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Nuclear Power Plant Simulators for Use in Operator Training and Examination

核电厂操纵人员培训及考试用模拟机

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Nuclear Power Plant Simulators for Use in Operator Training and Examination

1 Scope

This Document specifies the functional requirements of the full range simulator of the control room of a pressurized water reactor nuclear power plant (hereinafter referred to as the simulator) used for operator training and examination, as well as the simulation range, performance and functional criteria of the simulator.

This Document is applicable to the simulator of a pressurized water reactor nuclear power plant, and can also be used as a reference for simulators of non-pressurized water reactor nuclear power plants and other nuclear facilities.

2 Normative References

There are no normative references in this Document.

3 Terms and Definitions

For the purposes of this Document, the following terms and definitions apply.

3.1 Reference unit

Determine the specific nuclear power plant unit on which the simulator control room configuration, system control settings and design database are based.

3.1 Simulation

Use modeling techniques in a simulator development environment to replicate the systems or subsystems of the reference unit.

NOTE: The performance and fidelity of the system being simulated are based on the functional and operational limitations specified based on the design and operating data of the reference unit.

3.3 Stimulation

The simulator uses the actual hardware and software of the reference unit's system or subsystem

incorrectly respond to or interpret the reference unit.

3.30 Systematic approach to training

A commonly used process for establishing and maintaining a performance-based, quality-qualified training program to meet the job requirements of the reference unit. It includes analysis, design, development, implementation, evaluation and feedback of results.

3.31 Training needs assessment

An evaluation by an expert (3.18) of deviations, defects or changes in the simulator and their relative impact on the operator's ability to perform specified tasks.

3.32 Distributed control system; DCS

Based on computer, communication and screen display technology, the multi-computer monitoring system that realizes data collection, control and protection functions of the production process and realizes data sharing.

(SOURCE: DL/T 1083-2008, 3.1)

3.33 DCS level 1

The control logic layer of the distributed control system (3.32), which is used to execute the control and protection logic of the I&C system.

3.34 DCS level 2

The human-machine interface layer of the distributed control system (3.32), which is mainly used for status monitoring and command operation during the run of the power plant.

4 General

4.1 Overview

Nuclear power plant simulators used for initial training, retraining and examination of operators shall use a specific unit as the reference unit. The simulation range shall enable operators to take the same operation through the operating procedures of the reference unit to handle a certain change process on the simulator as the operation taken on the reference unit. The simulation range shall allow all the change processes specified in this Clause to be handled until a stable operating condition is obtained.

A structured software design and testing process shall be established to control the modification of the simulator. The overall design of the simulator should consider measures for examination confidentiality. In addition, the capabilities of simulator verification and confirmation testing, performance testing, and configuration management shall be provided.

4.2 Capabilities of the simulator

4.2.1 General requirements

The simulator response caused by the operator's operation, no operator operation, improper operator operation and the reference unit automatic control and inherent characteristics shall be realistic; it shall not violate the natural physical laws such as mass, motion and energy conservation; and shall comply with the provisions of the verification, confirmation and performance test criteria specified in Clause 5.

4.2.2 Simulator startup and shutdown time

The time to start up the simulator software (excluding the startup time of each simulator computer) should be no more than 15 min; the time to shut down the simulator software (excluding the shutdown time of each simulator computer) should be no more than 5 min.

4.2.3 Real-time and repeatability

When processing the change process specified in this Clause, the simulator shall be able to run in real time and have repeatability.

4.2.4 Simulation limit

In order to meet the requirements of real-time simulation, it is sometimes necessary to simplify the mathematical model of the physical process. This simplification may limit the simulator's ability to handle certain dynamic processes. In addition, simulation processes that exceed the design limits of the reference unit may also appear on the simulator, and the simulation may be incorrect at this time. To avoid possible negative training, when the model parameter reaches or exceeds a certain value, and this value indicates that the event exceeds the executable simulation range or the expected state of the reference unit, there shall be automatic or administrative control measures to remind the trainer.

