A FUEL COOLING BASIS FOR CRITICAL SAFETY PARAMETER TRAINING

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ABSTRACT

The Fuel Cooling course provides Nuclear Operations trainees with the supporting science fundamentals that form a basis for the Critical Safety Parameters Refresher Training program. The course material builds knowledge logically starting with thermalhydraulic principles and proceeding towards an understanding of the feedback effects associated with severe fuel cooling upsets. The course training methods follow a "Know, Show, Do, and Review" approach whereby knowledge built in classroom lectures and discussions is reinforced with practical simulator exercises. These exercises provide a valuable opportunity for the trainees to understand the fuel cooling processes that could occur during severe plant upsets. The simulator exercises are integrated with the classroom lectures such that each important section is followed by an associated simulator exercise. The simulator Instructor Facility provides a key role in assimilating the detailed fuel cooling transient data with the Control Room panel displays and alarms associated with the actual Point Lepreau GS Control Room.

1.0 INTRODUCTION

The Fuel Cooling course provides authorized staff training on the fundamental principles associated with maintaining adequate fuel cooling during plant transients. This training material includes information specifically relevant to the CANDU 600. In particular, rather than provide training that discusses thermalhydraulics subjects, the application of this theory to the operation of a CANDU 600 is emphasized. The result is training that integrates the information normally associated with Safety and Licensing analysis with the training requirements of Nuclear Operations.

The Fuel Cooling course provides the supporting science fundamentals for the Critical Safety Parameters (CSP) Refresher Training Program. This paper discusses the components of the fuel cooling course. Its main purpose is to show the training methods used to strengthen the operators understanding of fuel cooling processes.

2.0 FUEL COOLING AND CRITICAL SAFETY PARAMETER RELATIONSHIP

2.1 Goal of CSP Training

CSPs were introduced in the Joint Utility Task Group's report on Emergency Operating Procedures Standards[1] as an approach to assuring safe operation of CANDU reactors. The goal of CSP training is to ensure that control room staff can monitor and control a key set of plant parameters (CSPs) that, if maintained within acceptable limits, provide adequate fuel cooling at all times. The principle operator responsibility is to prevent activity release to the public. By maintaining adequate fuel cooling, this responsibility is assured. At the Point Lepreau Generating Station (PLGS), this goal has led to the definition of a CSP based refresher training program.[2]

Refresher training is defined as training that refreshes the knowledge or skill of the trainee. Refresher training is required for skills where on-the-job exposure does not maintain the skill level of the operator[3]. CSP training for plant upset response is an example of such a skill since its frequency of use is low. However, this low frequency emphasizes the need for CSP training as these skills are important for safe plant operation and the safety of personnel.

2.1 CSP Monitoring Responsibilities

The PLGS CSP based Response Strategy to Upsets defines the Shift Supervisor (SS) and Control Room Operator (CRO) roles in responding to any plant upset. This strategy outlines how CSPs are to used in resolving the upset. The primary CSP monitoring responsibility is with the Shift Supervisor (SS). The SS is trained to assess the instrumentation feedback for each CSP, accounting for instrumentation limitations and the transient system dynamics.

The CRO strategy follows a hierarchial list of procedures such as the Generic Emergency Operating Procedures (EOP), Specific EOPs, and Operating Manuals (OMs). Each of these procedures use CSPs where appropriate to the required corrective action. Hence, both the SS and CROs require knowledge of the principles of fuel cooling for a complete understanding of the CSP training program. These positions form the principal training group for the Fuel Cooling course.

2.2 CSP Definitions

The three operating principles :

1)**CONTROL** - the heat source,

2)**COOL** - the fuel, and

3)**CONTAIN** - any fission products,

are used to define the specific CSPs. The PLGS CSPs are summarized in Table 1. Figure 1 shows the relationship among CSPs and the three operating principles. The fuel cooling course material provides the support information that reinforces this relationship. The CSPs are applicable either to the energy balance among Heat Source, Heat Transport, and Heat Sink, or to the containment of fission products. Hence, the fuel cooling processes affect the response of all CSPs.

