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EMERGENCY RESPONSE TRAINING WITH THE BNL PLANT ANALYZER*

H.S. Cheng, J.G. Guppy, A.N. Mallen, and W. Wulff
Department of Nuclear Energy
Brookhaven National Laboratory
Upton, New York 11973
(516)282-2611

ABSTRACT

Presented is the experience in the use of the BNL Plant Analyzer for NRC emergency response training to simulated accidents in a BWR. The unique features of the BNL Plant Analyzer that are important for the emergency response training are summarized. A closed-loop simulation of all the key systems of a power plant in question was found essential to the realism of the emergency drills conducted at NRC. The faster than real-time simulation speeds afforded by the BNL Plant Analyzer have demonstrated its usefulness for the timely conduct of the emergency response training.

INTRODUCTION

The importance of operator training has been recognized from the outset of the commercial nuclear power development in the U.S. This is manifested in the early development of training simulators in parallel with the commercial nuclear power development. Unfortunately, the training of nuclear power plant operators to date has focused on normal operating conditions or minor upset conditions at most, mainly because of the limitations of existing training simulators.

For accident conditions the operators are instructed to follow documented emergency procedures. Emergency procedures are carefully developed sequences of the operator actions, designed to mitigate a large number of anticipated emergency scenarios. The ever increasing scope and complexity of the emergency procedures have increased the challenge to the nuclear operators of having to synthesize a response to unexpected events. In such an emergency, it is now possible for the reactor operator to be assisted by a reliable engineering simulator, often referred to as a nuclear plant analyzer (NPA).

Human errors have so far been the major contributing factor to the accidents in nuclear power plants. The recent Chernobyl accident in the Soviet Union is a case in point, which has heightened the public concern about the safety of nuclear power. One way to help regain public confidence in nuclear power is to intensify the emergency response training of the nuclear operators under accident conditions to mitigate any nuclear accident in the future. Needless to say, this cannot be done without a proper tool. The development of high-speed, high-fidelity NPAs for effective emergency response training should be promoted.

While plant performance monitoring can be done at real-time process speed, the prediction of plant responses to contemplated remedial actions in emergency situations requires much faster simulation speeds.[1] Furthermore, accidents usually take hours or days to complete. Thus, much faster than real-time simulation speeds of the NPA are not only desirable but also essential to the emergency response training.

Ideally, a low-cost facility based on a modern super-minicomputer and dedicated to a power plant or an institution, which can simulate plant transients and accidents accurately and realistically at very high speeds, is well suited to the emergency response training.

THE BNL PLANT ANALYZER

One such simulation facility that has been developed is the BNL Plant Analyzer (BPA),[2] currently set up for BWR plant simulations at up to seven times faster than real-time process speeds. The BPA is a state-of-the-art engineering simulator which models the nonhomogeneous, nonequilibrium two-phase thermal-hydraulics in the reactor vessel with a drift flux mixture model, the neutron kinetics with a point kinetics model, and the steamline dynamics with an adiabatic flow model. It also models the balance of plant (BOP), the control and

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MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED plant protection systems as well as the reactor containment, thus enabling a closed-loop system simulation (as shown in Fig. 1) without recourse to time-dependent boundary conditions.

The heart of the BPA is the two AD10 parallel processors, which are controlled by a PDP-11/34 host computer. The AD10 is specifically designed for time-critical systems simulations, utilizing the modern parallel processing technology with six task-specific microprocessors working in parallel, each equipped with its own program memory and extensive pipelining architecture to achieve very high simulation speeds.

The BPA can be operated locally via a 32-channel analog control panel as shown in Fig. 2 and a Tektronix storage oscilloscope, or remotely using an IBM personal computer with a color monitor. Operator actions and system malfunctions can be entered interactively from the keyboard or the control panel without halting the simulation. Input changes such as setpoints can also be entered from the keyboard. The output displayed on the color monitor is the transient response of a pair of output parameters. Furthermore, a total of 150 output parameters are stored as a function of time on disk during a simulation. Any pair of these can be displayed subsequently in the replay mode. The BPA can be operated continuously and indefinitely until halted by the user.

The unique features of the BPA that are important for the emergency response training are:

1. Much faster than real-time simulation speeds,
2. Fully interactive on-line simulation capability,
3. Complete closed-loop system simulation,
4. Remote-access operation via telephone lines, and
5. On-line display of transient responses.

THE NRC EMERGENCY RESPONSE TRAINING

The BPA has been used for emergency response training at the Operations Center of Nuclear Regulatory Commission (NRC). The purpose of the training is to assure the readiness of the NRC staff at the Operations Center to respond properly to a real accident at a nuclear power plant, if it should occur.

