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Near-Term Improvements for Nuclear Power Plant Control Room Annunciator Systems

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Prepared for
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ABSTRACT

This report sets forth a basic design philosophy with its associated functional criteria and design principles for present-day, hard-wired annunciator systems in the control rooms of nuclear power plants. It also presents a variety of annunciator design features that are either necessary for or useful to the implementation of the design philosophy. The information contained in this report is synthesized from an extensive literature review, from inspection and analysis of control room annunciator systems in the nuclear industry and in related industries, and from discussions with a variety of individuals who are knowledgeable about annunciator systems, nuclear plant control rooms, or both. This information should help licensees and license applicants in improving their hard-wired, control room annunciator systems as outlined by NUREG-0700.

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FOREWORD

Following the accident at Three Mile Island Unit 2, the NRC staff developed the Action Plan, NUREG-0660, to provide a comprehensive and integrated approach to improving safety at power reactors. Specific items from NUREG-0660 have been approved by the Commission for implementation at reactors. NUREG-0737 provides detail on these specific items, including information about schedules, applicability, method of implementation, review, submittal dates, and clarification of technical positions. The total set of TMI-related actions have been collected in NUREG-0660, while only those items that the Commission has approved for implementation to date are included in NUREG-0737.

Task I.D.1 of NUREG-0660, in conjunction with NUREG-0737, specifies that the NRC will require licensees and license applicants to perform a detailed control room design review, including annunciator warning systems, to identify and correct design deficiencies. NUREG-0700, "Guidelines for Control Room Design Reviews," provides guidance that the NRC staff believes should be followed to accomplish the control room design reviews described in NUREG-0660 and NUREG-0737.

NUREG/CR-3217 is a synthesis of the knowledge regarding hard-wired annunciator systems that is applicable to nuclear power plant control rooms. It presents the basic philosophy underlying annunciator systems and describes the functional criteria, design principles, and design features necessary for or useful to the implementation of the philosophy. Thus, this document should help licensees and license applicants in improving their current hard-wired annunciator systems in a manner consistent with the guidelines in NUREG-0700.

SUMMARY

This document proposes near-term improvements in present-day, hard-wired annunciator systems for nuclear power plant control rooms. It focuses on the basic philosophy of annunciator systems and the functional criteria and design principles relevant to this philosophy.

The basic philosophy--MINIMIZE THE POTENTIAL FOR SYSTEM AND PROCESS DEVIATIONS TO DEVELOP INTO SIGNIFICANT HAZARDS--is composed of four functional criteria.

- The annunciator system should alert the operators to the fact that a system or process deviation exists
- The system should inform the operators about the priority and the nature of the deviation
- The system should guide the operator's initial response to the deviation
- The system should confirm, in a timely manner, whether the operator's response corrected the deviation

These functional criteria are necessary, but not sufficient, to attain an optimal annunciator system design. Experience has shown that certain design principles are necessary to ensure that the functional criteria are achieved without unexpected disturbances to the operation of a nuclear plant. Accordingly, the following six design principles are discussed.

- Annunciators should alert, but not startle, the operators
- Annunciators should intervene in, but not disrupt, control room activities
- Annunciators should assist monitoring by operators, but should not encourage undue reliance
- Nuisance alarms should be minimized without endangering the generation of valid alarms
- Annunciators should guide appropriately timed action
- Annunciators should provide information, but should not increase the workload of the operators

A variety of design features that are capable of being implemented in hard-wired annunciator systems can be used to satisfy the functional criteria. These features include auditory devices, first out, grouping, inhibit, lock in, operator control over the system, re-alarm, reflash, ringback, signal conditioning, and tile design.

1. INTRODUCTION

Human factors reviews of control room annunciator systems have been performed in a variety of industries, including the nuclear industry (Seminara et al., 1976; Finlayson et al., 1977; NUREG/CR-1270; NUREG/CR-2147), the liquefied natural gas industry (Shikiar et al., 1982; DeSteese et al., 1983), and the aerospace industry (Boucek et al., 1977, 1980, 1981). Studies in these industries and operational experience have uncovered a variety of common problems with annunciator systems. These problems include: operators receive unnecessary information, especially during an emergency; too many nuisance alarms; lack of standardization in annunciator window design and labeling; poor location of annunciator windows; and annunciation of too many conditions that should not be part of an integrated warning system.

