# 18G Design Development and Validation Testing

## 18G.1 Introduction

As part of the ABWR design development, a five-year (1986–91) program was undertaken for the purpose of "studying the application of man-machine technologies to enhance the efficiency of operation control of nuclear power plants". During the course of this program, a variety of tests, studies and evaluations were performed in a number of areas of control room equipment design. These studies and evaluations culminated in the fabrication and testing of prototype control room human-system interface (HSI) equipment designs at two separate facilities. The results of this development program form the basis for the ABWR control room HSI design.

The purpose of this report is to provide summary descriptions of the studies, evaluations and validation testing performed during the joint study program. The studies, evaluations and testing, other than the prototype validation testing, are described in Subsection 18G.2 and the validation testing of the control room equipment prototypes is discussed in Subsection 18G.3.

## 18G.2 Design Development

### 18G.2.1 General

The program research described in this section is discussed under the following subtitles:

(1) Standard control room design features

(2) Allocation of functions

(3) Operator work load

(4) Other Areas of Interest

### 18G.2.2 Standard Control Room Design Features

There are eighteen standard design features for the ABWR control room HSI which are listed as follows:

(1) A single, integrated control console staffed by two operators; the console has a low profile such that the operators can see over the console from a seated position.

(2) The use of plant process computer system-driven on-screen control video display units (VDUs) for safety system monitoring and non-safety system control and monitoring.

(3) The use of a separate set of on-screen control VDUs for safety system control and monitoring and separate on-screen control VDUs for non-safety system control and monitoring; the operation of these two sets of VDUs is entirely independent of the

process computer system. Further, the first set of VDUs and all equipment associated with their functions of safety system control and monitoring are divisionally separate and qualified to Class l-E standards.

(4) The use of dedicated function switches on the control console.

(5) Operator selectable automation of pre-defined plant operation sequences.

(6) The incorporation of an operator selectable semi-automated mode of plant operations, which provides procedural guidance on the control console VDUs.

(7) The capability to conduct these pre-defined plant operation sequences in manual mode.

(8) The incorporation of a large display panel which presents information for use by the entire control room operating staff.

(9) The inclusion on the large display panel of fixed-position displays of key plant parameters and major equipment status.

(10) The inclusion in the fixed-position displays of both 1E-qualified and non-1E qualified display elements.

(11) The independence of the fixed-position displays from the plant process computer.

(12) The inclusion within the large display panel of a large video display unit which is driven by the plant process computer system.

(13) The incorporation of a "monitoring only" supervisor's console which includes VDUs on which display formats available to the operators on the main control console are also available to the supervisor.

(14) The incorporation of the safety parameter display system (SPDS) function as part of the plant status summary information which is continuously displayed on the fixed-position displays a portion of the large display panel.

(15) The use of fixed-position alarm tiles on the large display panel.

(16) The application of alarm processing logic to prioritize alarm indications and to filter unnecessary alarms.

(17) A spatial arrangement between the large display panel, the main control console and the shift supervisors' console which allows the control room operating crew to view the information presented on the large display panel from the seated position at their respective consoles.

(18) The use of VDUs to provide alarm information in addition to the alarm information provided via the fixed-position alarm tiles on the large display panel.

Specific studies and evaluations done in support of these standard design features, prior to the validation testing of the two prototype designs, are discussed in the following paragraphs of this subsection.

### 18G.2.2.1 Control Console

Analyses of trends in control panel configuration, including GE's NUCLENET control room design, as compared to older designs, were completed. The results of operating crew task analyses were used to aid in control panel layout studies and support evaluations of the operating crew size. Studies of the feasibility of main control panel size reduction and consolidation of two or more panel functions into one panel were completed. Other studies were made of alternate arrangements of control and monitoring equipment on the console.

### 18G.2.2.2 Video Display Units (VDUs)

Studies of trends in VDU uses in control rooms were made. Since VDUs have been used previously, not only in control rooms of other industrial processing plants but in nuclear plants as well. The issue of concern was not whether to use these devices but how to use them most efficiently. Studies of VDU control devices were completed and development testing of on-screen control devices was done. Figure 18G-1 shows some data developed during evaluations of the precision obtainable with touch screens. Means of enhancing the reliability of certain types of VDUs (e.g., CRTs) were also studied. An evaluation was made of the merits of different types of computer input devices (i.e., light pens, trackballs, mice and touch-screens).