3.0 DEVELOPMENT OF THE FUEL COOLING COURSE

3.1 Profile of Typical Nuclear Operations Trainees

While there are exceptions, within the past five years personnel hired for CRO training have had a formal education from a community college Power Engineering program. Those hired for shift-supervisor-in-training (SSIT) positions are either university engineering/science graduates or experienced CROs that have demonstrated strong supervisory skills and technical competence. The time period typically required for full authorization is 9 years.[4] The Nuclear General component of this training provides nuclear theory, thermalhydraulics, and reactor safety principles required as a prerequisite to this fuel cooling course.

Table 1 Critical Safety Parameter Classifications

1) Reactor Power
2) Primary Coolant Pressure
3) Primary Coolant temperature
4) Primary Coolant Volume
5) Primary Coolant Subcooling
6) Moderator Heat Sink Parameters
7) Feedwater Radioactivity
8) Steam Generator Level
9) Steam Generator Pressure
10) Containment Pressure
11) Containment Radioacitvity
12) Shutdown Cooling
13) ECC Heat Sink Parameters
14) Service Water Radioactivity

The difficulties involved with developing and implementing training material for SS and CRO positions stems from the

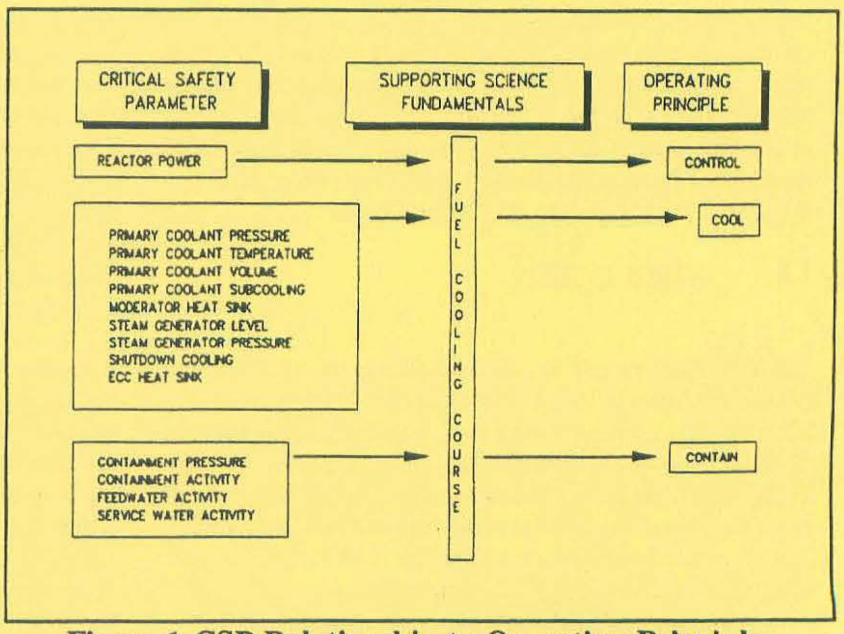


Figure 1 CSP Relationship to Operating Principles

multi-disciplinary nature of the work tasks. In addition, a lack of standard job knowledge requirements results in each utility developing its own requirements, and to a large extent its own training material. Typically operations personnel must have a broad general knowledge of many different industrial systems and their associated science principals. This includes electrical, nuclear, thermal, hydraulic, chemical, instrumentation and computer systems. CANDU plant safety system design has been analytically demonstrated to require a minimum of operator actions for stabilization of an event. However, considering the serious consequences of improper fuel cooling, utilities do not want employees who are merely button pushers, with little knowledge of the consequences of their actions.

3.2 Course Identification

The fuel cooling course was developed to provide a knowledge base that demonstrates how fuel cooling is affected by and influences the CSPs. When effectively presented, all trainees acquire background principles necessary for the subsequent CSP training. The goal of the training is to demonstrate the consequences of improper variation of CSPs on the ability to effectively cool the fuel. The trainee must recognize conditions, derived from Control Room information, leading to improper fuel cooling that may be pro-actively corrected by CSP monitoring and control. The training must not only provide the necessary theory, but also integrate the practical application of this theory with the operators capabilities to control the plant systems.