Problems with annunciator systems during an emergency event were demonstrated during the Three Mile Island (TMI) accident. Investigations into the accident (Rogovin Commission Report, 1979; Kemeny Commission Report, 1979) concluded that the continual sounding of the auditory alarms and the flashing of the annunciator windows during the accident were distracting and made the operators' job of diagnosing the accident more difficult. A human factors evaluation of the TMI control room (NUREG/CR-1270) also found design problems with the TMI annunciator system and concluded that it was of little use to the operators during the first 150 minutes of the accident.

In response to this accident, the NRC developed the TMI Task Action Plan (NUREG-0660) to provide a comprehensive and integrated approach to improving safety at commercial power reactors. A clarification of this plan (NUREG-0737) was also written. Both documents discuss the need for control room design reviews. To guide these reviews, NUREG-0700 was prepared. Section 6.3 of NUREG-0700 provides guidelines for specific human factors improvements for annunciator warning systems. However, it does not provide guidance regarding the basic design philosophy of annunciator systems--information necessary for an overall analysis of annunciator systems.

The principal reason that the problems encountered with annunciator systems have developed is that a systems approach has not been used in developing these systems for nuclear power plant control rooms. Of special importance is the fact that the basic philosophy of annunciator systems has never been carefully articulated nor have the related functional criteria been adequately analyzed so that the basic philosophy can be translated into engineering design. This report has been written to redress these deficiencies.

1.1 Scope

This report pertains to nuclear power plant control room annunciator systems and not to other aspects of the control room, such as the display panel or control panel. Annunciator systems can range on a continuum from hard-wired systems--through microprocessor-controlled systems that incorporate logic commands--to systems that are integrated with plant main frame computers that key annunciator functions to plant states and modes of operation. Since most annunciator systems found in nuclear power plants today are of the hard-wired variety, this document addresses only potential near-term improvements in such hard-wired systems. This is in no way meant to discourage the implementation of the more sophisticated systems; longer term improvements regarding more sophisticated systems will be considered in a continuation of this study. These near-term improvements are applicable to both licensees and license applicants.

1.2 Relationship to NUREG-0700

This document provides the underlying philosophy for the assessment of annunciator systems that is outlined in Section 6.3 of NUREG-0700. Thus, it is intended to aid the industry in understanding the bases for the review of control room annunciator systems. Section 3. presents the design philosophy, functional criteria, and design principles common to annunciator systems and should aid licensees and license applicants in evaluating and planning modifications to their current annunciator systems. It will prove most useful when used in conjunction with the more specific guidelines of NUREG-0700. Section 4. presents the relationships of design features to the functional criteria as a further aid in the NUREG-0700 review process.

1.3 Approach

The approach used in developing this document was to review the purpose and use of annunciator systems over a wide variety of applications and then to determine how this information could be applied to near-term improvements in nuclear power plant annunciator systems. The purpose and use of such systems was investigated through a manual and computerized literature search, site visits to nuclear power plants and related industries, and discussions with architect/engineers and nuclear steam supply system vendors. The visits to related industries included visits to an airframe manufacturer, a chemical processing plant, a Federal Aviation Administration (FAA) flight control center, liquefied natural gas plants, and a coal-fired power plant. Guidelines developed for commercial airplanes by the FAA and technical reports in the fields of aerospace and general industrial processing were especially important in the development of this document.

1.4 Assumptions

The first assumption is that annunciator systems will continue to serve an important role in the control room. The second assumption is that operators will continue to rely on the annunciator system for prompt indication of important deviations from normal operating conditions. Operators may then use other displays (e.g., panel displays, CRTs) for quantitative data regarding the deviation. The third assumption is that the improvements in control room annunciator systems suggested in this document will have to be compatible with present-day, hard-wired annunciator systems. However, computerized information systems can also be used to carry out the improvements that are suggested in this document, and the use of such systems will be discussed where appropriate.

1.5 Report Organization

The remainder of this report is organized in the following manner. Section 2. presents definitions of terms that are used throughout the report. Section 3. provides the main philosophy that should be met by an annunciator system and the functional criteria and design principles that need to be fulfilled to meet the philosophy. This section includes a discussion of the research literature on annunciator systems. In addition, it also relates the suggested improvements in this document (NUREG/CR-3217) to the suggestions for annunciator system improvements found in an Electric Power Research Institute (EPRI) report NP-2411. Section 4. discusses how annunciator design features can be used to meet the functional criteria. Finally, three appendices are included. Appendix A contains suggestions for updating the annunciator section in NUREG-0700. Appendix B provides an assessment of the impact on nuclear power plant control rooms that would result if the suggestions for upgrading annunciator systems that are outlined in this document were implemented. Appendix C provides a bibliography on annunciator systems.