4.2.5 Normal operation

4.2.5.1 Overview

The simulator shall be able to continuously simulate the change procedures of the reference units listed in 4.2.5.2 and 4.2.5.3 without changing the mathematical model or initial conditions.

The simulator shall be able to calculate the system parameters of different operating conditions and display these parameters on the corresponding instruments, while giving correct alarms and protection system actions.

4.2.5.2 Steady-state operation

The simulator shall accurately simulate the steady-state response of the reference unit within the operating range where the reference unit data can be obtained.

inside and outside the containment; large and small breach accidents showing multiphase flow phenomena; failure of the pressurizer safety valve and pressure relief valve);

b) Failure of the power transmission and distribution system of the power plant, including power failure of the entire plant, loss of external power supply, loss of emergency power supply, emergency generator failure, electricity shutdown of power distribution bus of the unit, electricity shutdown of a single AC or DC instrument power bus, electricity shutdown of a single power cabinet and a single power load, and electricity shutdown of control power of a single device;

c) Total loss of pressure of the instrument compressed air system or loss of pressure of the isolable part, affecting the static or dynamic performance of the unit;

d) Emergency shutdown of the reactor;

e) Emergency shutdown of the steam turbine;

f) Emergency shutdown of the generator;

g) Failure of one or more reactor coolant pumps, resulting in loss of forced coolant flow in the core;

h) Loss of condenser vacuum, including condenser water level control failure and condenser tube breakage;

i) Loss of plant water or plant cooling water for a single device;

j) Loss of shutdown cooling capacity;

k) Loss of cooling water for all or a single device;

1) Loss of normal water supply, or failure of normal water supply;

m) Loss of all water supply (including normal and emergency water supply);

n) Loss of a protection system channel;

o) Control rod failure, including rod jamming, uncoupling, sliding rod, rod drop, control rod refusal motion and uncontrolled rod lifting, etc.;

p) Damage to the fuel cladding, resulting in a high ratio of reactor coolant to exhaust gas, and the generation of corresponding high radioactivity alarms;

q) Failure of the automatic control system that affects reactivity control and core heat emission;

r) Reactor coolant pressure and volume control system failures;

s) Inside and outside rupture of the main steam and main feedwater pipe containment;

t) Failure of the alarm and control system;

u) Passive equipment failure, such as equipment failure in a dedicated safety facility;

v) Emergency shutdown system failure;

w) Main steam bypass discharge system failure;

x) Pump and fan out of control and out of control start-up failure;

y) Valve out of control opening, out of control closing, stuck in any position failure;

z) Measuring instrument output error, output specified value failure;

aa) Circuit breaker out of control disconnection, out of control closing failure;

bb) DCS level 2 equipment failure, including monitor failure, operator workstation failure, server failure, operator station peripheral equipment (keyboard, mouse, etc.) failure;

cc) DCS level 1 equipment failure, including integrated circuit board and channel failure, controller failure, power module failure;

dd) DCS network equipment failure.

The simulator shall support the implementation of abnormal and emergency events, including multiple failures occurring simultaneously or sequentially, to reproduce the inherent response and automatic control function of the reference unit. In the case where the operator's operation varies with the severity of the event, the severity of the corresponding failure shall be adjustable, and the size of the adjustable range shall be sufficient to reflect the possible operating conditions of the reference unit. When the training needs assessment deems it necessary, the simulator shall support subsequent failures of systems and equipment caused by operator operation or system failures.

The response of the simulator shall be compared with the actual response or best estimated of the reference unit in accordance with the requirements of Clause 5. The simulator shall support the operator in performing operations to recover or mitigate the consequences of failures. The simulation range shall enable the simulator to obtain stable, controllable and safe conditions and to operate to cold shutdown conditions or to the simulation limit (see 4.2.4).