To reach this goal, it was necessary to assimilate the knowledge and experience from several different departments. The overall course content and hence objectives of the training course were developed through input and review from: Nuclear Training, Nuclear Operations, Safety and Compliance, and the Nuclear Training Simulator. Much of the information regarding the performance of fuel under degraded cooling was obtained through consultation with Safety and Compliance (S & C). Lesson development for the presentation of the S & C information was assisted by Nuclear Training and Simulator staff. This process had the dual benefit of verifying the training simulator fuel model response to upsets against S & C data. Nuclear Operations staff provided valuable practical insight and comments on the training basis document.

3.3 Course Content

For CSP training, the fuel cooling course is presented to previously authorized (licensed) operating staff. As discussed above, the staff have completed a Nuclear General course of related thermalhydraulic material. The fuel cooling course content serves to focus this completed training by refreshing existing knowledge and demonstrating the application of this knowledge to the specific topic of fuel cooling. For example, the heat transfer principles of conduction, convection and radiation are reviewed, but the emphasis is on the application of heat transfer to nuclear fuel cooling in a CANDU 600. Specific reference is made to available PLGS operational or safety analysis data.

A summary of the main fuel cooling course topics is given below:

i) Fuel Cooling Thermalhydraulics

- a) Review of Basic Heat Transfer Considerations
- b) Material Properties of UO_2 and D_2O
- c) Specific Enthalpy
- d) Phases of a Material
- e) Quality
- f) Fuel Cooling Heat Transfer

ii) Full-Power Steady-State (FPSS) Fuel Cooling Condition

- a) Overall PHT Conditions
- b) FPSS Channel Cooling Conditions
- c) Axial Channel Heat Transfer
- d) Summary of FPSS Cooling Conditions

iii) Parametric Effects on Fuel Cooling

- a) Reactor Power Sensitivity
- b) Heat Transport System(HTS) Pressure Sensitivity
- c) HTS Temperature and Sub-cooling Margin Sensitivity
- d) HTS Flow Sensitivity
- e) Summary of Parametric Effects

iv) Fuel Cooling Transients

- a) Loss of Regulation - Loss of Reactivity Control
- b) Large Break Loss of Coolant Accidents (LLOCA)
- c) Single Channel Events
- d) Symmetric Feedwater Line Break

v) Fission Product Release Mechanisms

As can be seen from the topics listed above, the fuel cooling course is logically organized to progress from fundamental topics such as thermal properties, to heat transfer and thermalhydraulic subjects. Once these science fundamentals are covered, the remaining topics are designed to show how the fundamentals apply to fuel cooling conditions in a CANDU 600.

The applications section is logically divided into steady-state and transient conditions. The steady-state instruction consists of a study of NUCIRC[5] channel simulation data for PLGS at 100% Full Power (FP). The channel data consists of parameters such as power, flow, exit quality, exit temperatures, flow/power ratios, and feeder exit quality, displayed for each of the 380 fuel channels. Similar data is studied in detail for a single high power rated channel. This assists the trainee to develop conclusions concerning the various types of channel heat transfer and the onset of boiling. The concept of a flow to power ratio for each channel is used to explain the effects on the channel parameters listed above.

Prior to studying the effects of transient conditions on fuel cooling, a section is presented in which only a single CSP is varied (parametrically) from its steady-state value. For example, the effects of reactor power on other CSPs and supporting parameters is addressed over the range 0.5% FP to 120% FP. Other CSPs studied parametrically are Primary Heat Transport (PHT) Pressure, PHT Temperature, PHT Subcooling Margin, and PHT Flow. PHT Flow is not a CSP but it serves to illustrate certain feedback effects. The trainee is able to appreciate how the variation of only one parameter affects fuel cooling and causes feedback effects on other parameters. This training prepares the student for the more difficult concepts found in transient conditions.

Transient conditions are presented by studying the effects of both primary and secondary side events on fuel cooling. The transient events discussed in lectures and presented as simulator exercises include: Loss of Regulation, Large Break LOCAs, Single Channel Events (Flow Blockage, Feeder breaks), and Symmetric Loss of Feedwater to all boilers. This stage in the course integrates the theory presented with practical simulator exercises for the trainee to develop an appreciation of the mechanisms associated with maintaining an energy balance in the PHT.

