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INSTRUMENTATION FOR LIGHT-WATER-COOLED NUCLEAR POWER PLANTS TO ASSESS PLANT CONDITIONS DURING AND FOLLOWING AN ACCIDENT

A. INTRODUCTION

Criterion 13, "Instrumentation and Control," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," includes a requirement that instrumentation be provided to monitor variables and systems for accident conditions as appropriate to ensure adequate safety.

Criterion 19, "Control Room," of Appendix A to 10 CFR Part 50 includes a requirement that a control room be provided from which actions can be taken to maintain the nuclear power unit in a safe condition under accident conditions, including loss-of-coolant accidents. Criterion 19 also requires that equipment at appropriate locations outside the control room be provided, including instrumentation and controls to maintain the unit in a safe condition during hot shutdown.

Criterion 64, "Monitoring Radioactivity Releases," of Appendix A to 10 CFR Part 50 includes a requirement that means shall be provided for monitoring the reactor containment atmosphere, space containing components for recirculation of loss-of-coolant accident fluids, effluent discharge paths, and the plant environs for radioactivity that may be released from postulated accidents.

This guide describes a method acceptable to the NRC staff for complying with the Commission's requirements to provide instrumentation to monitor plant variables and systems during and following an accident in a light-water-cooled nuclear power plant.

B. DISCUSSION

Monitored variables and systems should be used by the operator in accident surveillance (1) to help determine the nature of an accident, with emphasis on possible situations that were not completely anticipated in the design of the plant; (2) to help predict the course that an accident will take; (3) to determine whether the reactor trip and engineered safety-feature systems are functioning properly; (4) to determine whether the plant is responding properly to the safety measures in operation; (5) to allow for early initiation of action to protect the public safety (if necessary); (6) to furnish data needed to take manual action if (a) an engineered safety feature malfunctions, (b) unanticipated conditions require operator intervention, or (c) the plant is not responding effectively to the safety systems in operation; (7) to provide information to the operator that will enable him to determine whether there has been significant fuel or system damage; and (8) to provide material evidence for post-accident investigation into the causes and consequences of the event.

At the start of an accident, the operator cannot always immediately determine what accident has occurred or is occurring and therefore cannot determine the appropriate response. For this reason, the reactor trip and certain safety actions (e.g., emergency core cooling actuation, containment isolation, or depressurization) are designed to be performed automatically during the initial stages of an accident. Instrumentation is also provided to indicate plant parameters that are required to enable the operation of manually initiated safety-related systems and other appropriate actions.

If normal power plant instrumentation remains functional for all accident conditions, it can provide indication, records, and (with certain types of instruments) time-history response for many parameters important to following the course of the accident. However, since some accidents impose severe operating requirements on instrumentation components, it may be necessary to upgrade some instrumentation components to withstand more severe accident conditions and to measure a greater

range of monitored variables than might normally be expected.

Examples of serious events that threaten safety are loss-of-coolant accidents (LOCAs), anticipated transients without scram (ATWSs), reactivity excursions, and radioactivity releases that initiate containment isolation. Such events require the operator to understand, in a short time period, the state of readiness of engineered safety features and their potential for being challenged by an accident in progress. Instrumentation provided for this purpose should simplify the accident assessment process and the determination of the status of engineered safety features.

To determine the important variables and systems whose values or status should be displayed to the operator and therefore the monitoring instrumentation that should be installed, a study (Ref. 1) was made of a range of postulated accidents. The study concluded that the following capabilities are most important to maintaining the integrity of the power plant after an accident: reactor shutdown, core cooling, containment isolation, containment pressure control, primary system pressure control, and a heat transfer path from the core to a heat sink. These vital capabilities are designed to preserve the integrity of the barriers to radioactivity release (i.e., the fuel cladding, primary coolant boundary, and containment).

In selecting parameters for accident surveillance, attention should be given to providing information that will aid the operator in achieving and maintaining a safe shutdown condition, with emphasis on controlling reactivity and establishing a heat transfer path from the core to the heat sink. Particular attention should be given to parameters that indicate that the barriers to radioactivity release are being challenged and that public safety may be in jeopardy. Thus, instrumentation that shows the absence or presence of significant fuel damage or metal-water reaction is of special importance.

Information concerning the integrity of the primary coolant boundary and the containment is also of vital interest. For example, the character of a postulated LOCA during the first two or three minutes of the accident can best be determined by monitoring the reactor coolant pressure transient. An analog recorder with a response and sensitivity consistent with the anticipated pressure transient would be the type of instrument needed for this purpose. Comparable records of the pressure transients and temperature gradient in the containment could also be very useful.

Because both short- and long-term operational effectiveness of the emergency core cooling system (ECCS) are important, sufficient information concerning the ECCS status should be provided to permit post-accident surveillance. Similarly, the status of the emergency power system should be displayed at all times to the operator in the main control room.

The effectiveness of containment atmosphere cleanup systems in removing airborne activity from the containment atmosphere should be monitored (i.e., measured). The temperatures and humidity of iodine traps should also be monitored to determine whether the traps are overheating and thus potentially in danger of losing their radionuclide inventory or failing to remove the radionuclides from the containment atmosphere.

The required instrumentation should be capable of surviving the accident environment that it must monitor. It therefore should either be designed to withstand the accident environment or be protected by a local, artificial environment. If the environment surrounding an instrument component is the same for accident and normal operating conditions (e.g., the instrumentation components in the main control room), the instrumentation components need no special environmental capability.