2. DEFINITIONS

Certain words and phrases are used throughout this report. The definitions of these terms are presented below.

Acknowledge	An operator sequence action, typically a pushbutton action, that indicates recognition of a new alarm.
Alarm point	The sequence logic circuit, tile, auxiliary devices, and internal wiring related to one annunciator tile.
Annunciator system	A device or group of devices that alerts the operators to the fact that a process parameter or system condition is not normal for the operating condition and has exceeded a predetermined set point, informs the operators about the deviation, guides the initial operator actions, and confirms whether the operator action corrected the deviation. Usually included are sequence logic circuits, labeled tiles (visual displays), auditory devices, and manually operated pushbutton controls.
Auditory device	An auditory device is an annunciator system design feature that attracts operator attention by sound. Auditory devices can differ in terms of location in the control room and in the type of signal that they produce. The type of signal can vary in terms of loudness, frequency, bandwidth, and modulation.

Design feature	Design features are the various aspects of annunciator systems that can be incorporated into the full system so that the overall annunciator philosophy can be met. Design features include such things as auditory devices, tiles, first-out indication, and ringback.
First out	A design feature that provides sequence information about which alarm operated first.
Functional criteria	The criteria that must be satisfied in order for the basic philosophy of an annunciator system to be realized.
Grouping	A design feature in which a number of alarm points are grouped within a general alarm tile. The more detailed information of the individual alarm points may be provided in the control room or outside the control room.
Inhibitor	A design feature that keeps various alarm points from operating while some specific alarm points are tripped and/or during different modes of reactor operation. This feature could be incorporated in several ways, e.g., through internal system logic or through manual operator control.
Lock-in	A design feature that continues the annunciated state of an alarm point until the alarm is acknowledged, even if the deviation is only momentary.
Operator control	Design features that allow operators to manually control various aspects of the annunciator system. Of importance to this document are the design features for silence, acknowledge, reset, and test.
Re-alarm	A design feature that causes the alarm point to initiate (flashing light and auditory signal) at any point in the alarm sequence when the set point is again exceeded, e.g., when the alarm point is in the acknowledged state or the ringback state.
Reflash	A design feature that allows one alarm point to cover several functions. An auxiliary logic circuit allows two or more process or system deviations to initiate or re-initiate the alarm point at any time. The alarm point cannot return to normal until all related processes return to normal.
Reset	An operator-controlled sequence action, typically a pushbutton action, that returns the annunciator system back to the normal state after an abnormal process or system condition has returned to normal.

Ringback	A design sequence feature that provides a distinct visual or auditory indication, or both, when the process or system condition returns to normal. This is also referred to as a "cleared signal."
Signal Conditioning	A general term used to designate several different types of design features that can be employed on the input to the alarm point, especially to end nuisance alarms. Three ways of conditioning the input signal include the addition of a noise filter, hysteresis, and a time delay.
Silence	An operator-controlled sequence action, typically a pushbutton action, that stops the sound of an auditory device.
Test	An operator-controlled sequence action, typically a pushbutton action, that is used to test whether the alarm point flashing light and auditory signal are working correctly.
Tile	A design feature of the annunciator system or lamp cabinet that indicates the process or system deviation. It is usually a backlighted translucent window. Tiles are also referred to as windows. Tiles can differ in terms of illumination (flash rate, color, and brightness), location, and inscribed legend.

3. ANNUNCIATOR SYSTEM PHILOSOPHY FUNCTIONAL CRITERIA, AND DESIGN PRINCIPLES

While there is a fairly extensive body of literature relating to annunciator systems (see Appendix C), the majority of it assumes, without stating, the purpose or design philosophy of such systems. The primary focus of this document is to redress this deficiency and articulate the design philosophy for the annunciator systems in nuclear power plant control rooms. A well-developed design philosophy will provide the nuclear industry with a rational foundation on which to base an evaluation of current annunciator systems.