Methods of optimization of VDU screen systems for aiding operator responses (a) during normal plant operation, (b) after discovery of an anomaly, (c) after a scram and (d) in the event of an accident were examined. Screen selection methods and methods of integrating the use of the console VDUs with that of the large display panel were also reviewed. As part of this study, operator decision making processes during each of the above-mentioned plant conditions were analyzed.

### 18G.2.2.3 Plant Operations

Automation of normal plant operations (e.g., startup, shutdown, power maneuvers) was evaluated for potential ABWR application to enhance operability and minimize the burden on the operating staff. The extent of automated operations was carefully selected to ensure that the primary control of plant operations remains in the hands of the operators. The general approach

which was followed in selecting the operations to be automated consisted of the following steps:

(1) Task analyses were performed which defined the type and sequence of tasks that are required for accomplishing normal plant operations. These analyses were done assuming completely manual operations (i.e., no automation).

(2) From these task analyses, assessments were made of the operator workload, the complexity of the operation, the degree of repetitiveness and tedium in the operation and the feasibility of automating the operation.

(3) From these evaluations, it was concluded that, for a given plant system, many tasks are conducted for the purpose of changing the operational status of that system (e.g., operation of the residual heat removal system in the suppression pool cooling mode). For many of these normal system operations, sequence master control functions were defined. This approach was applied to both safety-related and non-safety-related system operations. Dedicated sequence master control switches were incorporated into the main control console design for initiating these automation sequences. The sequence master control switches are located in the hard switch panels on the horizontal desk area of the main control panel.

(4) Operational changes in safety systems that require only minimal operator action (e.g., changing the position of the reactor mode switch) were not automated. Safety system mode changes are performed on the ABWR in a manner similar to conventional BWR operations.

(5) For tedious or repetitive operations, special plant level automation functions were incorporated into the control room design. Examples of such automated functions include control rod operations during startup (e.g., rod selection and movement of control rods to maintain the vessel heatup rate), changes in reactor recirculation flow controller setpoints to accomplish daily load following maneuvers, changes in the reactor pressure setpoint during normal heatup and cooldown of the reactor and transfers in the operational status of the reactor feed pumps.

In accordance with the above studies, the semi-automatic mode was provided to give the operator(s) automatic guidance for accomplishing the desired normal changes in plant status. In the semi-automatic mode of operation, the plant computer provides no control actions. The operator must activate all necessary system and equipment controls for the semi-automatic sequence to proceed.

A manual mode of operation was also retained in the design. The manual operating mode is equivalent to the manual operation of conventional BWR designs and is available at the operator’s discretion or when automatic operation is terminated due to abnormal plant conditions.

### 18G.2.2.4 Large Display Panel

Studies of trends in control room information presentation methods (e.g., the Halden IPSO project as described in Report No. HWR-184) were completed. An analysis of questionnaire survey responses from the manufacturing sector of Japanese industry, including fossil fuels and other process plants, indicated that large displays or combinations of large displays and console-mounted VDUs are regarded as an effective means of providing information to operators in a broad spectrum of industrial plant environments.

### 18G.2.2.5 Independence of Fixed-Position Displays

This feature was adopted as a result of evaluations of plant operations during periods of postulated equipment failures and studies of trends in fixed-position display designs throughout industry. The incorporation of the fixed-position displays provides redundancy in display modes and contributes to the ability to safely shut down the plant if the process computer system is lost.

### 18G.2.2.6 Large Video Display

Studies of large screen utilization trends and of how large screens can best be integrated with VDUs in the control room were performed. The large screen study topics are summarized in Table 18G-1.

Traditionally, during planned outages and at other times, large blackboards have been used, on a temporary basis, in control rooms to display information regarding the status of important ongoing processes. As summarized in Table 18G-1, large screens can be utilized as substitutes for these blackboards. Also, large screens can be used as industrial television monitors (ITV) to make local checks during normal plant operation. In addition, large screens can be used to display CRT screen formats to the entire control room crew simultaneously.

The technology for large screens was also reviewed. Video projectors and displays using liquid crystal projection, luminous source, liquid crystal transmission, LED and CRT technology were compared from the standpoint of screen size, optimum viewing distance, resolution, brightness and update speed.

