSes and products in plants, e.g. Control Room Upgrade Projects

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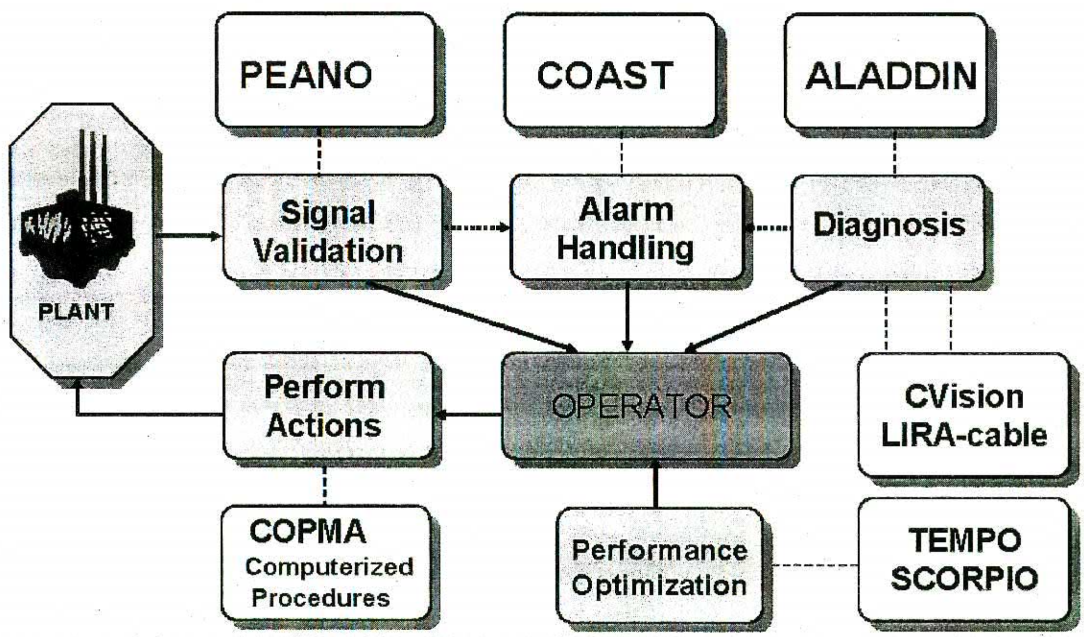
COSSes and operator tasks



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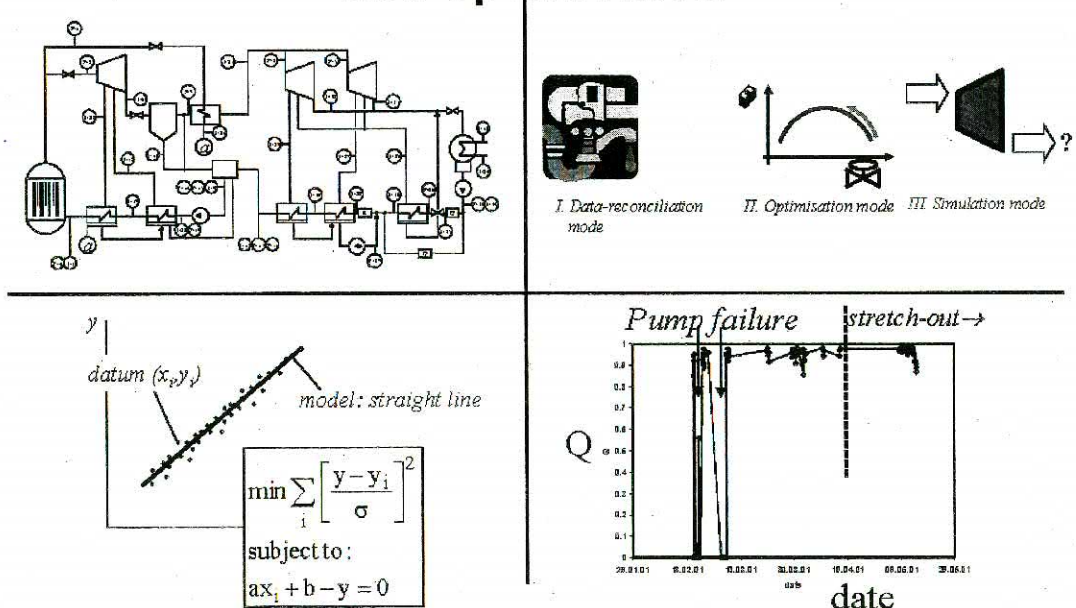
OLM - applications

- Thermal Performance Monitoring and Data Reconciliation (physical modeling application) **TEMPO**
- Signal Validation/Calibration Monitoring (empirical) **PEANO**
- Virtual Sensor (empirical) **PEMS, OiW**
- Event Detection and Diagnosis (empirical) **Aladdin**
- Core Surveillance **SCORPIO**
- Power Distribution calculation **VNEM**
- SPDS and Computerised Procedures (EOPs) **COPMA**
- Cable Condition Monitoring **LIRA**
- **HOLMUG** – Halden On-Line Monitoring User Group

TEMPO: Thermal Performance Monitoring and Optimisation



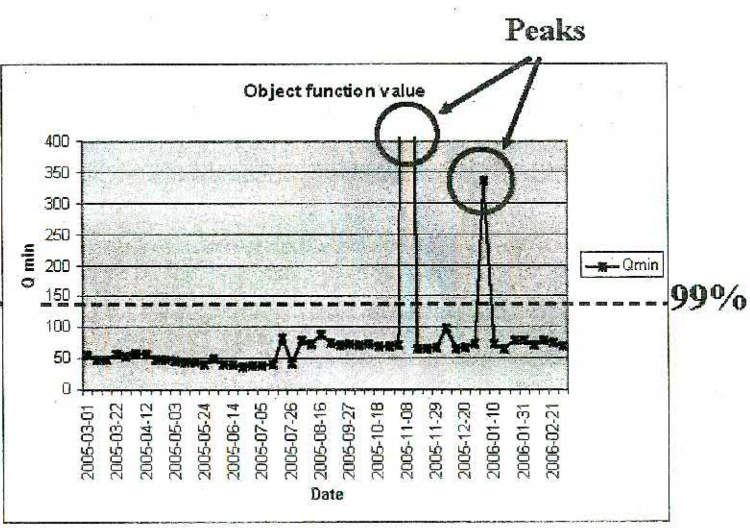
TEMPO: Where is it used?

Forsmark 3 Type: ASEA-Atom BWR Output: 1155 MWe Turbine: Stal-Laval Status: installed	Loviisa 2 Type: VVER-440 Output: 445 MWe Turbine: Atomenergoexport Status: installed
Olkilouto 2 Type: ASEA-Atom BWR Output: 810 MWe Turbine: Stal-Laval Status: installed	Dukovany Type: VVER-440 Output: 408 MWe Turbine: Skoda Status: Feasability study
Almaraz Type: Westinghouse PWR Output 892 MWe Turbine: Westinghouse Status: Feasability study	Paks Type: VVER-440 Output: 433 MWe Turbine: Ganz Electrical Works Status: Feasability study
EdF Feasability study for a 1300MW NPP.	

Outliers

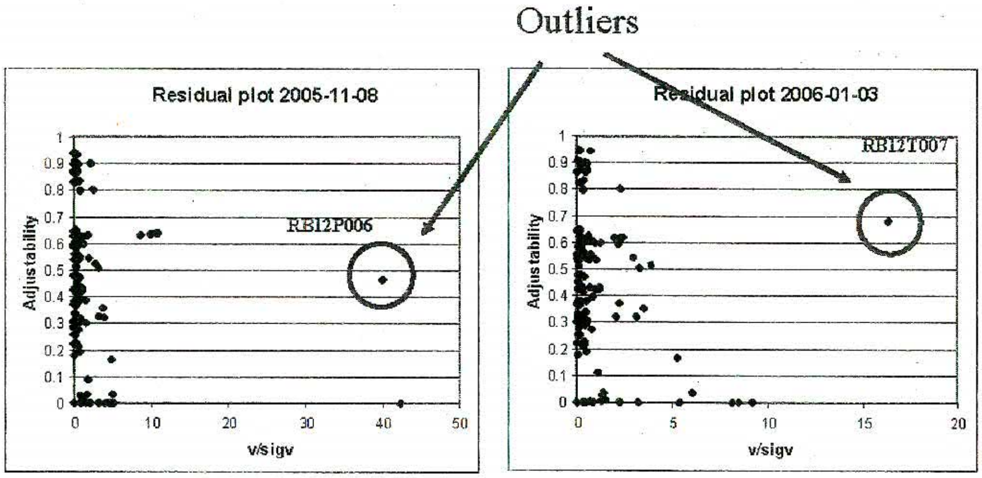
Measurement outliers (object function trend)

$$\chi^2 = \sum_{meas} \frac{(\hat{x} - x^+)^2}{\sigma^2_{x^+}} \equiv v F_x^{-1} v$$