3.4 Retention of Training Information

Training statistical studies have proven that retention of material drops quickly with time. It is estimated that two weeks after presentation in a lecture format, without any additional amplification, the average student will forget 75% of the training material.[6] Clearly, to improve the trainees retention, job-related amplification of the lecture material should be performed as early as possible following the initial training. In the case of fuel cooling, which is knowledge related to emergency operating response, job-related amplification can be performed through the use of a nuclear training simulator.

The format of the training has a large impact on the retention of the training material. Statistics again indicate that the closer the training can get to the actual performance of the function, the greater is the ability to retain the material. Figure 2 shows how retention varies with the learning format. At the low end of the scale, at 10% retention, is learning by reading. If we both see and hear the presented material a 50% retention rate is generally obtained. However, if the trainee can see, hear, verbalize and practice the skill, a 90% retention level is possible[6]. The methods used to instruct operations staff in fuel cooling follow this later approach whenever possible.

3.5 The Fuel Cooling Course Training Process

Mayfield and Bahrt[6] have recommended that nuclear training programs be designed around a "KNOW, SHOW, DO, AND REVIEW" training method. They call this method the KSDR process. This approach integrates knowledge based training with on-the-job training (OJT) such that OJT training occurs within close timing to classroom instruction. This approach maximizes the retention of the training. The OJT training component amplifies the training imparted through classroom methods.

Briefly the KSDR process follows these guidelines:

KNOW - present the classroom training that defines and provides what the trainee is to know.

SHOW - show the application of the skills learned in the classroom training.

DO - provide trainee practice sessions so that the skills can be mastered.

REVIEW - review the trainees skills by evaluating their knowledge retention.

The fuel cooling classroom training provides elements of the know, show, and review process. The nuclear training simulator provides the capability to "show and do" fuel

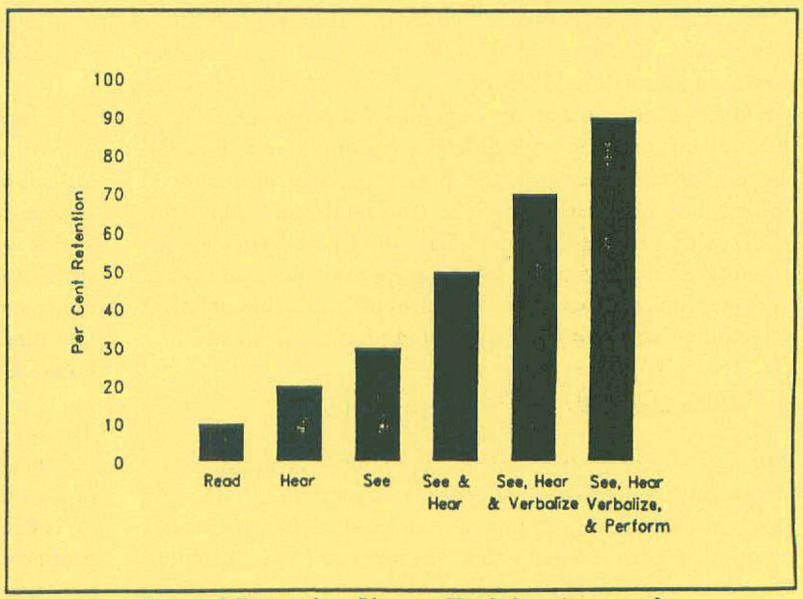


Figure 2 Retention Versus Training Approach

cooling transients that would otherwise be impossible to practise.

3.5.1 Classroom Training

Classroom lectures are presented covering each section of the fuel cooling course in the course content summary section 3.3. As mentioned earlier, the course material progresses naturally from science fundamentals to transient behaviour. Each section begins by defining the learning objectives (the Know component), so that the trainee clearly understands the scope of the knowledge requirements. This is followed by the lecture material itself.

A number of teaching aids are used in the presentation such as : actual channel components (Pressure tube and Calandria tube sections, normal and ruptured fuel sheaths, fuel bundle, and fuel pellet), overhead and slide illustrations, video tape of dryout research experiments, photographs from high temperature fuel research experiments, PC based fuel temperature simulations, and numerical examples. The lecture material and the visual aids constitute the classroom Show training component. In addition, each trainee receives a copy of the Fuel Cooling Basis Document that provides the detailed course reference material.