### 18G.2.2.7 Alarms

Studies of alarm system technologies, the uses of alarms in control rooms and alarm prioritization and suppression methods to reduce the information load on the operating crew in times of upsets were carried out. Improvements in methods of distributing alarm functions between fixed-position indicators and VDUs were examined. Evaluations of VDU alarm presentation methods and formats were also done.

### 18G.2.2.8 Control Room Spatial Arrangement

Control room functions and arrangements were studied. Evaluations were made of the free space requirements of the control room. Regulations and legislation affecting areas of control room design such as comfort, human factors engineering and control room habitability considerations were reviewed.

## 18G.2.3 Allocation of Functions

Studies of trends in automation of operator functions in nuclear power plants were done. In the early days of the industry, improvements in the level of automation were related chiefly to maintenance of safety. Later, attention has come to be focused on the goal of reducing the burden on the operators. Accordingly, the task analyses discussed in Subsection 18G.2.2.3 "Plant Operations", were performed and allocation of functions were made as described in that subsection.

## 18G.2.4 Operator Work Load

Studies of operator work load were performed as part of the automation studies. The task analyses performed on both system and plant operations were used to develop time histories of operator work load for both normal and abnormal operations. As discussed previously, the operator work load information was an important part of the basis for decisions regarding automation.

## 18G.2.5 Other Areas of Interest

Other study areas, not directly contributing to the development of the standard design features discussed in Subsection 18G.2.2, were also pursued. These other study areas included the following:

(1) Configuration of the HSI system:

  (a) Relation of process computer to other components

  (b) Data highway design

(2) Functions and configurations of plant data management systems:

  (a) Core management

  (b) Operation management

  (c) Maintenance management

  (d) Security controls

  (e) Management of documentary information

  (f) Management of site operation records

(3) Operator assistance technologies:

(a) Diagnosis

(b) Planning

(c) Routine maintenance assistance

(4) Audio response systems:

(a) Speech recognition

(b) Speech synthesis

## 18G.3 Validation Testing

### 18G.3.1 General

During the summer of 1990, a systematic program of testing on two separate prototypes was performed to validate the key features of the ABWR main control room equipment design. Three teams of three licensed plant operators each were used for the tests. The prototypes were fabricated according to a conceptual design prepared during the development program discussed in Section 18G.2.

#### 18G.3.1.1 General Test Description

**Schedule:** The tests were conducted per the schedule shown in Table 18G.2.

**Test Teams:** The test teams were composed of a utility's operations personnel from operating boiling water reactors. Each team consisted of three individuals; one senior operator, one operator and one shift supervisor. The test sequences were conducted with the two operators at the main control console and the supervisor located at a desk about 4.5m behind the operators.

**Data:** Test data were collected in the form of (a) performance measures: these consisted of observations of operator actions and behavior during the tests and examination of video tapes taken during the tests, and (b) opinions, which took the form of post-test operator interviews and questionnaires filled out by the operators during the post-test debriefing sessions. The objective of the data collection methods was to obtain as complete a record as possible of the operator's interactions with the HSI model and each other as they reacted to the simulated plant conditions and of the operator's reactions to the equipment design.

**Equipment Configuration:** The control room prototypes included the following key design features, which are correlated to the ABWR standard design features listed in Section 18G.2.2:

(1) A single, integrated control console staffed by two operators; the console has a low profile such that the operators can see over the console from a seated position [Standard Design Feature (1)].

(2) The use of on-screen control video display units (VDUs) for safety system monitoring and non-safety-related system control and monitoring [Standard Design Feature (2)].

(3) The use of a separate set of on-screen control VDUs for safety system control and monitoring [Standard Design Feature (3)].

(4) The use of dedicated function hardware switches on the control console [Standard Design Feature (4)].

(5) Operator-selectable automation of predefined plant operation sequences [Standard Design Feature (5)].

(6) The incorporation of an operator-selectable semi-automated mode of plant operations, which provides procedural guidance on the control console VDUs [Standard Design Feature (6)].

(7) The capability to conduct these pre-defined plant operation sequences in an operator manual mode [Standard Design Feature (7)].

(8) The incorporation of a Large Display Panel, located behind the main control console, which presents information for use by the entire control room operating staff [Standard Design Feature (8)].

(9) The inclusion on the Large Display Panel of key plant parameters and major equipment status displayed at fixed positions on the panel [Standard Design Feature (9)].