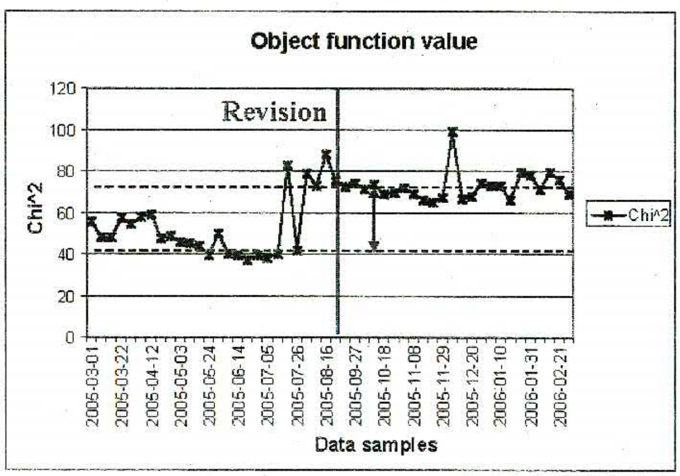
Outliers

Residual plots (identifying measurement outliers)



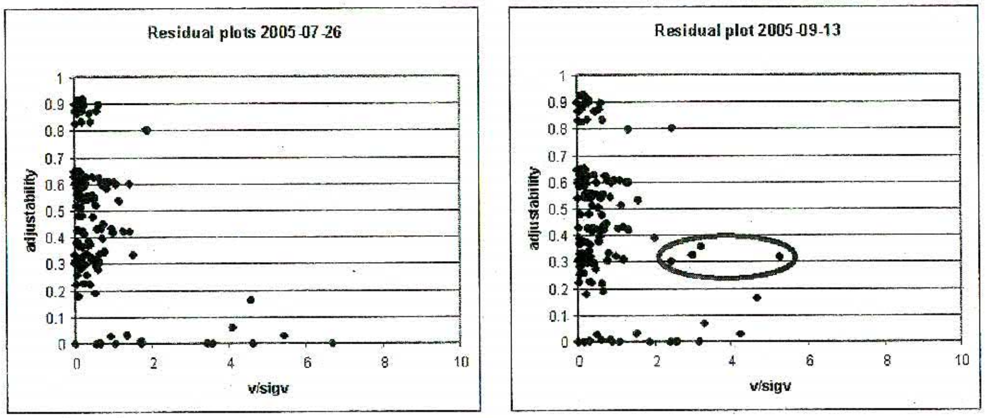
Revision

Increased object function after revision



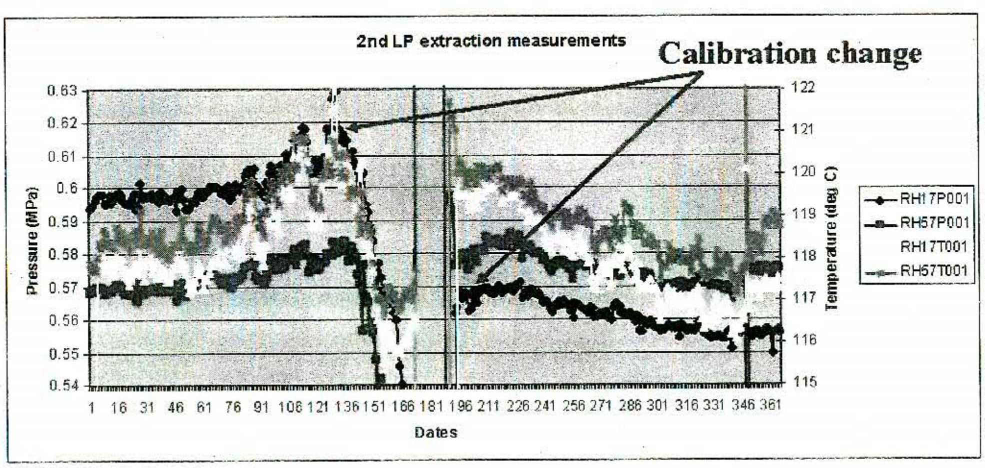
Revision

Residual plots before and after revision.



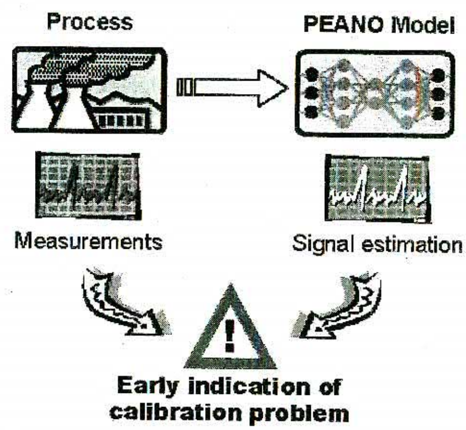
Revision

2nd LP extraction measurements



PEANO System

- On-line Calibration Monitoring and Sensor Validation system, based on Fuzzy-Neural Network models



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PEANO Test Applications - Nuclear

- EdF/CEA (France)
- PAKS (Hungary)
- HRP (Norway)
- CESI and ENEA (Italy)
- Tecnatom (Spain)
- EPRI, VC Summer (USA)
- Tepsys (Japan)
- Sizewell B (UK)
- Oskarshamn (Sweden)
- Temelin (Czech Rep.)

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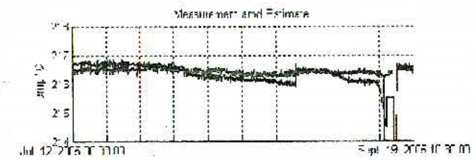
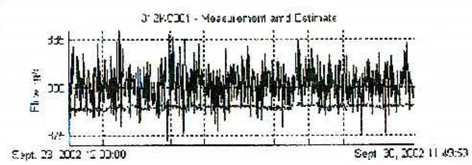
OKG Unit 3 - Results

- Feed Water Line Temperature
  Range: 0 – 250°C
  0.4°C drift was detected.
  (i.e. 0.16% of the range)



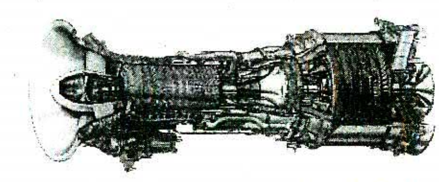
- Feed Water Flow
  Range: 0 – 1100 kg/s
  3 kg/s drift was detected.

  Corresponding 3 MW power loss
  was also detected.

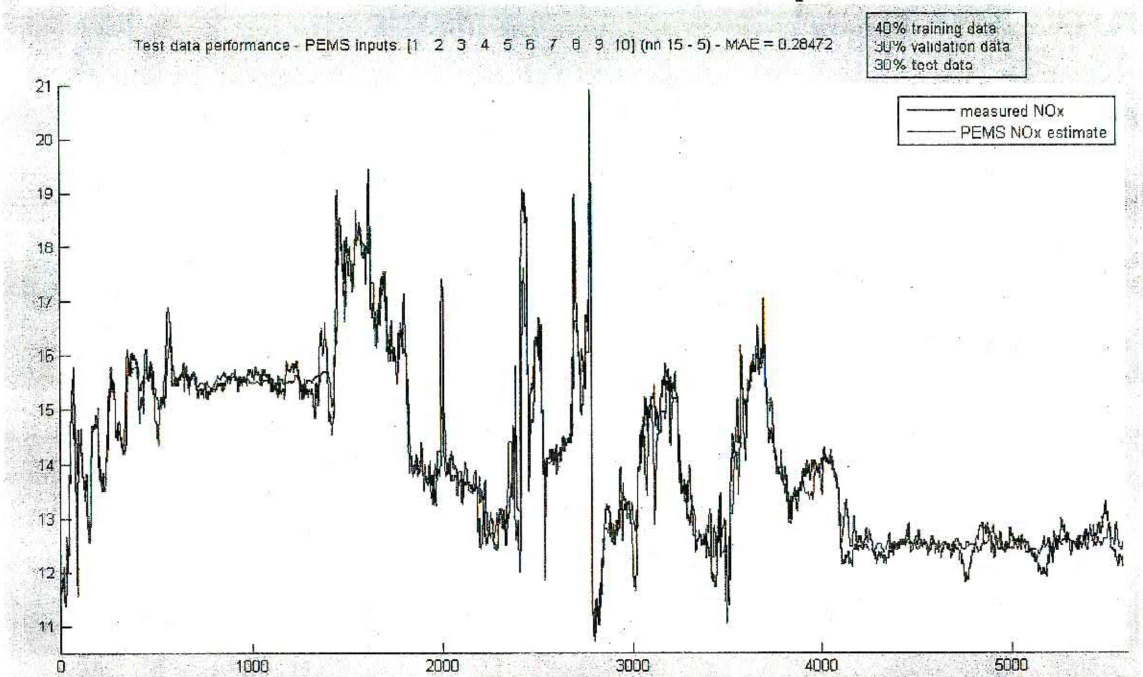


The PEMS Virtual Sensor

- PEMS – Parametric Emission Monitoring Systems
  - A PEMS uses current process parameters and on-line measurements to calculate (estimate) expected NOx emissions
  - First introduced in the US in 1992 and approved by the US EPA
- The only available alternatives are CEMS – Continuous Emission Monitoring Systems
  - Permanently installed sensor equipment
  - More expensive to install, certify and maintain