The classroom based Review process consists of several components. During the lecture presentations, as each section was completed, the material presented was summarized with a "Practical Significance" discussion. The objective of this is to summarize how the material just presented is directly applicable to the operators job of maintaining fuel cooling. As an example the section on Specific Enthalpy ends with the following:

Practical Significance

. **Specific enthalpy numerically represents the amount of energy that is stored in the coolant on a mass basis. If power was increased above FPSS, a temporary energy mismatch would occur between heat source and coolant heat sink. When a new steady-state is reached, the additional heat removed by the coolant would result in an increase in coolant enthalpy. If there is quality at the header outlet, this enthalpy increase gives rise to increased coolant voiding, decreased flow rates, and if severe enough, an impairment of the heat removal capability.**

This form of review, provided just following the detailed lecture material served to reinforce the knowledge objectives that where given at the beginning of the lecture session.

The final Review component consists of the course check-out examination. The questions require short answers or diagrams on material covered as knowledge objectives or directly from observations during the simulator exercises. A portion of the questions test for a degree of cognitive understanding of transient fuel cooling processes.

3.5.2 Simulator Training

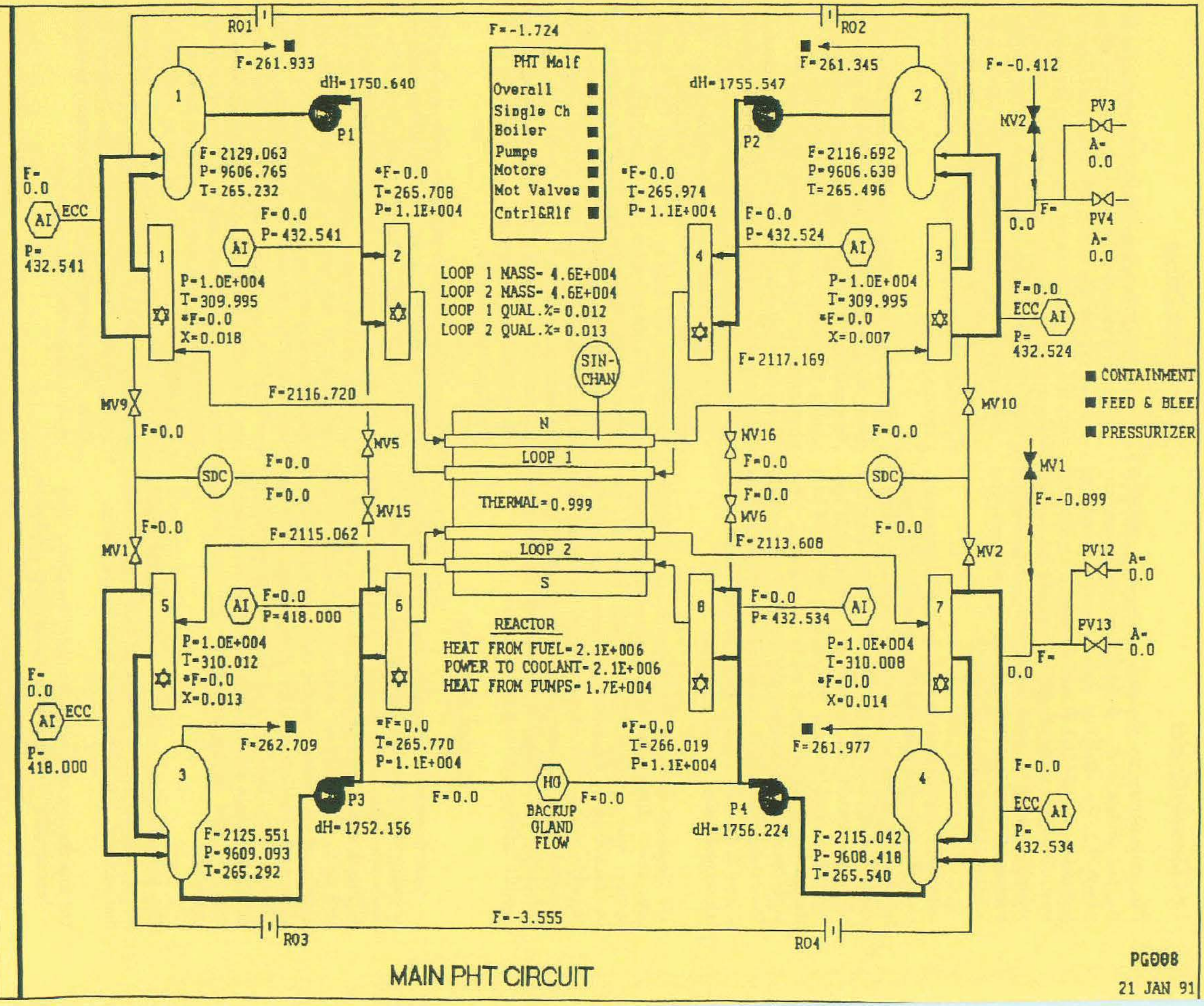
The simulator training provides the link between the lecture material and its application. More importantly, it allows the trainees to relate the theory with their own experience of operating the plant via interaction with the plant panels and displays during the fuel cooling transients. The simulator exercises provided both a Show and Do function for the training process. This was particularly valuable as the simulator provides the only practical opportunity for operators to witness emergency upset conditions and fuel cooling response.