The Operations Center consists of several teams, each responsible for a particular functional duty. One such team is the Reactor Safety Team (RST) whose primary responsibility is to monitor the plant behavior, diagnose the abnormal plant conditions based on the data received from the affected plant, and make recommendations to the Executive Team (ET) for making decisions. Another important team is the Protective Measures Team (PMT) whose responsibility is to monitor the radiological release and to determine the seriousness of the accident for ET to declare the emergency status of the accident.

Accidents of concern to NRC such as the station blackout and the Anticipated Transients Without Scram (ATWS) have been simulated by the BPA for several hours, and the results were presented to the trainee every 10 minutes during an emergency drill. The trainee had no prior knowledge of the accident being simulated so that their responses during the drill would indicate the degree of merit of their judgments, knowledge and expertise as well as their mental attitude. At the end of the drill, the performance of each team was critiqued and recommendations were made for future improvements.

The current NRC emergency training program is based on a central telephone communication system at the training center. A separate room was used to set up the remote-access facility of the BPA for simulation of the accidents. The results of key parameters of safety importance were sent via telephone to the master communicator at the center, who then relayed the data to the communication officer of each team. If any team needed additional data, it would work in reverse order. The key parameters are the reactor power, reactor vessel pressure, water level, steam and feedwater flow rates, suppression pool level and temperature, containment pressure and temperature, containment radiation level, and containment sump level.

This manner of operation does not require an on-line and interactive simulation of the accident, even though the BPA was set up to do so. Thus, the simulated accident could be precomputed and stored on a tape or file, then replayed to the trainee. This has so far been the practice of the NRC emergency response training using the NPA of Idaho National Engineering Laboratory (INEL).[4] The advantage of the on-line interactive simulation capability of the BPA is that it allows the trainee to take part in the management of the accident. This is absolutely necessary for emergency response training of the operators.

EXAMPLE BPA APPLICATIONS

Examples of how the BPA was used to support the NRC emergency response training are given below. They include: (a) the simulation of a complete station blackout (CSB) in the Fermi-2 BWR/4 plant, and (b) the simulation of a long-term ATWS induced by the Main Steam Isolation Valve (MSIV) closure in the Browns Ferry-1 BWR/4 plant.

Simulation of Fermi-2 Station Blackout

The BPA was used to simulate the Fermi-2 BWR/4 plant behavior during a postulated CSB for the NRC emergency drill conducted on July 16 and 17, 1986. An off-site power failure was postulated to have occurred as a result of the crash of a DC-10 on its approach to Detroit Metro Airport. It was also assumed that all four diesel generators failed to start due to lubrication oil circulation system failure, thus constituting a complete station blackout.

As the consequence of CSB, the automatic plant protection system triggered generator load rejection, reactor scram, MSIV closure, recirculation pump trip, and the startup of High Pressure Coolant Injection (HPCI) and Reactor Core Isolation Cooling (RCIC) systems.

Without AC power, the drywell coolers and compressors as well as the pressure suppression pool (PSP) coolers became inoperable. Battery power was used to operate the HPCI and RCIC systems. The HPCI system was shut off by operator action 6.1 minutes into the accident as RCIC alone was adequate to compensate for boil-off due to decay heat. The RCIC system was used to control the Reactor Pressure Vessel (RPV) water level. To avoid extensive valve cycling, one safety/relief valve (SRV) was used to manually control the RPV pressure by alternating among 13 SRVs. Without PSP cooling, the steam discharge into the suppression pool was minimized by opening the SRV briefly to depressurize as necessary. Seventy minutes after the CSB, the RPV was depressurized to around 4 MPa to avoid potential drywell overheating.

The main concern in the first few hours of the accident was the potential overheating of the drywell and suppression pool. Figure 3 shows the temperature response of the drywell and PSP during the first three hours of the accident. The simulations have shown that core cooling can be maintained for as long as the battery power is available to operate RCIC. However, drywell and wetwell venting would be necessary after three hours from the loss of AC power unless the Residual Heat Removal (RHR) system can be restored.

This simulation has demonstrated the importance of containment modeling of the BPA for the emergency response training.

Simulation of Long-Term BWR/4 MSIV Closure ATWS

The BPA was also used to conduct a NRC emergency drill in response to a postulated ATWS in the Browns Ferry-1 BWR/4 plant. The postulated accident was assumed to be initiated by an inadvertent closure of all MSIVs due a calibration error by an Instrumentation and Control technician working on the main steamline radiation monitors. It was also assumed that the reactor failed to scram due to excess water in the scram discharge volume caused by a water lock in the control rod drive hydraulic system, thus constituting an ATWS.