PEMS Results – 10 inputs



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On-Line Early Fault Detection & Diagnosis with the aladdin Transient Classifier

Davide Roverso
Øivind Berg

IFE - Institute for Energy Technology
OECD Halden Reactor Project

aladdin

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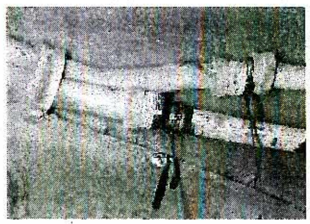
29.02.2008

System Purpose

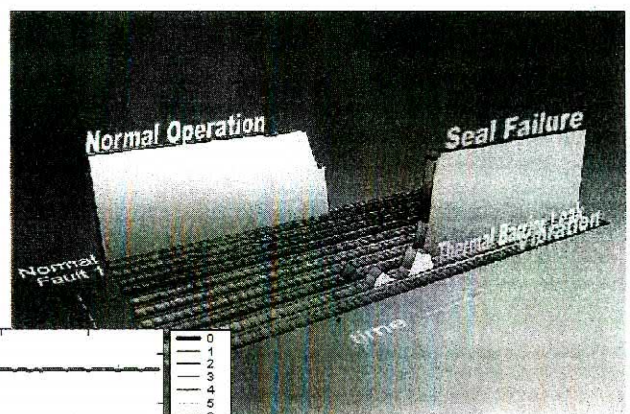
- Assist plant operators in the early detection and diagnosis of faults and anomalies that either have an impact on plant performance, or that could lead to an emergency shutdown or component damage if undetected.

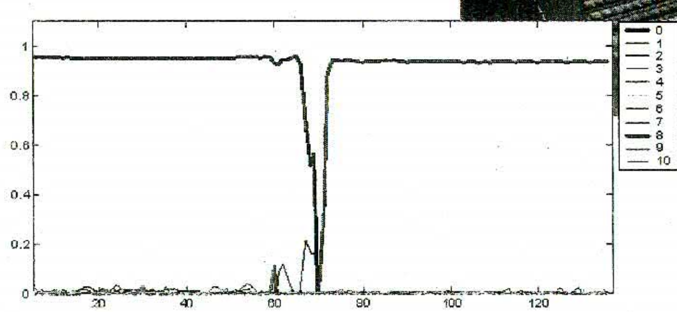
- Assist engineers in the recognition and classification of equipment or process signatures



VC Summer Application Example

- Example of detection and diagnosis of a seal failure





Application Example

Gesellschaft für Anlagen und Reaktorsicherheit (GRS) mbH

PWR application

- 10 faults of 5 fault classes
  - `fdu_open, fwvalve_close, prvalve_open, sbloca_coldleg, steamline_break`
- 27 input measurements
- 13 blind tests
  - 10 correctly recognized
  - 3 undecided

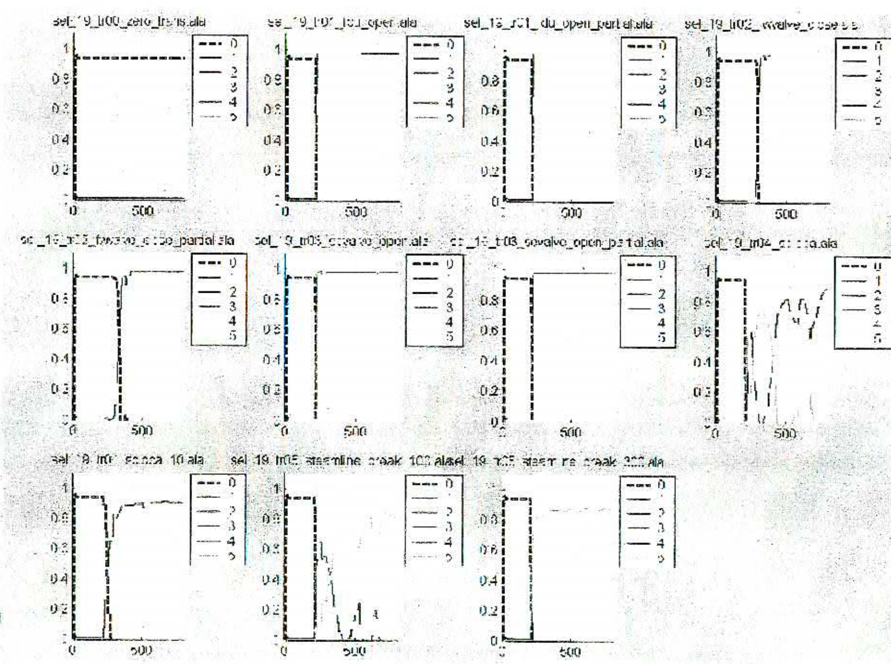
BWR application **(under development)**

- 10 faults of 5 fault classes
  - `fdu_open, fwvalve_close, sevalve_open, sbloca, steamline_break`
- 19 input measurements
- 10 blind tests received

Gesellschaft für Anlagen und Reaktorsicherheit (GRS) mbH

GRS Application Example

- BWR application



COAST

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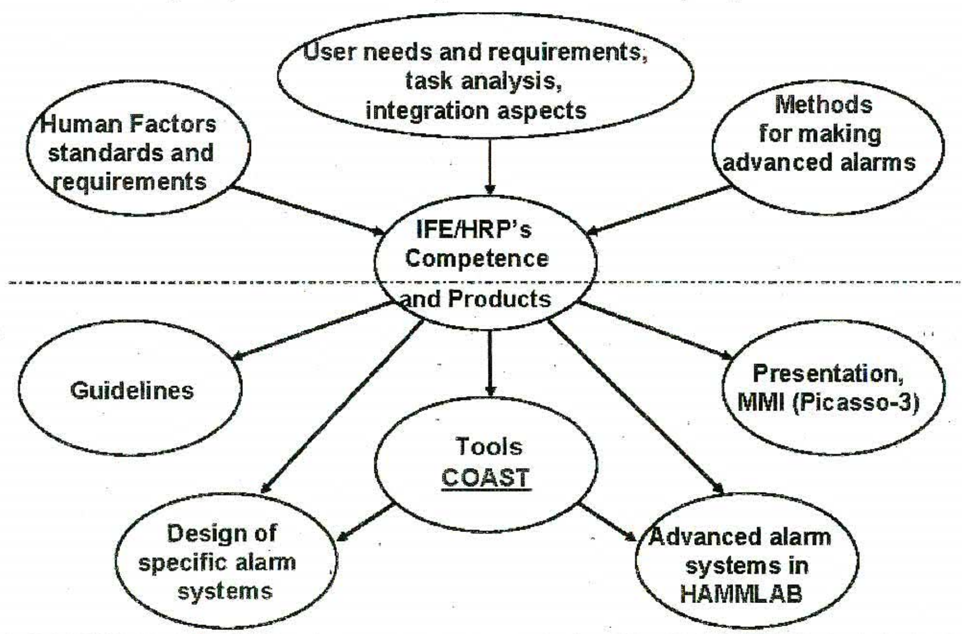
Alarm systems competence and products



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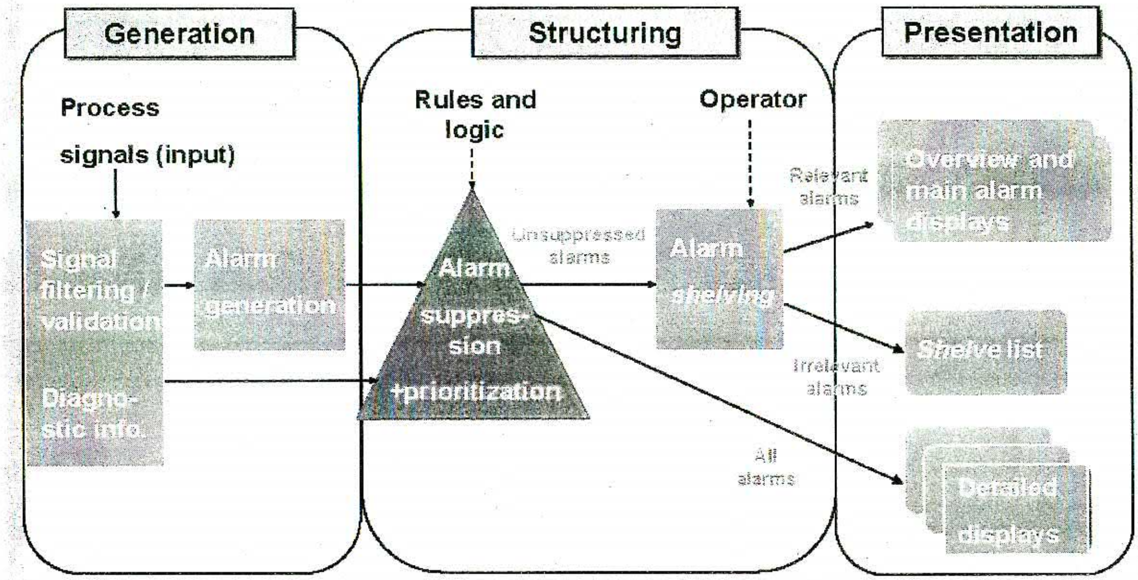
Alarm system solutions