The PLGS simulator was placed into service for training in June 1991. At present, this simulator is the most recently commissioned CANDU simulator and hence has some unique features not present on older CANDU simulators. In particular, the PC-based Instructor Facility (I/F) running under Microsoft Windows 3.0, allows the instructor and student to view and plot the transient response of simulation parameters not available to the operator on the plant panels. These parameters are any of the approximately 100,000 modelled parameters from the simulation software, computed in real time by the simulator VAX computers. There are a number of display formats including system flowsheet type displays (Figure 3) and a graphical recorder that interactively displays up to 48 parameters on 12 different trends (Figure 4). Figure 5 schematically shows the communication links between the I/F PCs, the panels, and the VAX computers. The I/F PCs have direct access to the common data base parameters calculated by the VAX based simulator software.

Process parameters such as the temperature of the fuel or the development of void are not directly observable on the control room panels. The I/F facility then allows the instructor to illustrate the fuel cooling transient processes and link in individual parameter behaviour with panel indications. In this way, a better understanding of the information displayed on the control room panels is obtained when linked with the detailed parametric behaviour shown on the I/F. As an example, the I/F display may show that the loop void fraction is suddenly rising. However, void fraction is not directly indicated on the control room panels. The operator is also able to observe from the Heat Transport System panel that the PHT pump ammeters begin to oscillate at the same time as the I/F shows sudden void development. The I/F also shows a drop in PHT loop flow and the panel CRTs indicate a Low Heat Transport Flow alarm. This is an example of the I/F capability to reinforce understanding of the transient process.

The actual simulator training is provided as a series of team exercises directly following coverage of the appropriate