An annunciator system should be viewed from a perspective of human information processing (Randle et al., 1980). That is, the system should be designed to optimize the ability of the operators to acquire information through their senses (typically visual and aural) and to process that information (e.g., retrieve information from storage [memory or procedures] and make decisions on the basis of the information) so that a response can be made. Obviously, the first important decision to be made about an annunciator system is to decide what information the operators need to know--specifically, what information should be provided through an annunciator system as opposed to, say, through status indicators. This document speaks only generally about what should or should not be annunciated (e.g., valve status indications and security door information should not be annunciated to operators). At present, an industry-sponsored group is developing guidelines regarding the types of information that should be annunciated. Licensees and license applicants are encouraged to use this forthcoming information in order to determine what should be annunciated at their specific plants. Then this document (NUREG/CR-3217) and NUREG-0700 should be used to determine how best to set up the annunciator system to provide this information to the operator. In addition, a 1982 report (referred to hereafter as NP-2411), sponsored by EPRI, discusses many of the problems with annunciator systems and proposes backfits to overcome these problems. These backfits will be referred to throughout this document.

The design philosophy of annunciator systems and the related functional criteria and design principles are the main focus of this chapter. These are first presented briefly below and are then discussed in more detail.

3.1 Description of Philosophy, Functional Criteria, and Design Principles

The overriding philosophy of a nuclear control room annunciator system, or, in fact, warning systems generally, should be to: MINIMIZE THE POTENTIAL FOR SYSTEM AND PROCESS DEVIATIONS TO DEVELOP INTO SIGNIFICANT HAZARDS.

This annunciator system philosophy is composed of four basic functional criteria:

- The system should alert the operators to the fact that a system or process deviation exists
- The system should inform the operators about the priority and nature of the deviation
- The system should guide the operator's initial response to the deviation
- The system should confirm, in a timely manner, whether the operator's response corrected the deviation

A well-designed annunciator system will probably not satisfy these four functional criteria to the same degree. Annunciators are best able to alert and to inform the operators and secondarily to guide and confirm the operators' actions.

Articulating these four functional criteria is necessary, but not sufficient, to attain an optimal design for annunciator systems. Experience has shown that these basic requirements must be tempered in order to facilitate safe operation (Randle et al., 1980; Berson et al., 1981). The following collection of design principles are necessary to ensure that the four functional criteria are achieved without unexpected disturbances to the operation of a nuclear plant. The specific relationship to NUREG-0700, if any, is indicated in parentheses following a discussion of the principle.

Design Principle One:	Annunciators should alert, but not startle, the control room operators. (NUREG-0700 Sections 6.2.2.6.b, 6.2.2.6.c, and 6.3.2.1.c)
Design Principle Two:	Annunciators should intervene in, but should not disrupt, control room activities. The distracting effect of the annunciator system on other operator tasks should be minimized.
Design Principle Three:	Annunciators should assist monitoring by control room operators, but should not encourage undue reliance. Annunciators should minimize the time required for the control room staff to detect and evaluate system and process deviations and to initiate corrective action. However, the quantitative information needs and status information needs of the operators should be satisfied by other control room indicators.
Design Principle Four:	Nuisance alarms should be minimized without endangering the generation of valid alarms. [NUREG-0700 Sections 6.2.2.7.b and 6.3.2.1.a(1)]
Design Principle Five:	Annunciators should guide appropriately timed action by control room operators.
Design Principle Six:	Annunciators should provide information, but should not increase the workload of control room operators. That is, annunciators should offer clear and succinct information and reduce, not increase, the information processing requirements of the control room staff. This principle also dictates that annunciators should only be used to annunciate actual deviations that require operator attention and should not be used as status monitors. (NUREG-0700 Section 6.3.3.4 and 6.3.3.5)

The following four subsections discuss the four basic functional criteria, outlining methods recommended for meeting the criteria. The design principles relevant to each criterion are included in the discussions.

3.2 Alerting the Operator

The most basic of the functional criteria of annunciators is to alert the control room personnel to a current or potential deviation from an acceptable parameter level (Society of Automotive Engineers, 1980;

Andreiev, 1976; Visuri et al., 1981; Berson, 1981; TVA, 1982). There are two principle reasons annunciators are needed for this purpose. First, the complexity of reactor operation and the large number of relevant parameters create a situation in which it is impossible for control room personnel to monitor all relevant systems, subsystems, and components. Second, deviations frequently are not immediately apparent from available control room instrumentation, e.g., because acceptable parameter levels are often dependent upon phase of operation and because out-of-limit markers are often not incorporated in many of the control room displays (Seminara et al., 1976). In order to fulfill the full range of annunciator purposes, the system must first attract the attention of control room personnel when an important set point has been exceeded.