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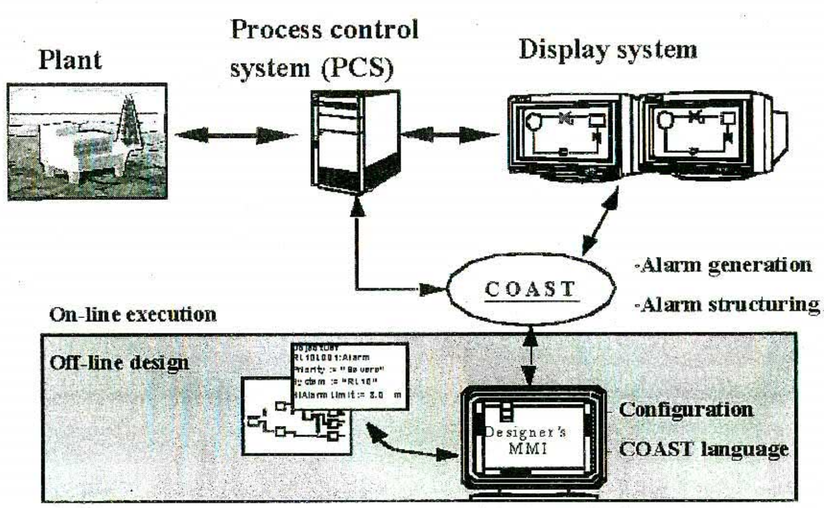
COAST: A specialised toolbox for making alarm systems



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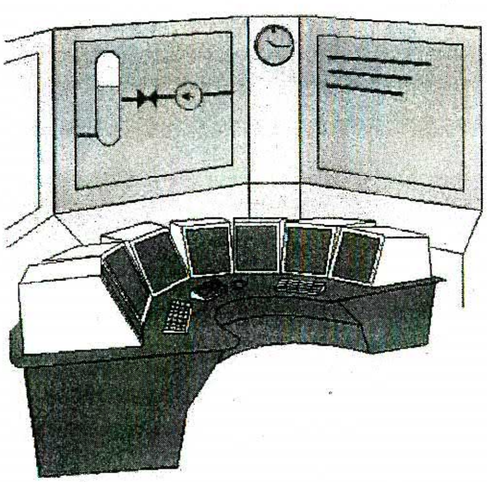
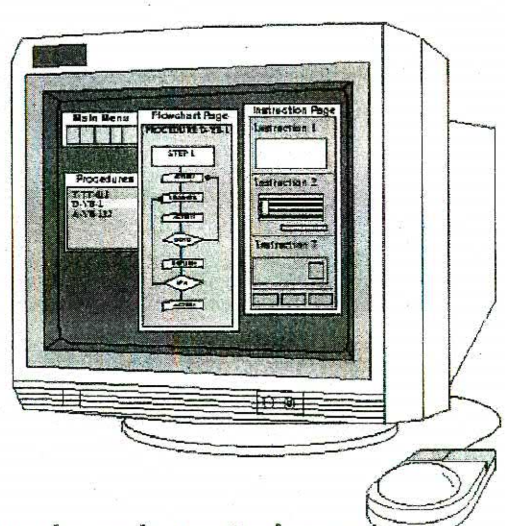
COAST functionality

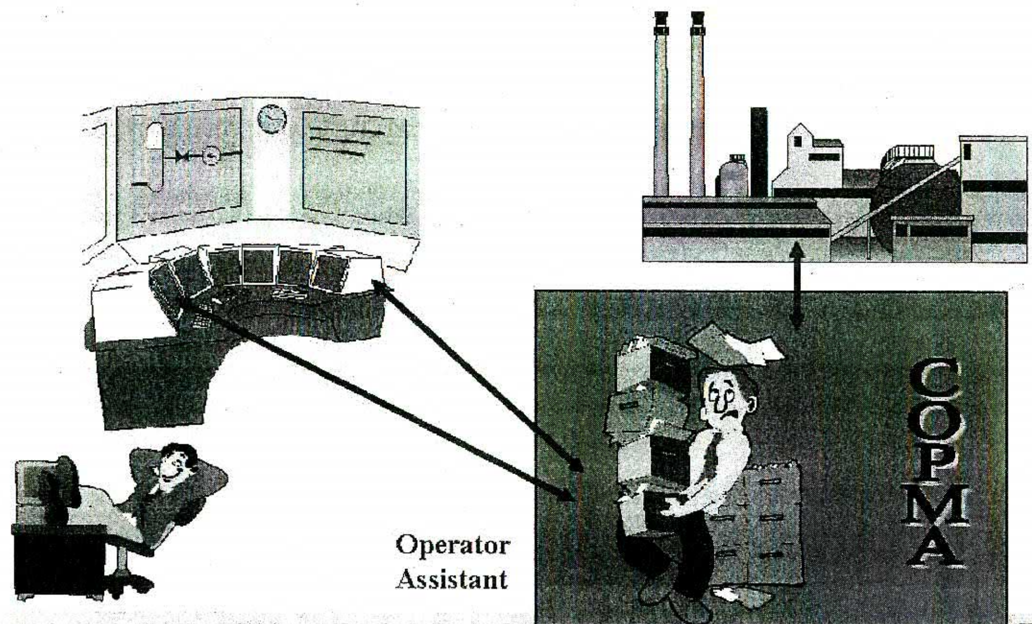
- COAST can generate most types of alarms
  - Limit check
  - Model-based
  - Function-oriented
- COAST can structure alarms
  - Supports different alarm processing techniques
  - "Transparent" suppression based on well defined criteria
  - Cause-consequence relations
- COAST supports various presentation strategies
  - Strong alarm selection capabilities
- COAST offers easy interfacing to existing systems
  - Supports incremental alarm system development

COPMA





For integrating computerised procedures in control rooms

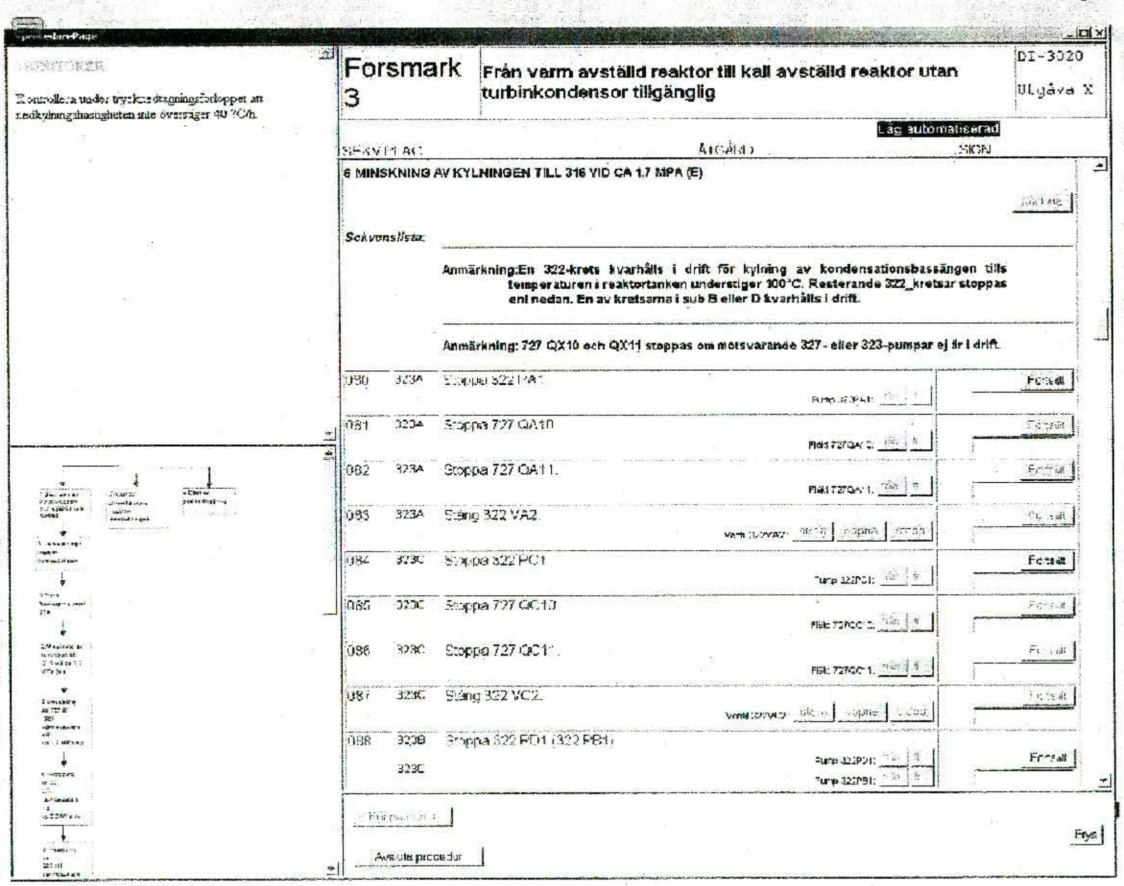


COPMA-III features

- Process integration (different levels of automation)
  - Display of dynamically updated process variables
  - Data monitoring
  - Process control
- Integration with other COSSes.
- It is possible to implement most types of procedures
- Supports multi-user execution (crew support)
- Different procedure presentation ...
  - depending on what kind of procedure
  - depending on the role of the operator
- Configurable procedure execution support