(10) The inclusion on the Large Display Panel of critical plant parameters which are continuously displayed at fixed positions on the panel [Standard Design Features (10) and 14)].

(11) The independence of the fixed-position displays from the process computer [Standard Design Feature (11)].

(12) The inclusion on the Large Display Panel of a large video display unit to supplement the information presented on the fixed displays [Standard Design Feature (12)].

(13) The use of fixed-position alarm tiles on the Large Display Panel [(Standard Design Feature (15)].

(14) The application of alarm processing logic to prioritize alarm indications and to filter unnecessary alarms [Standard Design Feature (16)].

(15) Spatial arrangement between the large display panel, the main control console and the supervisors' console which allow the entire control room crew to monitor the information presented on the large display panel [Standard Design Feature (17)].

(16) The use of VDUs to provide low-level alarm indications and detailed information on the alarms which are presented on fixed-position alarm tiles [Standard Design Feature (18)].

Standard Design Feature (13) was not specifically incorporated in the prototype testing program. The essential feature of the supervisors' console which was modelled was its lack of control capability.

**Test Items:** The testing consisted of exercising a variety of plant operation scenarios which were generated by a dynamic simulator. The operating crew would respond to the changing plant conditions during the scenarios by monitoring the information which was available to them and manipulating the appropriate controls. The scenarios included in the test program are summarized in Table 18G-3. Video tapes were taken of the operators as the scenarios were being run.

### 18G.3.1.2 Test Results

The operator interviews and questionnaire data collected during debriefing sessions at both test facilities, plus the video tape evaluations, fully supported the key design features summarized previously in Section 18G.3.1.1. Specific, relevant results regarding those key features are summarized below.

(1) Under normal, abnormal and accident conditions it is easy to comprehend the plant condition from the information presented on the Large Display Panel (LDP).

(2) The LDP contributes much to improve overall monitorability of the plant.

(3) The fixed position displays and large alarm tiles on the LDP are very effective in promoting understanding of the conditions during accidents.

(4) The large variable display on the LDP is watched more often during normal operation than during abnormal operation. However, in general, the large variable display is not watched as often as the fixed position displays.

(5) Suggested formats for display on the large variable screen include trends, plant summary and Safety Parameter Display System (SPDS) information during abnormal/ accident events and alarms.

(6) Work space and sitting posture at the Main Control Console are good, in general.

(7) Work space on the tested Main Control Console arrangement would be crowded if more than two operators were required at the console.

(8) The presentation of top-level, fixed position alarms on the LDP is very effective.

(9) The display of individual alarms on the VDUs is good.

(10) The size of the CRT screens was preferred over that of the flat panel devices. However, the touch screen operations on the flat panels were rated as better than on the CRTS.

The operator's comments focused on those design features which were new to them. Hence, the comments dealt with the LDP, alarm presentation scheme, main console configuration and operations with touch screens. There were little or no comments regarding the automated, semi-automated or manual operating modes or the hardware switches because of the particular operator's experience with such features.

The direct operator feedback and evaluation of the test sequence video tapes also provided much additional data which was relevant to the specific details of the equipment employed and the scope of the prototype control console dynamic simulation. Although these additional test results are not pertinent to the evaluation of the ABWR key features described in Section 18G.2.2, they are being addressed and incorporated into the ongoing control room.