The required instrumentation should also be capable of functioning after, but not necessarily during, a safe shutdown earthquake.

Instrumentation selected for accident monitoring should permit relatively few devices to provide the essential information needed by the operator to satisfy the general objectives. Where practical, the same instruments should be used for normal and accident operation to obtain the advantage of normal inservice surveillance. However, the instruments should be specifically identified on control panels so that the operator can easily determine that they are intended for use under accident, as well as normal, conditions.

C. REGULATORY POSITION

1. For each postulated accident that threatens public safety (for example, a LOCA or ATWS event, reactivity excursion, or radioactivity release that initiates containment isolation), the applicant should perform detailed safety analyses to determine (a) the parameters to be measured and (b) the instrument ranges, responses, and accuracies required to provide the operator with the information necessary to assess the nature of the accident, the course the accident will take, the response of the safety features, the potential for breaching the barriers to radioactivity release, the need for manual action, and the operating status of significant equipment during and following the accident. The guidelines in References 1 and 2 should be used to make such analyses, along with the guidelines in Reference 3 dealing with monitoring inside the power plant.

2. The essential instrumentation required by the operator to diagnose and monitor significant accident

conditions should be specified for each system required to be operable during and after the accident. A tabulation of such instrumentation should be provided, along with a documented justification to show that the instrumentation is adequate to provide the operator with the necessary information. The table should include the instruments' major operational parameters and indicate the manner in which the instrument outputs will be recorded.

3. The accident monitoring instrumentation components and modules should be of a quality that is consistent with minimum maintenance requirements and low failure rates. Quality levels should be achieved through the specification of requirements known to promote high quality.

4. The accident-monitoring instrumentation should be designed with sufficient margin to maintain necessary functional capability under extreme conditions (as applicable) relating to environment, energy supply, malfunctions, and accidents. The instrumentation should either be qualified to survive the appropriate operating conditions or be suitably protected from the environment. Its qualifications should be in accordance with Regulatory Guide 1.89, "Qualification of Class 1E Equipment for Nuclear Power Plants," and it should continue to function within the required accuracy subsequent to, but not necessarily during, a safe shutdown earthquake.

5. The accident-monitoring instrumentation should be designed with redundant channels so that a single failure does not prevent the operator from determining the nature of an accident, the functioning of the engineered safety features, the need for operator action, and the response of the plant to the safety measures in operation. One channel of each redundant set of channels should be recorded and energized from the station Class 1E instrumentation a.c. system.

NOTE: "Single failure" includes such events as the shorting or open-circuiting of interconnecting signal or power cables. It also includes single credible malfunctions or events that cause a number of consequential component, module, or channel failures. For example, the overheating of an amplifier module would be a "single failure" even though several transistor failures might result. Mechanical damage to a mode switch would be a "single failure" although several channels might become involved.

6. Channels that provide signals for redundant channels should be independent and physically separated to accomplish decoupling of the effects of unsafe environmental factors, electric transients, and physical accident consequences documented in the design basis and to reduce the likelihood of interactions between channels during maintenance operations or in the event of channel malfunction.

7. To the extent practical, accident-monitoring instrumentation inputs should be from sensors that directly measure the desired variables.

8. To the extent practical, the same indicators should be used for accident monitoring as are used in the normal operations of the plant.

9. The accident-monitoring instrumentation should be specifically identified on control panels so that the operator can easily discern that they are intended for use under accident conditions. The displays should be arranged to simplify the operator's surveillance, interpretation, and response determination following an accident signal.

10. Any equipment that is used for both accident monitoring and control functions should be classified as part of accident-monitoring instrumentation. The transmission of signals from accident-monitoring equipment for control system use should be through isolation devices that are classified as part of the accident-monitoring instrumentation and that meet all recommendations of this document.

11. Means should be provided for checking, with a high degree of confidence, the operational availability of each input sensor during reactor operation. This may be accomplished in various ways; for example:

a. By perturbing the monitored variable;

b. By introducing and varying, as appropriate, a substitute input to the sensor of the same nature as the measured variable; or

c. By cross-checking between channels that bear a known relationship to each other and that have readouts available.

12. Capability should be provided for servicing, testing, and calibrating the accident-monitoring instrumentation. For those parts of the instrumentation where the required interval between testing will be less than the normal time interval between generating station shutdowns, a capability for testing during power operation should be provided. Servicing, testing, and calibration programs should be specified to ensure proper performance at all times.

13. The design should permit administrative control of the means for manually bypassing channels.

14. The design should permit administrative control of the access to all setpoint adjustments, module calibration adjustments, and test points.

15. The accident-monitoring instrumentation should be designed to provide the operator with accurate,

complete, and timely information regarding its own status. The design should minimize the development of conditions that would cause meters, annunciators, recorders, alarms, etc., to give anomalous indications confusing to the operator.

16. The instrumentation should be designed to facilitate the recognition, location, replacement, repair, or adjustment of malfunctioning components or modules.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, this guide will be used by the staff in evaluating all construction permit applications submitted after August 1, 1976.

REFERENCES

1. Battelle-Columbus Laboratories. "Monitoring Post-Accident Conditions in Power Reactors," BMI-X-647, Apr. 9, 1973.

2. U.S. Nuclear Regulatory Commission, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants," NUREG-75/094, Regulatory Guide 1.70, Rev. 2, Sept. 1975.

3. BNWL-1635, "Technological Considerations in Emergency Instrumentation Preparedness," May 1972.

Copies of the above documents are available from the National Technical Information Service, Springfield, Va. 22161.