COPMA-III features *cont.*

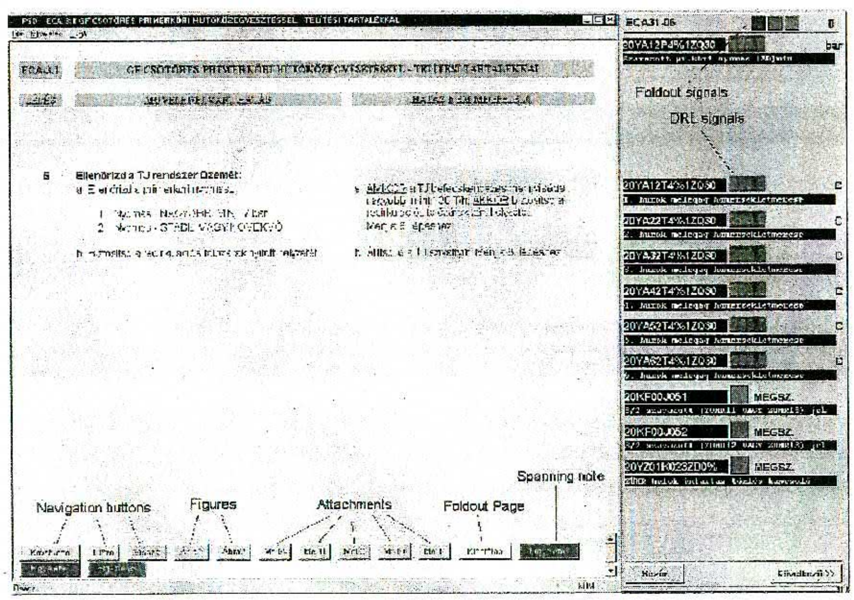
- Integration with other off-line systems e.g. *procedure maintenance systems*
- COPMA-III is built on standards related to document representation
  - XML eXtendible Markup Language,
  - XSL eXtendible Stylesheet Language,
  - SVG Scalable Vector Graphics
  - Basic tools supporting presentation and transformation of XML document content
  - Portability among documents and tools



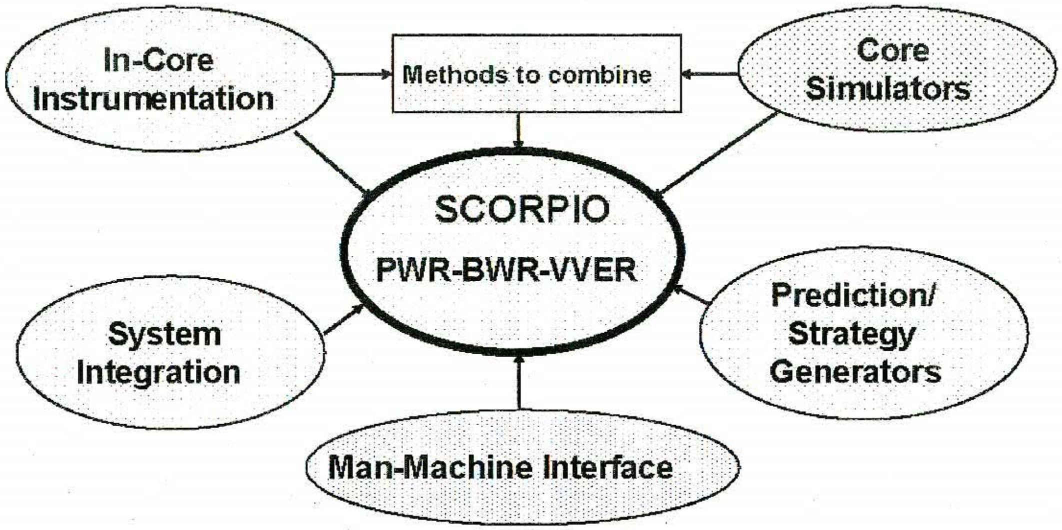
SPDS systems

- Kola, NPP, Russia.
  - Safety Parameter Display System (SPDS) at all the 4 units
  - SPDS coupled to their training simulators
- Paks, NPP, Hungary
  - PLASMA project where the COPMA computerised procedure system is used for implementation of the EOPs from Westinghouse