4.2.7 Severe accidents

The simulator should be able to simulate severe accident conditions of nuclear power plants, including severe accident conditions such as core melting, pressure vessel failure, and containment failure. It should simulate the generation, transmission, and release of radioactive materials to the environment under severe accident conditions. It should support emergency

o) display systems;

p) telephones and broadcasts;

q) clock systems.

4.3.1.3 Control room environment

It shall simulate the environmental characteristics of the control room of the reference unit during normal, abnormal and emergency operation. It shall simulate the communication system used by the operator to command local operations; and at least the operator can communicate with the trainer through an appropriate communication system.

The following items should be considered:

a) spatial layout;

b) lighting characteristics;

c) communications;

d) decoration (including furniture);

e) general appearance;

f) sound sources and effects;

g) office information network;

h) obstructions.

4.3.1.4 Control room differences

Where there are physical fidelity and human factors differences between the simulator and the reference unit, those differences that have been assessed for training needs and meet the requirements of 5.3.1.4 may be retained.

4.3.2 Simulated systems and their integrity

4.3.2.1 Monitoring systems inside the control room

The simulation range shall include the reference unit systems required for operators to perform varying duty operation conditions specified in 4.2.5.3 and failure handling operations specified in 4.2.6. These systems shall be of sufficient integrity so that operators can perform relevant operations and observe the response of the simulated unit as if they were on the reference unit. The simulation range shall include the interaction between the simulated systems to provide a comprehensive unit response.

4.3.2.2 Monitoring systems outside the control room

The simulation range shall include systems required for control room operation or monitoring when performing varying duty operation conditions specified in 4.2.5.3 and failure handling specified in 4.2.6. Operators shall be able to handle local operations in a similar manner to the reference unit. It shall also have the ability to communicate with emergency center facilities so that the simulator has the ability to assist in supporting emergency drills.

4.4 Functions of the simulator trainer station

4.4.1 Initial conditions

The simulator shall be able to store a sufficient number of initial conditions to support normal operation listed in 4.2.5. A set of initial conditions for operator training and examination shall be determined and administratively controlled. This set of initial conditions shall include various operating conditions of the reference unit, including various power operating conditions, unit full power to cold shutdown, unit cold shutdown to full power, different fuel consumption and fission product toxin concentration effects.

The system shall provide a summary window for interactive initial condition, which shall provide relevant information about the initial condition, including its creation date and time, key values and text description.

4.4.2 Failure function

The simulator shall have the ability to introduce failures specified in 4.2.6 and in the training and retraining outline for licensed operators.

The simulator shall have the ability to introduce failures at any time; be able to introduce multiple failures simultaneously or in sequence; and be able to terminate these failures appropriately. It also should have event-triggered and time-triggered failure introduction methods. The introduction of the failures shall not remind the operator of the upcoming event in any way different from the failure of the reference unit.

4.4.3 Local operation function

The simulator shall enable the trainer to perform local operations outside the control room as specified in 4.2.5 and 4.2.6, such as changing the status of valves, circuit breakers and other local operation equipment. Functional features aimed at enhancing the trainer's ability to simulate the external environment (such as atmospheric temperature and circulating water temperature, etc.) of the reference unit can also be implemented. When the reference power plant has multiple units, if there are no other measures to control the common resources that affect the response of the reference unit operators, such as steam sources, compressed air, power supply, etc. from other units, the trainer shall be able to control them. The trainer station should have a system flow chart to support the trainer to easily find the local operation equipment.

comparing the results of simulating components or systems in separate or integrated tests with actual or expected performance data of the reference unit.

4.5.4 Simulator performance test

4.5.4.1 Overview

Simulator performance test includes operability test, scenario-based test, reactor core performance test and post-event simulator test. Simulator performance test shall be performed in a fully integrated state.

4.5.4.2 Simulator operability test

In order to confirm the completeness and integrity of the model of the entire simulator, the simulator operability test shall be carried out by testing the following:

a) Simulator steady-state performance;

b) Simulator transient performance corresponding to a set of benchmark transients;

c) Simulator availability test.