Prior to the accident, the reactor was operating normally at full-power conditions. As a result of the MSIV closure, the vessel pressure increased rapidly causing a sharp increase in reactor power due to void collapse in the core. The plant protection system automatically tripped the recirculation pump. The SRVs operated automatically to open and close in accordance with their setpoints. The feedwater was lost after the MSIV closure due to the loss of steam to the feedwater turbine. The low-level setpoint then activated the HPCI and RCIC systems to inject cold water into the reactor vessel.

Following the Emergency Procedure Guidelines (EPG),[5] the SRV bank 2 was opened to reduce the RPV pressure so as to avoid extensive SRV cycling and to increase the PSP heat capacity limit. The RPV pressure was kept above 4.8 MPa throughout the ATWS to avoid the activation of the low-pressure ECCS systems, which would otherwise complicate the situation. The HPCI was used to control the RPV water level above the top of active fuel (TAF). This helped reduce the reactor power in the early stage of the ATWS, thus minimizing the heat dumped to the PSP.

In the meantime, the PSP cooling was turned on to help keep the pool temperature below its heat capacity limit. At two minutes into the accident, the operator was assumed to start manual rod insertion (MRI), one at a time in accordance with the EPG. At five minutes into the accident, the Standby Liquid Control System (SLCS) was activated manually to inject borated water into the vessel. The MRI in conjunction with the SLCS achieved hot shutdown at approximately 18 minutes into the ATWS. From there on, it was primarily the long-term cooling of the decay heat to achieve cold shutdown.

The containment integrity was the main concern of the trainee for this accident. The PSP water temperature and level were the two safety parameters of most interest to the trainee. Figure 4 shows the long-term behavior of these two parameters. The maximum pool temperature of 78 C was reached at 1350 sec, and from there on, it started to decrease slowly after the reactor power had been reduced to below the total capacity of the RHR coolers.

CONCLUSIONS AND RECOMMENDATIONS

The experience in the use of BPA for the NRC emergency drills has shown the usefulness of the BPA as an effective and reliable tool for the emergency response training. We draw the following conclusions:

1. The behavior of reactor containment during an accident is important to the trainee for accident diagnosis. The containment must be modeled as an integral part of the simulation for the emergency response training.

2. The plant protection and control systems as well as the key safety systems must be modeled realistically in a closed-loop simulation of the plant in question.

3. The simulation speed should be at least the same as real-time process speed, and preferably much faster than the real time to permit the involvement of the trainee in accident mitigation.

4. The remote-access operation of the BPA is a necessary capability for the emergency response training.

5. The on-line, interactive simulation capability of the BPA with graphic display is highly desirable.

The current NRC practice in emergency response drills is limited to a passive training in that the trainees are not actively involved in the emergency management of the accident. While it may be appropriate for NRC to play a passive role in the maneuver for accident recovery, the trainee can gain more insight about the accident, if more actively involved. Thus, we recommend that the emergency drill be conducted in an on-line, interactive mode with graphic display terminals for each team, especially the RST and ET, so that the trainee can take part in the emergency management of the accident.

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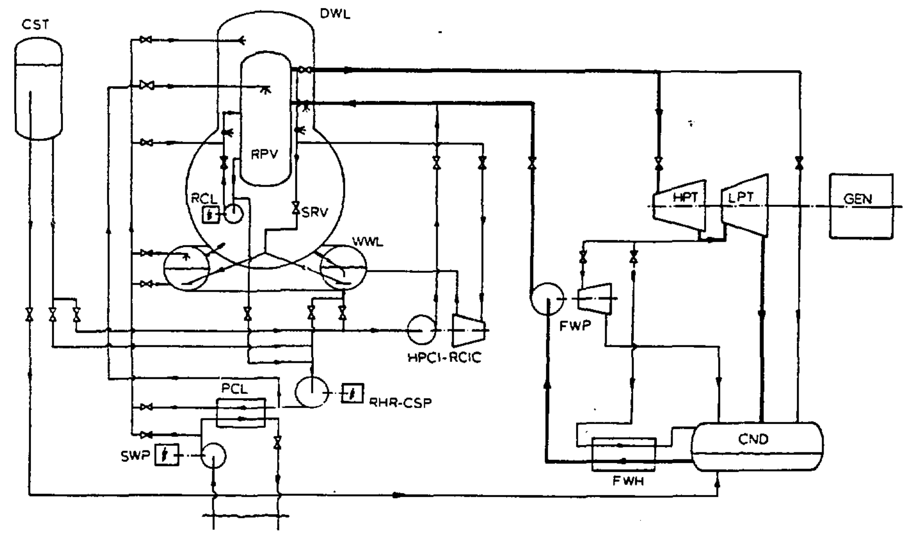