## Table 18G-1 Large Screen Utilization Topics

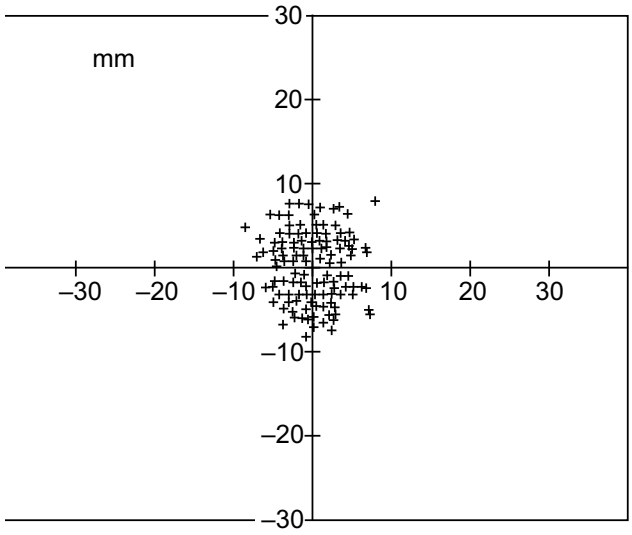
| | | During Planned Outages | During Startup & Shutdown | During Normal Operation | During Abnormalities / Accidents |
|---|---|---|---|---|---|
| BLACKBOARD | SUBSTITUTES | • Status of system isolation<br>• Status of refueling<br>• Status of incoming power | • Startup/shutdown curves | • Status of equipment repair<br>• Schedule tables<br>• Load-following curves | • Weather / environment<br>• Instrumentation during accidents |
| USED CONCURRENTLY | ASITV | • Local Equipment status<br>• MSIV room<br>• Turbine operating floor, etc. | • Status of startup and shutdown auxiliaries<br>• Drywell inspection status | • Radwaste control room, etc. | • Local equipment status |
| | ASVDU | • Plant summary<br>• Ordinary alarms<br>• Trend displays | • Plant summary<br>• Ordinary alarms<br>• Trend displays<br>• Summary display of core status | • Plant summary<br>• Ordinary alarms<br>• Trend displays<br>• Summary display of core status | • Emergency alarms<br>• Plant summary<br>• ECCS summary<br>• Trend displays |

## Table 18G-2 Validation Test Schedules

| | Prototype Facility A | Prototype Facility B |
|---|---|---|
| First Test Team | June 6–8, 1990 | June 11–18, 1990 |
| Second Test Team | June 25–27, 1990 | July 10–12, 1990 |
| Third Test Team | July 26–27, 1990 | July 23–25, 1990 |

## Table 18G-3 Test Scenarios and Evaluations

| Test Case Classification | Test Scenarios | Key Items of Evaluation |
|---|---|---|
| Normal Startup/Shut down and Surveillance | Reactor Critical<br>Reactor Temperature Increase<br>Power Adjustment to Support Drywell Inspection<br>Generator in Parallel<br>Condensate/ Feedwater System Alignment<br>Power Increase<br>Generator Trip/Turbine Trip<br>Reactor Core Isolation Cooling System Surveillance | 1) Transition to manual from automated operations.<br>2) Hardware switch operation capability.<br>3) Functions identified for implementation using hardware switches.<br>4) Adequacy and effectiveness of displayed information for monitoring.<br>5) Location of displayed information.<br>6) Adequacy and need for expansion of operator support function(s). |
| Equipment Trips | Reactor Feed Pump Trip<br>Reactor Internal Pump Trip<br>Condensate Pump Trip | Items 2) through 5), plus<br>7) Large display panel effectiveness.<br>8) Alarm system effectiveness. |
| Scrams and Accidents | MSIV Closure<br>Loss of Preferred Power<br>Loss-of-Coolant Accident | Items 2) through 5) and 7) through 8), plus<br>9) Appropriateness and effectiveness of level of automation after a scram. |
| Computer Failure | Loss of Automated Operating Mode<br>Loss of all Process Computer supported VDUs | Items 1) through 5), plus<br>10) Operability by sub-loop automation. |




DISTRIBUTION OF TOUCH POINTS

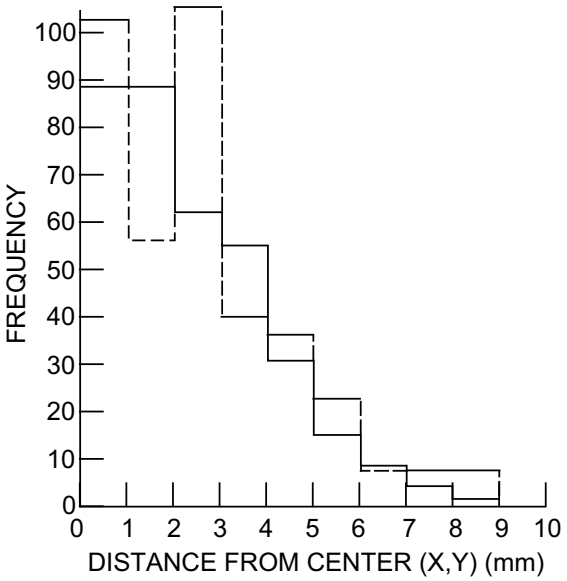



**Figure 18G-1 Typical Data from Touch Screen Precision Tests**