4.5.4.3 Simulator scenario-based test

To ensure that the simulator is capable of producing the expected reference unit responses to meet the predetermined learning and examination objectives, the simulator scenario-based test shall be performed by using the existing training and examination scenario validation processes.

At a minimum, the following types of simulator scenarios shall be tested scenario-based:

a) Initial licensing test scenarios;

b) Renewal of license test scenarios;

c) Scenarios used to gain operational experience in reactivity control.

Supplementary test should be considered for other scenarios for operator training.

4.5.4.4 Simulator reactor core performance test

The simulator reactor core performance test shall be performed to confirm that the simulator's neutron kinetic and thermohydraulic models replicate the core responses of the reference unit within the simulation range.

4.5.4.5 Post-event simulator test

Certain reference unit events provide an opportunity to obtain relevant reference unit performance data. The post-event simulator test should be performed on these data to confirm

that the simulator is capable of reproducing the responses of relevant reference unit parameters within the simulation range.

5 Test Requirements

5.1 Overview

The following verification, confirmation and performance test criteria are formulated to ensure that there are no noticeable differences BETWEEN the simulator control room and simulated systems AND the reference unit control room and systems. 5.2~5.5 specify the assessment requirements for the main performance of the simulator.

5.2 Simulator capability criteria

5.2.1 General requirements

Where simulator responses are inconsistent with natural physical laws such as conservation of mass, momentum and energy, it shall be verified that noticeable differences have been eliminated, or a training needs assessment has been conducted in accordance with the method provided in 5.3.1.4.

5.2.2 Simulator startup and shutdown time

It shall be verified that the simulator startup and shutdown are completed within the time recommended in 4.2.2. If not, a training needs assessment has been conducted in accordance with the method provided in 5.3.1.4.

5.2.3 Real-time and repeatability

It shall be verified that the simulator software used to meet the requirements of 4.2.3 can be executed within the designed time interval and is repeatable. At the same time, it shall be verified that there are no noticeable differences in the timing relationship, sequence, duration, rate and acceleration between consecutive and repeated simulator tests.

5.2.4 Simulation limits

It shall be verified that the simulation limits are part of the simulator design database; and there are automatic or administrative control measures to prompt the trainer when the simulation limits are reached or exceeded.

5.2.5 Normal operation

5.2.5.1 Overview

It shall be verified that the change procedures of the reference unit listed in 4.2.5 can be simulated continuously without changing the mathematical model.

d) Water level of steam generator;

e) Up-flow;

f) Down-flow;

g) Main steam flow;

h) Main steam temperature;

i) Turbine impulse stage pressure;

j) Generator power.

5.2.5.3 Varying duty operation

The results of the execution of the procedures on the simulator shall be verified by comparison to correctly simulate the response of the reference unit at the same power level and be consistent with the procedures and data availability of the reference unit.

It shall be verified that the simulator can meet the following acceptance criteria when performing varying duty operation in accordance with the requirements of 4.2.5.3:

a) The same acceptance criteria as the start-up test procedures of the reference unit;

b) The same acceptance criteria as the supervision test procedures of the reference unit;

c) The same acceptance criteria as the normal operation procedures of the reference unit;

d) Any visible change trend of the simulation parameters is consistent with the actual or best estimated change trend of the corresponding parameters of the reference unit;

e) If the reference unit has an alarm or automatic action, it shall also appear on the simulator under exactly the same conditions;

f) If the reference unit does not have an alarm or automatic action, it shall not appear on the simulator under exactly the same conditions.

5.2.6 Failures

It shall be verified that the simulator meets the following acceptance criteria during the simulation of failure specified in 4.2.6:

a) The operating procedures of the reference unit can be used on the simulator;

b) Any visible change trend of the simulation parameters is consistent with the actual or best estimated change trend of the reference unit under the same failure state;

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