Figure 1 BWR-4/Mark I Flow Schematic

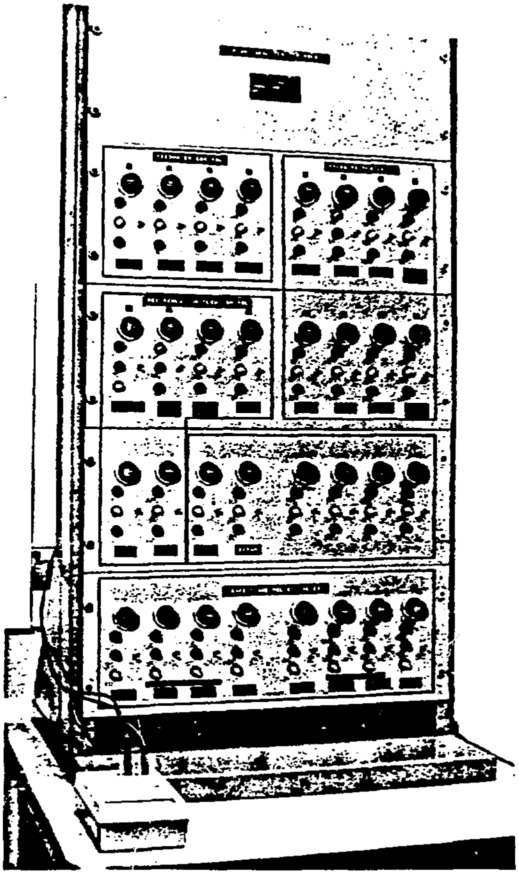

Figure 2 Control Panel

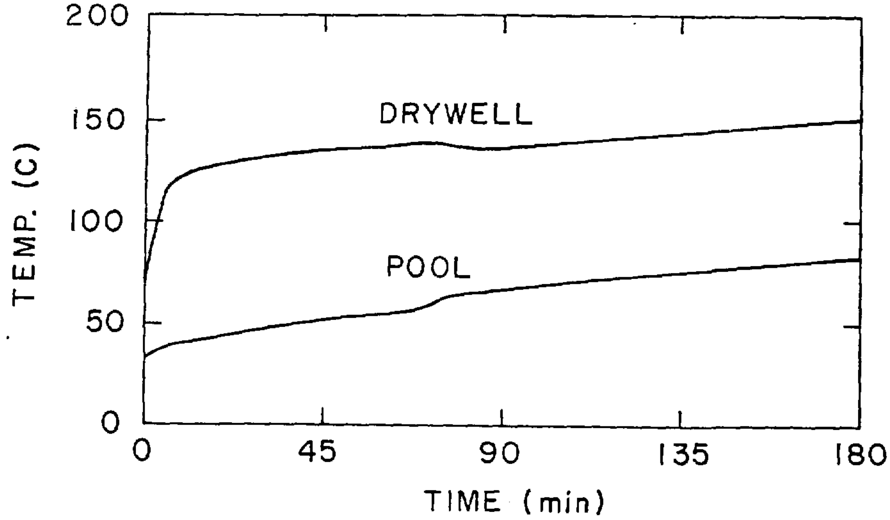

Figure 3 Temperature Response of Drywell and Pressure Suppression Pool During a Complete Station Blackout

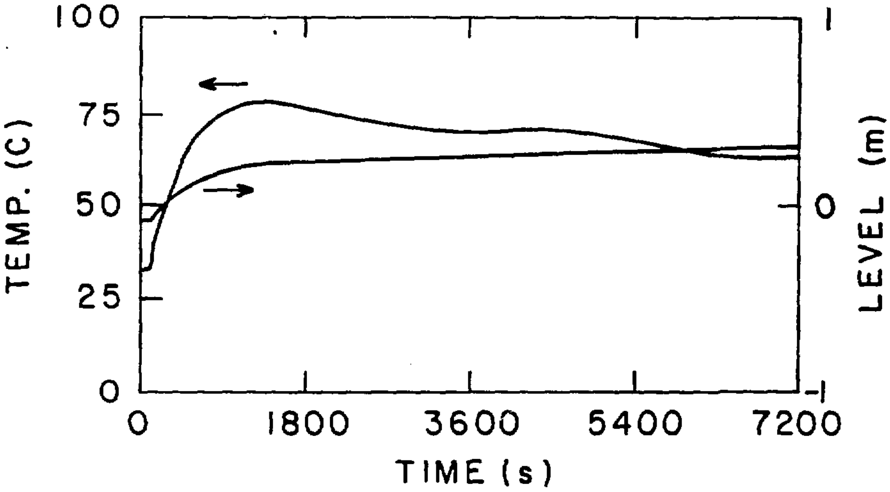

Figure 4 Long-Term Behavior of Suppression Pool Temperature and Level During the MSIV-ATWS