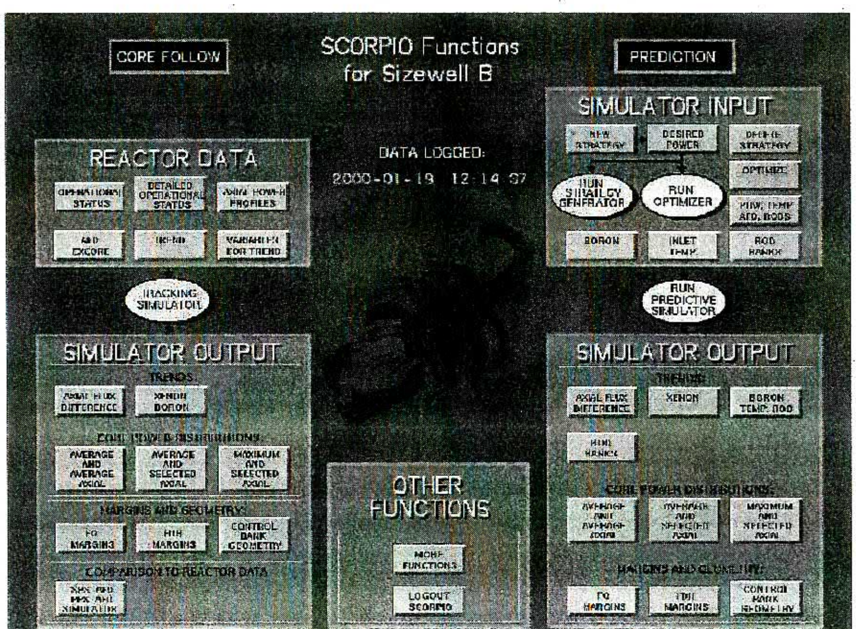
Screenshot of EOP display



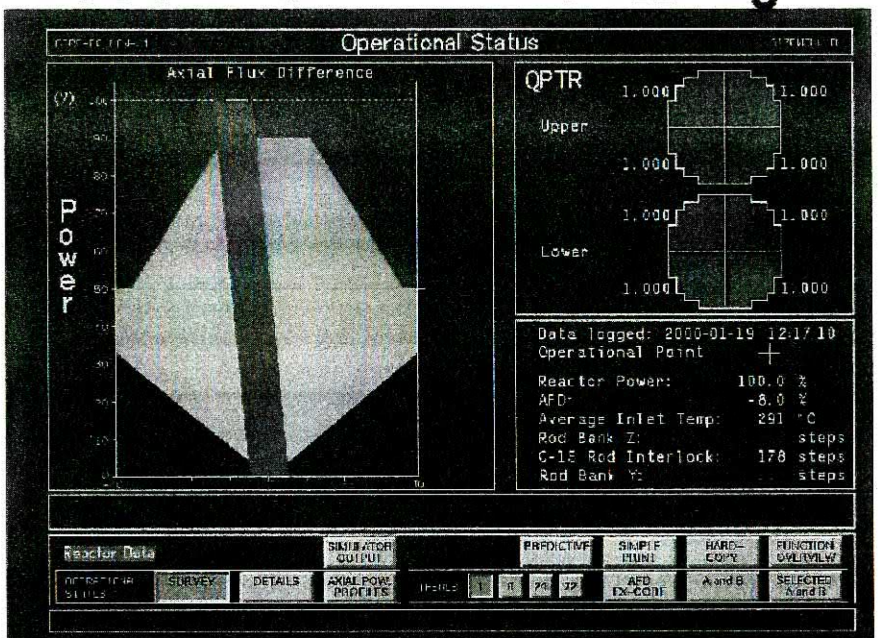
SCORPIO - Overview

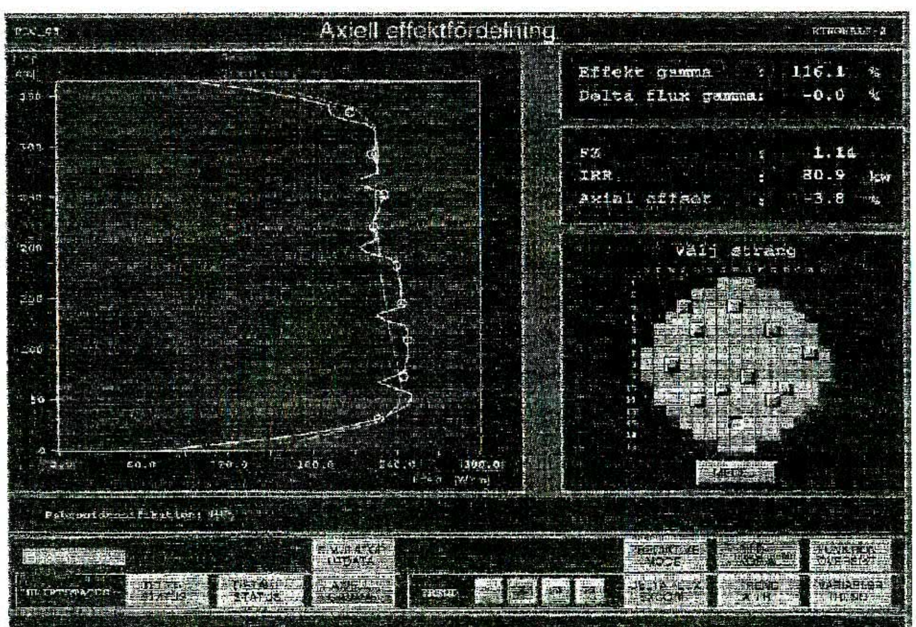


SCORPIO – PWR version

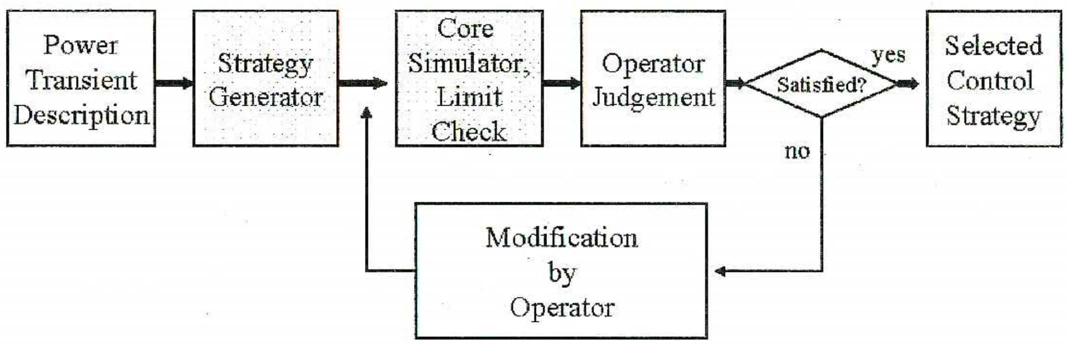


SCORPIO – PWR monitoring

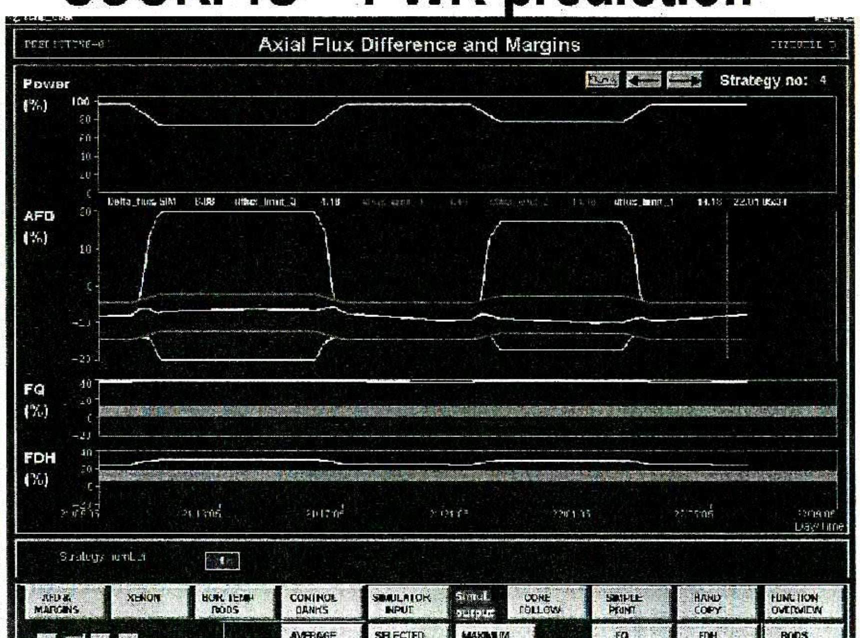




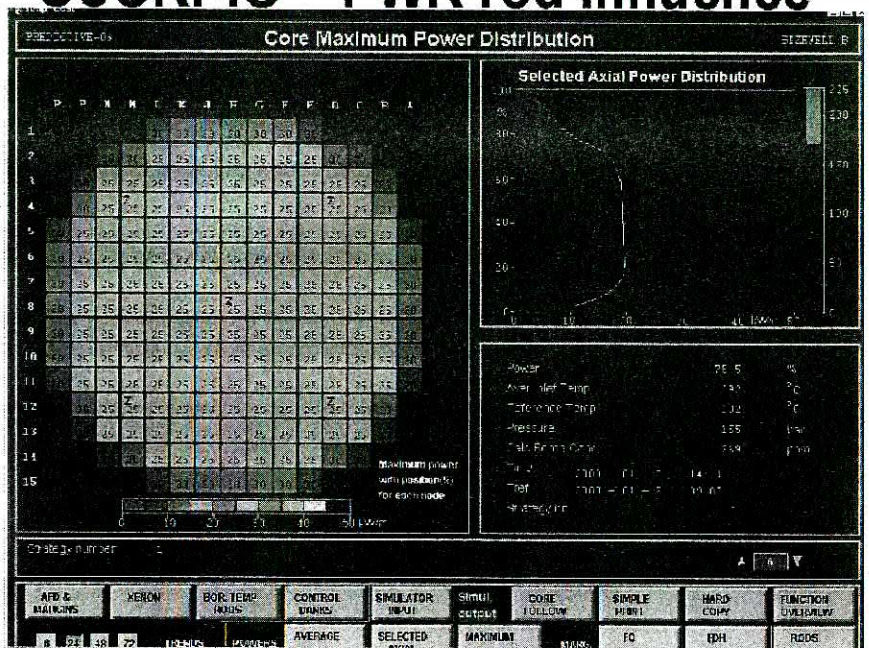
SCORPIO – Procedure for predictive analysis



SCORPIO – PWR prediction



SCORPIO – PWR rod influence



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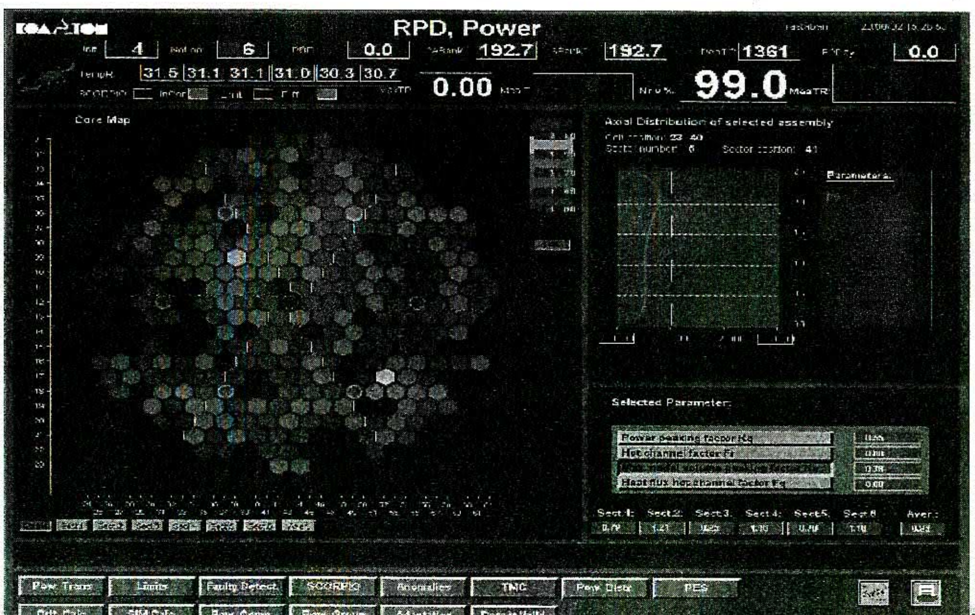
SCORPIO – Core Surveillance



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SCORPIO Installations

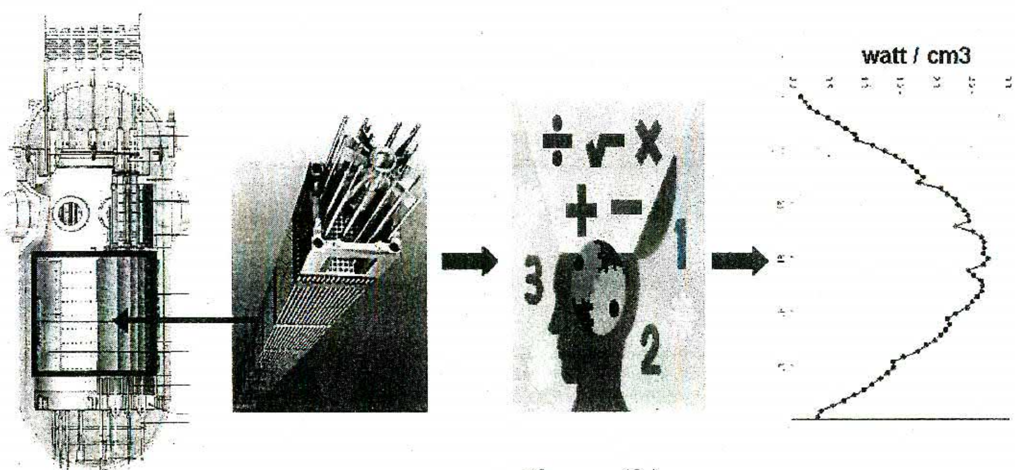
- Dukovany NPP, Czech Republic (Unit 1-4)
- Bohunice NPP, Slovak Republic (Unit 3-4)
- Kola NPP (KNPP), Russia (Unit 3-4)

