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DEVELOPMENT OF BWR AND PWR EVENT DESCRIPTIONS FOR NUCLEAR FACILITY SIMULATOR TRAINING*

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ABSTRACT

A number of tools that can aid nuclear facility training developers in designing realistic simulator scenarios have been developed. This paper describes each of the tools, i.e., event lists, events-by-competencies matrices, and event descriptions, and illustrates how the tools can be used to construct scenarios.

INTRODUCTION

Background

The U.S. Nuclear Regulatory Commission (NRC) is responsible for: prescribing uniform conditions for licensing individuals as operators of nuclear production and utilization facilities; determining the qualifications of these individuals; and issuing licenses to such individuals (Ref. 1). This operator licensing system is comprised of both a written and an operating examination. The operating exam is further divided into two parts, oral and simulator. These three examinations are oriented towards determining whether the applicant for an operator's license has learned to operate a facility competently and safely, and additionally, in the case of a senior reactor operator (SRO), whether the applicant has learned to direct the activities of licensed operators competently and safely.

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Guidance to the facility licensee in regards to the simulator exam is detailed in paragraph 23 of part 55 to title 10 of the Code of Federal Regulations (Ref. 2). It states that the simulator examinations for reactor operator (RO) and SRO applicants are generally similar in scope and require each applicant to demonstrate an understanding of and the ability to perform the actions necessary to accomplish a list of 13 items. Paragraph 23 also says that the content is identified, in part, from information in the final safety analysis report, operating manuals, facility license and license amendments, licensee event reports, and learning objectives derived from a systematic training analysis performed by each facility licensee.

NUREG-1021 (Ref. 3) provides the policy and guidance to NRC operator licensing examiners and establishes the procedures and practices for the examination and licensing of applicants for NRC operator licenses. It is intended to assist NRC examiners and facility licensees to understand the exam process better and to provide equitable and consistent administration of examinations to all candidates for either RO or SRO licenses by NRC examiners. Guidance and policy on the administration, scope, and objectives of the operating and simulator exams are detailed in examiner standards (ES) 301 - 305 and 501 - 502, respectively.

Overview

In 1982, the Office of Nuclear Reactor Regulation at the NRC started a program which is oriented towards improving the validity of the operator licensing examination and the reliability of the exam process. Spilberg described the project and the issues and problems which are being addressed at a previous Training of Nuclear Facility Personnel symposium (Ref. 4). Oak Ridge National Laboratory has recently completed a research project which was peformed in support of this NRC program. The purpose of the effort was to develop a set of tools for examiners to use during the construction of scenarios for boiling-water reactor (BWR) and pressurized-water reactor (BWR) simulator exams. The focus of the project was on the generation of

BWR and PWR event lists, a mapping of the competencies which are scored on the simulator examination to the events, and the design of off-normal, i.e., abnormal and emergency, event descriptions. While these tools were created for use by the NRC in operator licensing, they seem to be applicable to the nuclear power industry as a whole and can be used by a facility's training department in its design of scenarios for simulator training.

SCENARIO PREPARATION TOOLS

Event Lists

Four event lists consisting of 87 events were constructed. The breakdown of these events in terms of reactor type and severity of event are as follows:

a. BWR-abnormal - 26
b. BWR-emergency - 22
c. PWR-abnormal - 26
d. PWR-emergency - 13

The events were selected based on the following criteria:

a. The event should be a significant casualty or abnormality.
b. The event should be able to be replicated on the majority of plant-referenced simulators in use today.
c. The event should be able to be effectively administered and evaluated within the time limits of a typical simulator exam.
d. The event should provide a useful base upon which to evaluate candidate eligibility for licensure.

The source data for the generation of the event lists consisted of the Institute for Nuclear Power Operations (INPO) job-task analysis, American National Standard 3.5 (Ref. 5), an event list derived during an NRC examiners workshop**, emergency procedure guidelines (EPG), and other related references. Tables 1 - 4 present the four event lists.