The major determinants of an annunciator's alerting ability (Randle et al., 1980) are the number of modalities that are signaled (typically aural and visual) and the physical characteristics of the signals themselves. Several sections of NUREG-0700 are relevant to the alerting ability of an annunciator system. For an auditory signal, Sections 6.2.2 and 6.3.2.1 are relevant; for a visual signal, Section 6.3.3.2 is relevant. In addition, NP-2411 discusses the problem of determining alarm state condition because of inadequate flash rate or inadequate contrast detectability (Problem 4.8--Alarm State Detection). The backfits given in NP-2411 are recommended for helping the annunciator to meet the functional criterion of alerting the operator.

Research in alerting ability has typically centered on whether a visual or auditory signal is the better alert. Research has shown (e.g., Siegel and Crain, 1960; Cooper, 1977; Boucek et al., 1980) that auditory signals are superior to flashing visual signals, but that both in combination are superior to either used singly. The aerospace industry has also studied the use of voice alerts (Cooper, 1977; Boucek et al., 1980) in aircraft cockpits and has concluded that they are most useful for time-critical warnings (i.e., where responses had to be carried out within 20 seconds). However, voice alerts do more than just alert the pilot to that fact that a problem has occurred. The alert also signifies the priority of the problem, because only high priority alerts are provided using a voice alert. The alert also guides the pilot's immediate actions, since the voice alerts that were studied were commands (e.g., "Pull up left") rather than simple warnings (e.g., "Plane directly ahead"). Other research in the aerospace industry has focused on the use of a central master alert system in aircraft cockpits in addition to specific alerts in other areas of the cockpit (Boucek et al., 1980). The use of a central master alert in the cockpit was found to be beneficial to speeding pilot response to the problem, but, again, the use of a master alert was of most benefit for the time-critical conditions.

As soon as the alerting signal has served its purpose (alerting the operator that a deviation exists), it should he discontinued. In attempting to assure that the operators do, in fact, perceive and correctly interpret the alerting signal, there are two opposing points to keep in mind. First, the only way to guarantee that the operator has perceived the alerting signal is to require the operator to take some positive action to indicate that the signal has been perceived. On the other hand, requiring the operator to take such a positive action during conditions of high work load, such as during an emergency event, forces the operator to take an action that does not contribute to problem correction. Thus, second, it is equally undesirable for an alerting signal or signals to continue once the condition has been detected, since these signals can cause added distraction and/or confusion during an emergency event. Such was the case, for example, during the TMI accident, especially for the auditory signal.

Thus, the question arises as to whether the alerting signal should be cancelled manually or should be allowed to cancel automatically after a specified time period. Van Cott and Kinkade (1972) recommend that the alerting signals be provided only with a manual shut-off capability. Cooper (1977), in a survey of aerospace industry representatives, found that most of the respondents preferred a manual cancellation of the alerting signal(s). Boucek et al. (1980) found that a significant majority of the pilots that they interviewed favored automatic cancellation of the alerting signal combined with automatic cancellation of the warning message upon correction of the problem. There was also a small group who preferred automatic cancellation after a fixed number of alerting signal repetitions.

Berson et al. (1981), in a continuation of the Boucek et al. (1980) study, proposed the following guidelines for the alerting auditory signal for the airline industry [see Section 3.3.1 of this report (NUREG/CR-3217) for a definition of time-critical warnings, warnings, cautions, and advisories]. The pilots should be alerted to: (1) a time-critical warning by a 0.75 second tone that is automatically cancelled and followed by a voice command that must be cancelled manually; (2) a warning by a tone that continues until it is manually cancelled; (3) a caution by a 1.2 to 2.0 second duration tone that cancels automatically after one presentation and then repeats at 8- to 12-second intervals until it is manually cancelled; and (4) an advisory by a 0.6 to 0.8 second tone that cancels automatically after one presentation. Thus, the more important the deviation, the more important it is to have a continuous alerting signal that is manually cancelled; conversely, the less important the deviation, the shorter the alerting tone can be and the more acceptable an automatically cancelled alerting tone is.