VNEM Variational Nodal Expansion Method

Enhanced neutronics model based on transport theory for more accurate power distribution calculations:

- Yonden (PWR), Japan
- TEPSYS (BWR), Japan
- Ringhals, Sweden

VNEM: LWR neutronics calculation

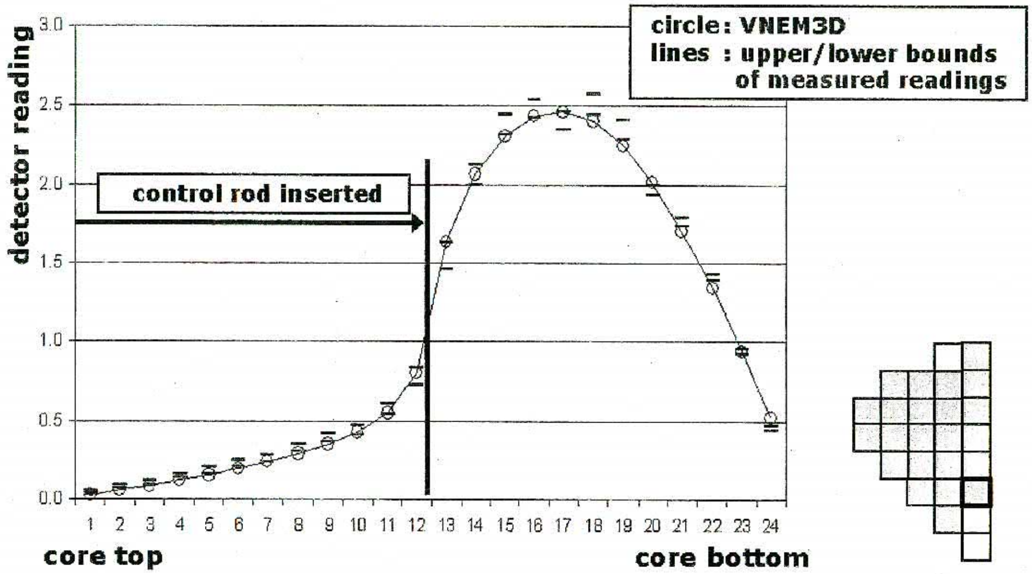


core / fuel composition, geometry

mathematics model on neutrons behavior

power distribution, reactivity

Ringhals case 2: detector readings in assembly (8,6) = controlled assembly



purpose of VNEM*

increase accuracy of power distribution calculations

⬇

less safety margin requirements

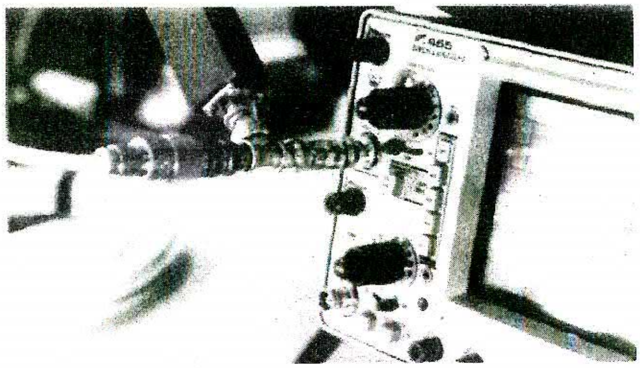
⬇

more economy oriented core operation
e.g., less fresh fuel, higher fuel burnup, less high level wastes, etc.

⬇

*** Variational Nodal Expansion Method**

Wire System Aging Assessment and Condition Monitoring Using Line Resonance Analysis (LIRA)



wirescan

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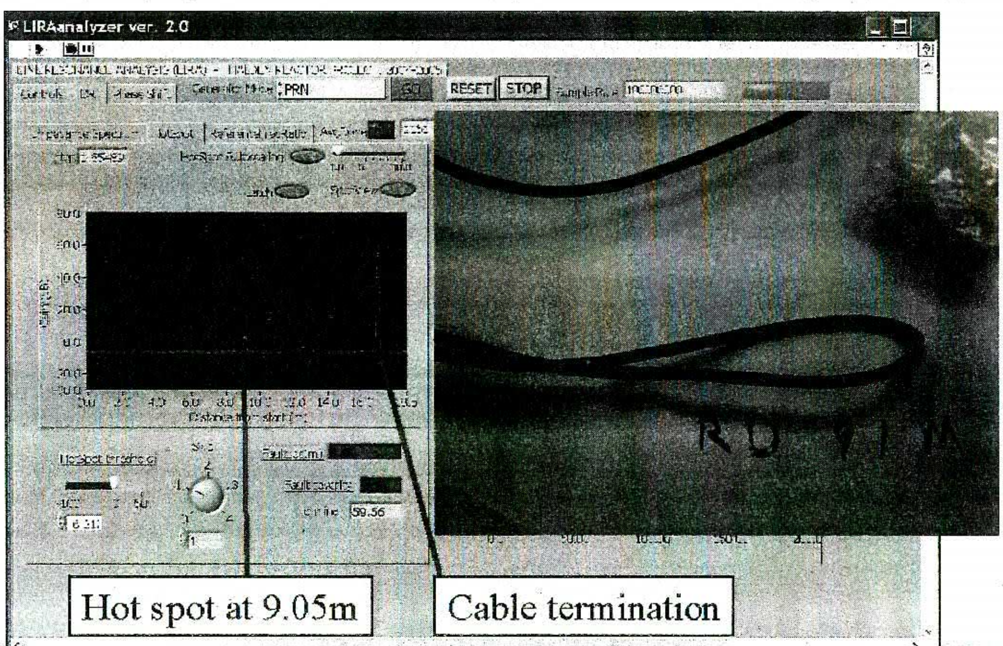
EPRI Tests
Hot spot at 9.1m of 17m total length



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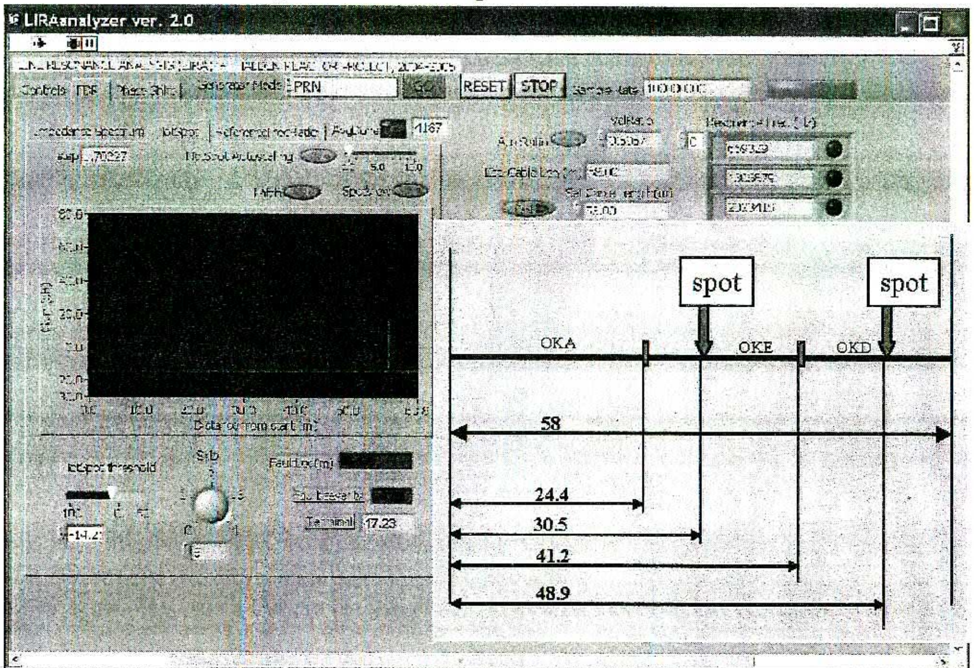
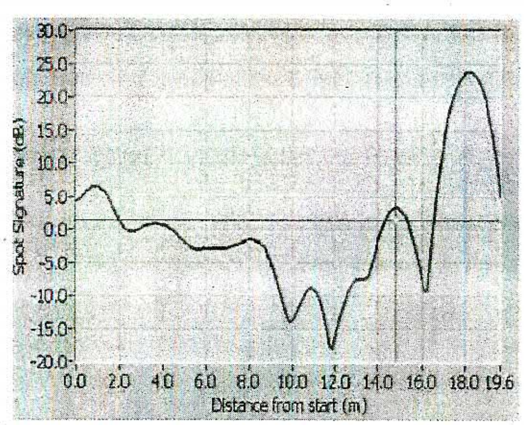
Multiple hot-spot detection



Test at Ringhals January and June 2007

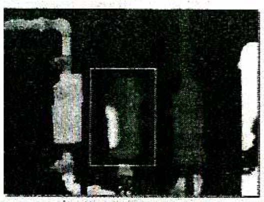


LIRA measurement of a Lipalon cable with a splice at 15m and end of cable at 18.5m.