Figure 3 Example Instructor Facility System Flowsheet Display



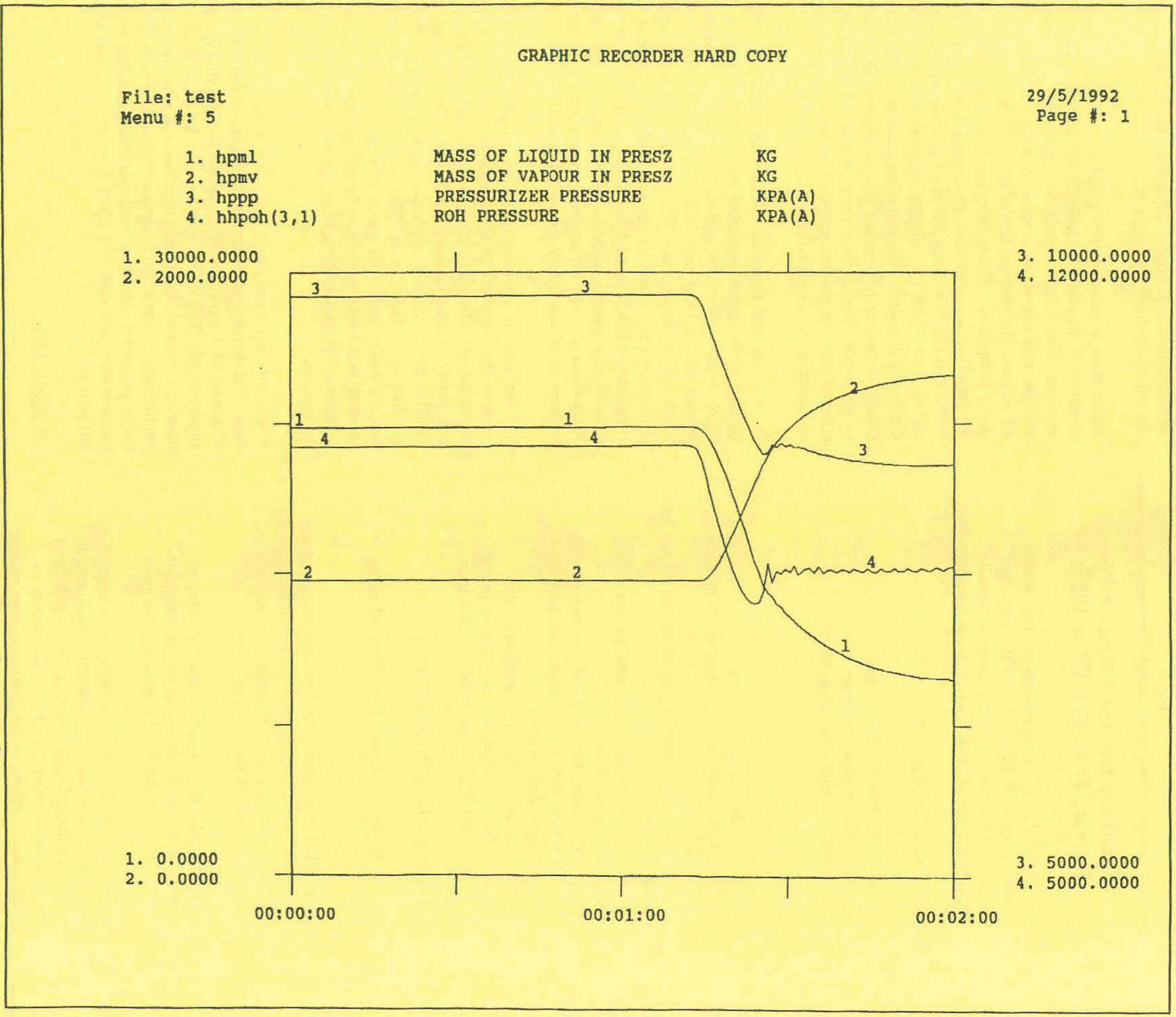


Figure 4 Graphic Recorder Trend Example

Table 2

Simulator Exercise : Reactor Power Increase From 80% FP to 100% FP

OBJECTIVE: To show how increasing reactor power from 80% FP to 100% FP affects fuel cooling. To show how other thermalhydraulic parameters are affected by increasing reactor power.

INITIAL CONDITIONS:

1) 80% Full Power Steady-State
2) All 4 HTS pumps operating
3) Turbine running - Alternate Mode

PROCEDURE:

a) Class is divided into 2 teams
b) Instructor facility (I/F) plotting set to plot file "FCOOL7"
c) Any channel parameters plotted on the I/F are for channel Q10
d)Trainees may display and hardcopy any DCC trends during exercise.
e) At start of exercise power will be raised using Reactor Power Rate and Setpoint Alternate Mode, with a rate of 2 (0.05%/second)
f) After reaching 100% FP steady-state the simulator will be frozen and all plots collected.
g) Copies of I/F plots are made for each team.

TEAM DISCUSSION QUESTIONS :

1) At what power is void first produced in the ROH?

2) a) What other parameters are contributing to the production of void aside from the power increase ?
b) What is causing these parameters to produce a feedback effect on fuel cooling?

3) a) Describe the magnitude and direction of change in the RIH subcooling margin transient.
b) Repeat 1) for the ROH subcooling margin.