Events-By-Competencies Matrices

The eight competencies, as described in revision 2 to ES-302 in NUREG-1021, were mapped to the BWR and PWR events. Each event was

Table 1. Boiling-Water Reactor Abnormal Events

Master Feedwater Controller Failure
Nuclear Instrument Channel Failure
Rod Position Indicating System Failure
One Reactor Recirculation Pump Trip
Trip of Both Recirculation Pumps
Recirculation Pump Seal Failure
Scoop Tube Lock
Increasing Suppression Pool Temperature
Drywell Cooler Failure
Stuck Control Rod
Uncoupled Control Rod
Control Rod Drift
Control Rod Drive Hydraulic Pump Trip
Loss of All CRD Hydraulic Pumps
CRD Flow Control Valve Failure
Condensate or Condensate Booster Pump Trip
Reactor Feedwater Pump Trip
Loss of Feedwater Heater Extraction Steam
Stator Cooling Water Pump Trip
Steam Jet Air Ejector Malfunction
Loss of One Reactor Protection System Bus
Area Radiation Monitoring System Alarm
High Main Steam Line Radiation
High Ventilation Exhaust Radiation
Inadvertant HPCI or RCIC Initiation
Loss of One RBCCW Pump

Table 2. Boiling-Water Reactor Abnormal Events

Reactor Scram With MSIVs Open
Reactor Scram With MSIVs Closed
Loss of Shutdown Cooling
Gross Fuel Failure
Excessive Reactor Cooldown Rate
Anticipated Transient Without Scram
Stuck Open Main Steam Safety/Relief Valve
Small Break Loss of Coolant Accident
Reactor Coolant Leakage Outside Primary Containment
Jet Pump Failure
High Suppression Pool Water Temperature
Main Turbine or Generator Trip
Main Turbine or Generator Trip Without Bypass Valves
Loss of Condenser Circulating Water
Loss of Feedwater System
Loss of All High Pressure Feedwater
Loss of Plant Control/Instrument Air
EHC Pressure Regulator Failure (All Valves Open)
Loss of Nuclear Service Water
Loss of Reactor Building Closed Cooling Water System
Loss of Off-Site Power
Loss of All AC Power (Station Blackout)

Table 3. Pressurized-Water Reactor Abnormal Events

Loss of RCS Makeup
Loss of Automatic Pressurizer Pressure Control
Failure of Pressurizer Spray Valve
Loss of Automatic Pressurizer Level Control
Progressive Failure of No. 1 Seal in RCP
Failure of Steam Dump to Open
Steam Generator Safety Valve Fails Open and Fails to Reseat
Steam Generator Level Control Failure High/Low
Dropped Control Rod
Inoperable or Stuck Control Rod
Inadvertant Boration at Power
Inadvertant Dilution at Power
Failure of N-44 High
Loss of Instrument Air
Failure of Turbine to Runback Automatically and Manually
Failure of Impulse Pressure Transmitter (Low)
Steam Generator Tube Leak Within Capacity of Charging Pump
Loss of Condenser Circulating Pump
Criticality Outside Expected Band
Failure of Loop Temperature Instrumentation High/Low
Loss of One Main Feedwater Pump at High Power
Spontaneous Opening of the Main Generator Output Breakers
Loss of RCP Without Reactor Trip
Main Steam Leak Inside Containment
Rupture in Letdown Nonregenerative Heatexchanger to CCW
Failure of Pressurizer Control Bank Heaters

Table 4. Pressurized-Water Reactor Emergency Events

Reactor Trip
Large Break LOCA - Reactor Trip With Safety Injection
PZR/PORV Failure to Open
Steam Generator Tube Rupture
Failure of Main Turbine to Trip
Small Break Loss of Coolant Accident
Anticipated Transient Without Scram
Loss of Auxiliary Feedwater - Inadequate Core Cooling
Loss of Off-Site Power
Station Blackout - Loss of All AC Power
Control Room Fire Requiring Evacuation
Main Steam Break Inside Containment
RHR LOCA - Complete Loss of RHR

analyzed in an iterative fashion by job position, i.e., RO, SRO, and balance-of-plant operator (BOP). The purpose of this analysis was to determine whether the event provided enough opportunity for the examiner to observe each of the competencies. Four events-by-competencies matrices were arranged based upon the results of the analyses. In each matrix the events are the rows and the competencies are the columns; an "X" appears in a cell of the matrix if it was determined that a competency is exercised by a specific operator during an event. These matrices aid in the selection of a sufficient number of events and ensure that each candidate demonstrates each of the applicable competencies over the course of the simulator examination. A page from one of the competency matrices is shown in Table 5.

Event Descriptions

An event description of about 2-4 pages was prepared for each of the events. Each was written to be as generic, i.e., apply to many plants, as possible. The descriptions for the abnormal events were designed using available event-based plant procedures. The emergency event descriptions were developed using symptom-based EPGs from various owners groups (Refs. 6-9). Each event description is organized into two major parts: a cover sheet and a progression of operator actions. An example event description is exhibited as Table 6.