In a nuclear power plant, it would be desirable to provide the operator with more control of the alerting signals than the operator typically has now, because of the large number of annunciated conditions during an emergency event. Since the auditory alert is more distracting than the visual alert (the auditory alert will be heard no matter where an operator is facing and can interfere with voice communications while the visual alert will only be distracting when the operator is looking at the annunciator panel), some extra provision should be made for silencing low priority auditory alerts during a higher priority emergency event. While the auditory signal could be cancelled either automatically or manually, we recommend manual cancellation unless it causes interference with other more critical operator actions. This follows from the aerospace philosophy that the more important the condition is, the more important it is to have manual cancellation of the signal.

Design Principles One, Two, and Four are relevant to alerting the operator:

Design Principle One. An annunciator should alert, but not startle, the control room operators. Alerting is the threshold activity of an annunciator. The other design philosophies can be realized only if an annunciator first attracts an operator's attention. While an annunciator must alert, it should not create an alarm situation that results in decreasing the control room operators' ability to receive, understand, or act on the information that follows. For instance, the control room operator could be startled rather than just alerted if the auditory signal were too loud.

Design Principle Two. An annunciator should intervene in, but not disrupt, control room activities. An annunciator must be capable of alerting the control room operator. Once the operator is alerted, however, it should not continue its auditory or visual signal in a manner that disrupts control room activity.

Design Principle Four. Nuisance alarms should be minimized without endangering the generation of valid alarms. Nuisance alarms can have at least two detrimental effects. First, the operator can believe that something really is wrong and carry out "inappropriate" action. However, it is more common that nuisance alarms will decrease the operator's expectancy that the annunciator system will provide a true alert that some process or system deviation has occurred, so the usefulness of the auditory and visual signals will decrease.

3.3 Informing the Operator

Once the operator has been alerted to a problem, the annunciator system should inform the operator about the priority of the problem and about the nature of the problem. These two information functions are discussed separately below.

3.3.1 Priority of the Problem

Annunciators should indicate the priority of the deviation. This information allows the control room staff to select those reported abnormalities that require their immediate attention. Developing a basis for prioritization is the important first step. Priorities could be based upon several different criteria but should always consider public/plant safety as primary. Other priorities could be based on how quickly the operators must respond to the deviation, or on how pertinent the deviation is regarding violations of technical specifications. Several different examples of priority formats are presented below.

The aerospace industry has developed a priority format based upon passenger safety and how quickly the flight crew must respond. The need for a time-sensitive priority format results from the need for commercial airline pilots to respond to highest order alarms within seconds in order to avoid serious accidents. Few, if any, situations in the nuclear power plant control room require as short a response time. The time-sensitive priority format that appears in the recent aerospace industry literature is summarized below in language applicable to the nuclear control room (Boucek et al., 1980; Berson et al., 1981).

- Time-critical warning: Emergency condition that requires immediate (within 20 seconds) corrective or compensatory operator action

- Warning: Emergency condition that requires immediate corrective or compensatory operator action

- Caution: Abnormal conditions that require prompt operator awareness and could require prompt corrective or compensatory action

- Advisory: Conditions that require operator awareness and may require operator action

One important aspect of this 4-priority system is that all of the conditions that are annunciated require operator awareness of the condition (most of the time this condition will actually be a change in a parameter value) and require, or are likely to require, corrective or compensatory operator action. The aerospace industry has also defined a fifth category--the information category--for conditions that require control room indications, but not as part of the integrated warning systems. In the nuclear industry, this information category would include such things, for example, as status indications for valves and pumps. Thus, the annunciator system would not, for example, be used to indicate simply the on/off status of the high-pressure injection pumps. Neither should the annunciator system be used to indicate, as another example, that the high-pressure injection pumps had started when the engineered safety feature system sent an actuation signal. Rather, the condition should only be annunciated if the pump failed to start when called upon by the system logic.

The American Nuclear Society (1977) has recommended designing control rooms and operating procedures so that operator actions required after a system or process deviation could be divided into three categories--those actions required after 10, after 20, or after 30 minutes. This arrangement suggests that a time-critical priority system may also be feasible for nuclear power plant control room operation. However, these recommendations have never been adopted.

The Nuclear Regulatory Commission has suggested that two to four priority levels be used. An example of a 3-priority system was provided

(NUREG-0700, Section 6.3.1.4) that included both importance and the need for operator action.