Computer Vision Based Condition Monitoring

- improve process monitoring
- improve hazard detection
- improve safety

Detect elevated temperatures in process equipment



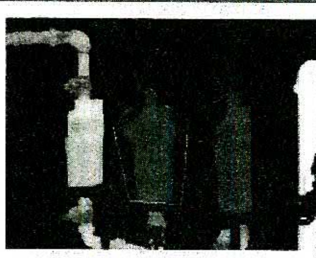
Determine liquid level in tanks

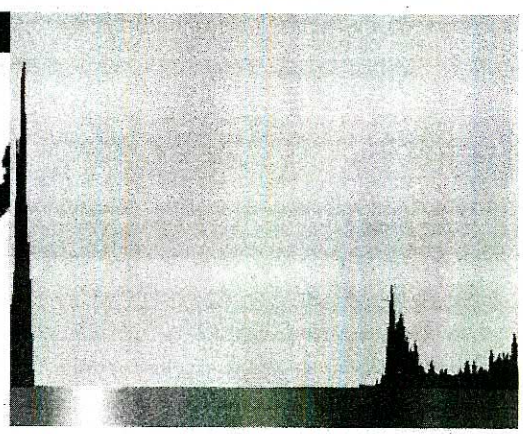
Detect fire, gas or vapour emissions

Infrared Image Analysis

Histogram Analysis

Temperature elevations can be recognised as new peaks in "yellow" part of infrared histograms:





The HOLMUG meeting
(Halden On-Line Monitoring User Group)

Olkiluoto, Finland,
October 3th – 4th, 2007
Øivind Berg, HRP

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Objectives

- **Information dissemination** and status of on-line monitoring:
  - Methods
  - Available systems
  - Regulatory aspects
  - Feedback from utilities, research institutes, universities, and vendors
- Promoting activities leading to the **implementation of on-line monitoring** strategies at plants
- Previous Meetings:
  - 2003 in Halden,
  - 2004 at the EHPG in Sandefjord
  - 2004 IAEA technical meeting on "Increasing instrument calibration interval through on-line monitoring technologies", in Halden
  - 2006 at OKG, Sweden

Figure 1
HAMMLAB Simulator

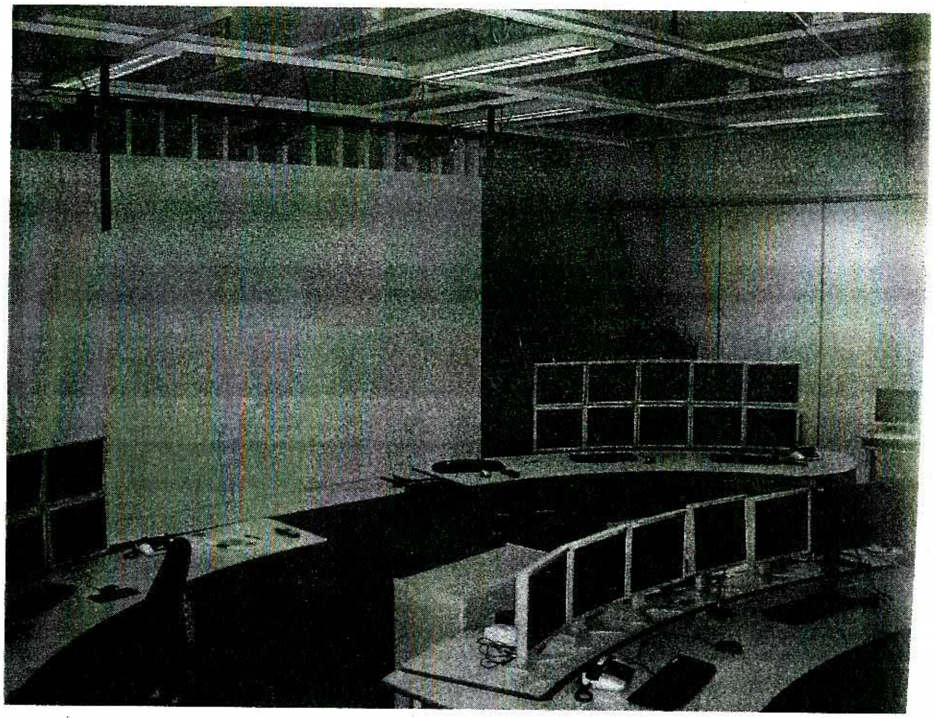

Figure 2
Individual Operator Work Station

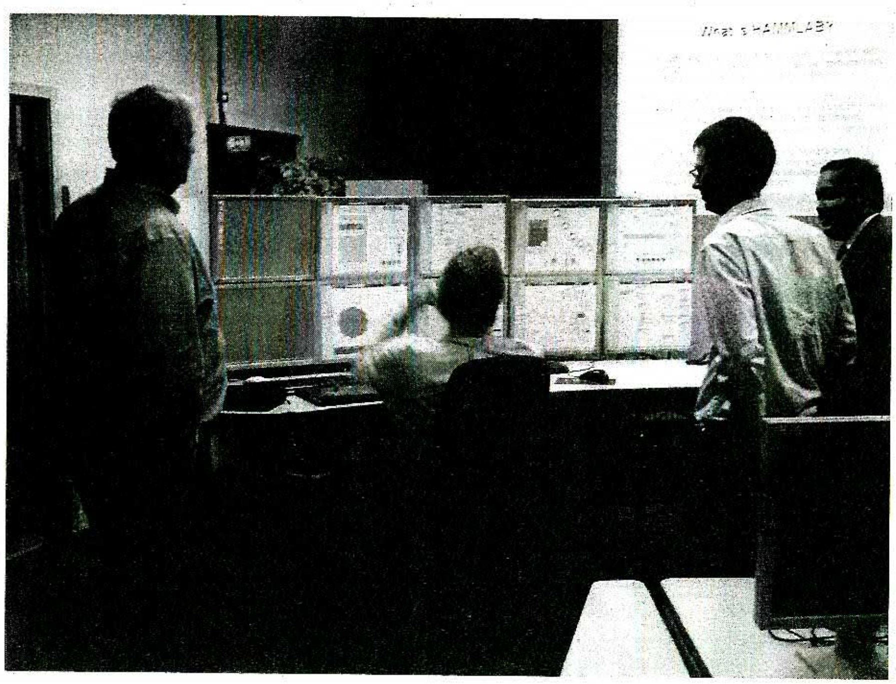

Figure 3
HAMMLAB Plant Status Summary Display

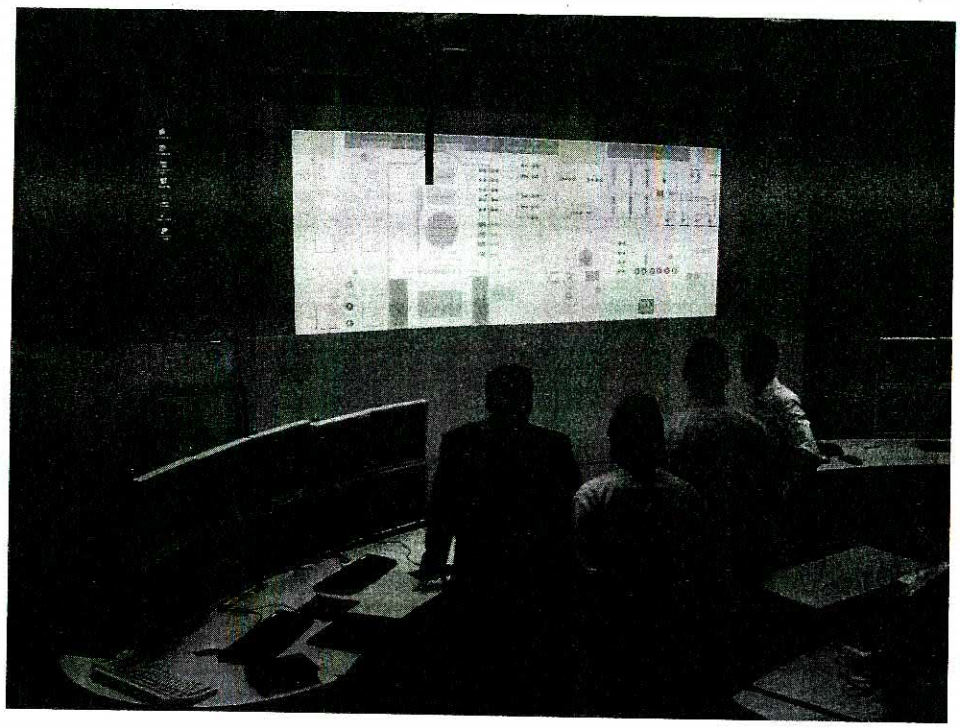

Figure 4
Operator Work Station Tables