Cover Sheet

The cover sheet presents the following general information:

1. Operating Sequence--The title of the event.
2. Nuclear Steam Supply System Vendor/Reactor Type--The nuclear steam supply system vendor(s), i.e., General Electric, Westinghouse, Combustion Engineering, and/or Babcock & Wilcox, and the type of reactor.

** The examiners workshop was held at the NRC headquarters in Bethesda, Maryland on August 8, 1985.

Table 5. A Page from a Competency Matrix

PWR ABNORMAL EVENTS COMPETENCY MATRIX

EVENTS	S = SRO R = RO B = BOP	UNDERSTANDING/ INTERPRETATION OF ANNUNCIATOR/ ALARM SIGNALS	DIAGNOSIS OF EVENTS/ CONDITIONS BASED ON SIGNALS/READINGS	UNDERSTANDING OF INSTRUMENT/SYSTEM RESPONSE	COMPLIANCE/USE OF TECHNICAL SPECIFICATIONS	COMPLIANCE/USE OF PROCEDURES	CONTROL BOARD OPERATIONS (RO AND INSTANT SRO)	SUPERVISORY ABILITY (SRO)	COMMUNICATIONS/CREW INTERACTION
		COMPETENCIES							
Loss of RCS Makeup	S					X		X	
	R	X	X				X		
	B								
Loss of Automatic Pressurizer Pressure Control	S				X	X			
	R		X	X			X		
	B								
Failure of Pressurizer Spray Valve	S					X		X	
	R	X	X			X	X		
	B								
Loss of Automatic Pressurizer Level Control	S				X	X			
	R		X	X			X		
	B								
Progressive Failure of No. 1 Seal in RCP	S		X		X	X		X	
	R	X	X	X		X	X		
	B					X	X		
Failure of Steam Dump to Open	S				X	X			
	R		X			X	X		
	B								
Steam Generator Safety Valve Fails Open and Fails to Reseat	S				X	X		X	
	R	X	X		X	X	X		
	B					X	X		
Steam Generator Level Control Failure High/ Low	S				X			X	X
	R	X	X	X			X		
	B						X		
Dropped Control Rod	S				X	X			X
	R		X	X		X	X		
	B					X	X		
Inoperable or Stuck Control Rod	S				X	X		X	
	R		X			X	X		
	B					X	X		

Table 6. An Example Event Description

Operating Sequence: Failure of Loop Temperature Instrumentation High/Low

NSSS/Type: Westinghouse/PWR

Initial PLant State: Reactor Controls in Automatic Power Level at About 75%, All Other Control Systems in Automatic

Sequence Initiator: Loop (X) Hot Leg RTD (Narrow Range) Fails High/Low

Important Plant Parameters: 1) RCS Temperature/Pressure, 2) Reactor Power, 3) PZR Level, 4) Rod Position

Progression of Operator Actions: See Flow Chart

Final Plant State: The reactor/turbine plant is at steady state. The temperature defeat switches (delta T and Tave) in loop (x) are defeated. The affected loop bistables for overtemperature/overpower delta T have been placed in the tripped condition.

Major Plant Systems: Rod Control, Reactor Proection and Control, RCS

Tolerance Range: The reactor/turbine plant is stable. The operator must place the rods in manual to mitigate the casualty. The bistables should be placed in the tripped position; the loop Tave and delta T inputs should be defeated.

Competencies Tested:

SRO - Compliance/Use of Technical Specifications
Supervisory Ability

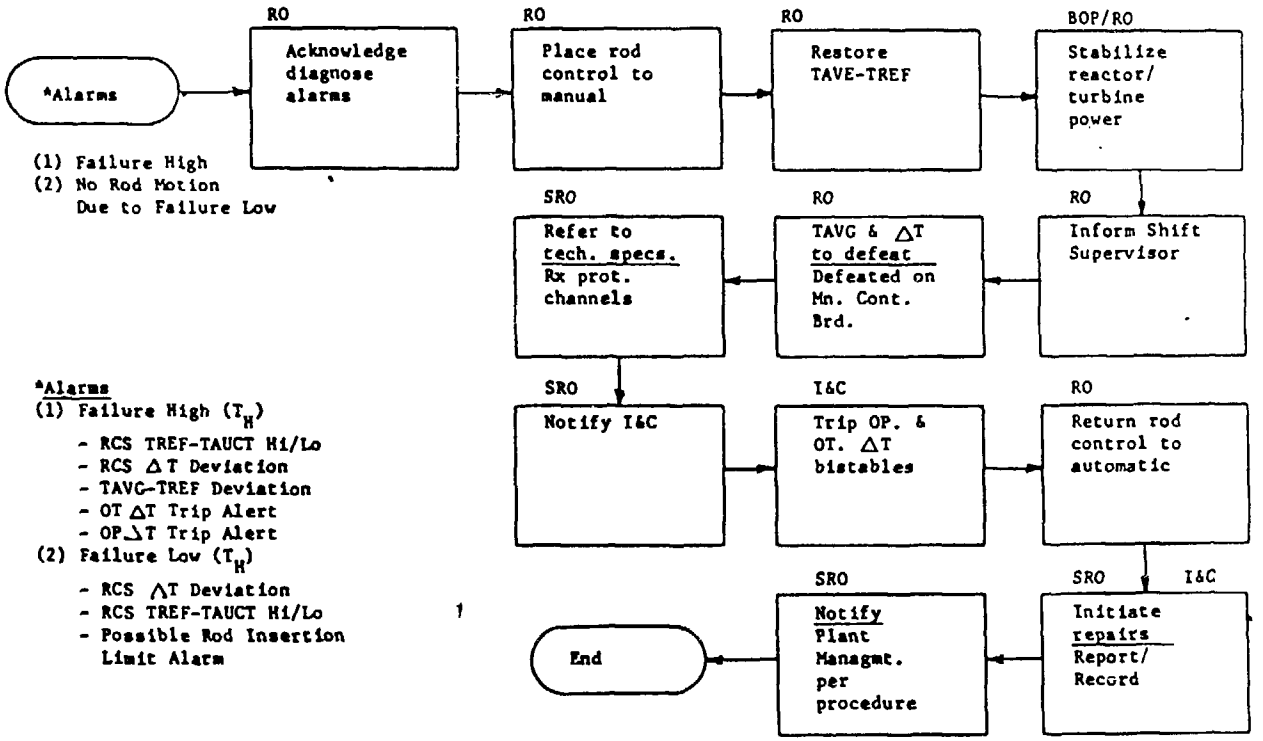
RO - Understanding/Interpretation of Annunciator/Alarm Signals
Diagnosis of Events/Conditions Based on Signals/Readings
Understanding of Instrument/System Response
Control Board Operation

BOP - Control Board Operation

NOTE: Most C-E units have similar system response, but operator response and corrective actions are different.

Table 6. Cont.

FAILURE OF LOOP TEMPERATURE INSTRUMENTATION HIGH/LOW
Progression of Operator Actions:



(1) Failure High
(2) No Rod Motion Due to Failure Low

*Alarms
(1) Failure High (T_H)
- RCS TREF-TAUCT Hi/Lo
- RCS ΔT Deviation
- TAVG-TREF Deviation
- OT ΔT Trip Alert
- OP ΔT Trip Alert

(2) Failure Low (T_H)
- RCS ΔT Deviation
- RCS TREF-TAUCT Hi/Lo
- Possible Rod Insertion Limit Alarm

3. Initial Plant State--The operating status of the plant at the time the event starts. The initial plant state may be obtained either by use of the initial conditions input into the simulator computer, or by instructing the candidates to take the plant into the desired state.
4. Sequence Initiator--A brief description of the equipment failure(s) that causes the event.
5. Important Plant Parameters--Those plant parameters that should be monitored by candidates during the course of the event. Only parameters which are unique to the event are listed; parameters that are important in virtually every off-normal condition, such as primary system pressure, water levels, and reactor power, are not repeated in each description. The important plant parameters are intended to provide objective bases for use in candidate evaluations, including the ability to diagnose plant conditions, comply with procedures, and observe technical specification limits.
6. Progression of Operator Events--This is discussed below.
7. Major Plant Systems--Those plant systems that are uniquely affected by the event. The plant systems which are listed either experience the failure(s) or are used in mitigating the consequences of the failure(s).
8. Tolerance Range--The tolerance range of operator actions represents the bounds within which the candidates must respond before the technical limits are exceeded. Similar to "important plant parameters", tolerance ranges are intended to provide objective bases for use in candidate evaluation.
9. Final Plant State--The possible plant conditions by which a judgment can be made to end the event and move on to the next part of the scenario/examination. The event may be ended before this point is reached provided that enough information has been gathered to adequately assess candidate performance. However, if time permits, the event should be taken to the indicated final plant state.
10. Competencies Tested--This was discussed above.