4) Examine the I/F trends showing inner/outer fuel, fuel sheath, and coolant temperature transients at node 3 in channel Q10. What is the magnitude of temperature increase for each of the above components ? Where is the greatest energy storage taking place ?

lecture material. A typical simulator training exercise from the course is shown in Table 2.

Again these exercises follow a KSDR training process. The objective of the exercise is clearly defined at the start of the exercise. The initial simulator conditions and simulator exercise procedures are discussed in the classroom so that all trainees are clear as to the intent of the exercise (the Know component). The trainees are then divided into groups for the exercise so that each group may have access to one of the two I/F PCs. Each PC has a predefined plot file for the exercise which may display transient data for up to 48 different parameters. Any instructor actions (in this case the raising of reactor power) are clearly defined. Questions to be answered by each team are read out and 15 minutes is allowed for team preparation prior to leaving the classroom and starting the simulator exercise.

On entering the simulator facility the simulator will be running at the initial conditions given for the exercise (the Show component). The trainees then have 15 minutes to prepare and display any DCC trends to monitor on the panels during the exercise. The transient is then run and all observations are noted by the teams (the Do component). Hardcopies of DCC and I/F trends are taken and distributed to assist in preparing answers to the questions. During the 30 minutes allowed for answer preparation the instructor prepares overheads of all the trends collected.

For the Review component of the training, each group presents their answers to the simulator exercise using the trends and recorded panel observations (alarms, EMIs, trips and safety system actions) to backup their arguments. Finally the instructor discusses any important points overlooked by either team. This simulator based training process works well with teams of 4 to 5, allowing each member to actively participate in the exercise. In general, comments by trainees have been quite favourable towards the process.

While only one exercise example has been given here, a total of 12 different simulator exercises are undertaken. Out of a total of 4 days for the complete fuel cooling course, approximately 50% of the time is spent on these simulator training exercises. As in the lecture material, the knowledge requirements are gradually increased by starting with simple single parameter effects at steady-state and building to full transient exercises such as a 100% Loss of Feedwater from full power

4.0 SUMMARY

The fuel cooling course provides an effective basis for the Critical Safety Parameter Refresher Training program by preparing the trainee with the fundamental principles associated with fuel cooling for a CANDU 600. The course material follows a "Know, Show, Do, and Review" training

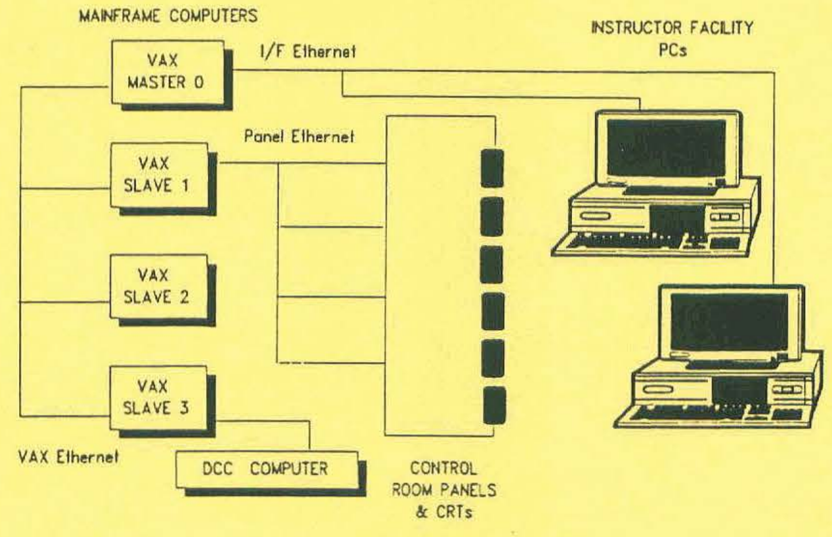


Figure 5 Schematic of Simulator Computer Communications

structure that serves to reinforce classroom lecture and visual material with simulator transient exercises. The timing of the exercises are such that they occur immediately following a particular lecture subject and so reinforce the retention of the theory with the application. On completion of the course, the trainee has undergone the necessary preparation for CSP training.

5.0 REFERENCES

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