Progression of Operator Actions

The progression of operator actions depicts in a flow chart manner the representative sequence(s) of expected immediate and subsequent candidate actions, including communication, that can be observed during the event. These flow charts are intended to be as generic as possible for a given reactor/vendor type. The flow charts indicate that, in some cases, there is more than one path which the event can take. The path taken will depend on the likely pertubations of the system, the decisions of the candidates, and/or choices made by the examiner. The objective of these multiple paths is to provide as much flexibility as possible, while retaining simplicity.

SCENARIO PREPARATION

Development of effective scenarios using the event descriptions is a five-step process:

1. Selection of the events.
2. Listing of the events.
3. Completion of the simulator scenario form.
4. Completion of the simulator administration form.
5. Completion of the competency checklist.

Step One: Selection of the Events

The event descriptions are intended to aid the examiner in selecting simulator events for compliance with the criteria described in ES-302. These criteria include:

1. Events requiring candidates to operate in normal evolutions, instrument failures, component failures, and major plant transients.
2. Events requiring candidates to operate under a range of conditions within each category as listed in item #1 above, such as degraded heat removal, degraded electrical power, containment challenges, and degraded pressure control.
3. Events that impact important safety systems such as the systems identified in PWR/BWR knowledge and ability catalogues, i.e., NUREGS-1122/1123 (Refs. 10 & 11).

4. Events that, together, will provide ample opportunity to evaluate each candidate on each relevant candidate competency.
5. Events that will complement and/or supplement information gained on the candidates during the written and oral examinations.

The events-by-competencies matrices should be used as an aid during the selection of events. They will be helpful in choosing a sufficient number of events and ensuring that the candidates demonstrate each of the applicable competencies over the course of the simulator exam. At a minimum, enough events should be selected so that each competency is demonstrated at least once more than once.

Step Two: Listing of the Events

Each exam scenario should present the candidate with a logical and realistic set of problems to which he/she is to respond. For example, component and instrument failures can be used as precursors to major casualties. This will fulfill two or three examination requirements while achieving scenario realism. A rough list of the events that are to be used in each scenario should be made. The events should be placed in a sequence which is logical and in which they will be initiated during the scenario.

Step Three: Completion of the Simulator Scenario Form

The simulator scenario form (ES-302, Attachment 3) provides the simulator operator with a set of instructions for entering initial conditions and malfunctions into the simulator computer. The information for this form is obtained from the event description cover sheets and simulator reference materials, particularly the initial conditions and the malfunction cause-and-effect descriptions. The cover sheets are useful for providing information on the initial plant state for a given event and the simulator malfunctions that may be used to initiate the event. The first item is to select the appropriate plant condition from the initial conditions menu. For

example, if the event description specifies that the event should be initiated from high power, an initial condition for this power level may be selected from the menu, or a lower power level may be selected and the candidates directed to perform a power escalation. This will meet the requirements for a normal evolution or reactivity change, and a major casualty. The malfunctions to be run during the scenario, along with the elapsed time that the malfunction should be initiated, should then be included on the simulator scenario form.

Step Four: Completion of the Simulator Administration Form

The simulator administration form (ES-302, Attachment 5) should include the observable candidate behaviors for use in evaluating candidates. The progression of operator actions can be used as an aid in developing these expected actions/behaviors. This information should be compared to the plant specific procedures and technical specifications to ensure the appropriateness of the flow chart information for that facility.

Each action block in the flow charts indicates the candidate primarily responsible for the action. This is intended as a guide and may not be accurate for every situation. In general, the SRO is responsible for directing the actions of the RO and the BOP, communication with the auxiliary operator and other support personnel, and all administrative duties. The RO is primarily responsible for the reactor and reactor auxiliaries within easy reach of the reactor panel. The BOP is responsible for all plant secondary systems, electrical distribution, emergency core cooling systems, and process/area radiation monitoring. However, when the workload on one operator becomes excessive, assistance may be given by another operator. When an action is entered on the simulator administration form, the candidate responsible for the action is indicated in the "position" column.

Step Five: Completion of the Competency Checklist

After the first scenario has been drafted, the expected actions/ behaviors listed on the simulator administration form should be

reviewed, along with the competencies tested which are identified on the event description cover sheet or the applicable events-by-competencies matrix, to determine which competencies should be addressed for each candidate. Subsequently, these competencies should be entered onto the competency checklist (ES-302, Attachment 8). If the checklist contains competencies that have not been checked off, the selection of events for the next scenarios should be chosen, in part, to evaluate these competencies.

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