First Priority Alarms

- Plant shutdown (reactor trip, turbine trip)
- Radiation release
- Plant conditions which, if not corrected immediately, will result in automatic plant shutdown or radiation release, or will require manual plant shutdown

Second Priority Alarms

- Technical specification violations which, if not corrected, will require plant shutdown
- Plant conditions which, if not corrected, may lead to plant shutdown or radiation releases

Third Priority Alarms

- Plant conditions representing problems (e.g., system degradation) that affect plant operability but which should not lead to plant shutdown, radiation release, or violation of technical specifications

Singer and Reeder (1982) developed a 4-priority system for use at the San Onofre Nuclear Generating Stations Units 2 and 3. The prioritization criteria were as follows (annunciator tile color used to signify priority level is included in parentheses):

Priority 1 Alarms (Red)

- Challenge to safety, unit availability, or the acceptable performance of a major system

Priority 2 Alarms (Yellow)

- Condition with the potential for developing into a first priority alarm event if allowed to continue without operator intervention

Priority 3 Alarms (White)

- An operating constraint that can be verified and assessed from other displays in the control room

Priority 4 Alarms (Blue)

- An operating constraint that cannot be verified and assessed from other displays in the control room

The TVA (1982) has also developed a priority format that includes three categories of alarms. These are briefly outlined below:

Category I - Critical (Magenta)

- Immediate operator action required to prevent or mitigate significant damage to equipment or property and/or to avert conditions leading to an imminent loss of load

Category II - Urgent (Yellow)

- Unusual or serious operational or maintenance situation requiring prompt operator action

Category III - Operational (White)

- Operational or maintenance situation requiring operator attention

The TVA (1982) document lists examples of alarms that fit into the above three categories. It also provides guidance on how many of the alarms should fall into each of the three categories--5% to 15% in Category I, 20% to 30% in Category II, and the remainder (55% to 75%) in Category III.

Once the criteria have been set for the priority format, a decision must be made regarding how to indicate the priority of the annunciated condition. Either the auditory signal or the visual signal or both can be used to provide priority information. As discussed in NUREG-0700 (Section 6.3.1.4), the visual signal (i.e., the annunciator tile) can be coded for priority by varying color of the bulb used for backlighting, color of the tile, position of the tile, shape of the tile, or symbolic coding on the tile. Bulb color and tile color are easy ways to indicate priorities. Population stereotypes and accepted human factors practices suggest that red symbolize the highest priority, yellow the second highest priority, and other distinct colors lower levels of priority. Van Cott and Kinkade (1972) provide a listing of nine colors that both color-sighted and color-blind people can recognize relatively easily. Exact wavelength is important if color blindness is a consideration.

Position coding can also be used. The top position would symbolize the highest priority. Also, left-right position in the matrix of tiles could be used (left would be the higher priority for U.S. operators), but is not recommended, since placing a tile above the relevant subsystem or component is a better utilization of tile placement. The geometric shape of the tile or pictorial shapes (symbols) on the tile can also be used for priority coding. Van Cott and Kinkade (1972) recommend that the shapes be compatible with, and have association with, the priority to be coded and that the shapes be highly discriminable (see p. 72 of their book for 15 highly discriminable shapes).

In a comparison of coding methods, Van Cott and Kinkade (1972) rate coding with colored lights as "good" (up to 3 colors recommended and 10 maximum), coding with colored surfaces as "good" (up to 9 colors recommended with 50 maximum), coding with pictorial representations as "good" (up to 10 recommended with 30 maximum), and coding with geometric shapes as "fair" (up to 5 recommended with 15 maximum). Position coding is not evaluated. The recommended number of codings assumes operational conditions and a high need for accuracy. The maximum number of codings assumes high training and high use of the codes with an expected error rate of five percent. Given the alphanumerics required on the tile to describe the alarm condition, pictorial representations and geometric shapes do not appear to be a practical solution for priority coding. Thus, we recommend color and position (top to bottom) as the best visual coding methods.

As discussed earlier, auditory signals can also be used alone or in conjunction with visual signals to convey priority. NUREG-0700 (Section 6.2.2.3) recommends that auditory coding be accomplished by using different pulse rates or different frequencies (coding by intensity is not recommended). Van Cott and Kinkade (1972) and Pollack (1953) recommend a maximum of five frequencies if the signal is varied only by frequency when perfect identification is required. Coding via two dimensions (e.g., frequency and pulse) would expand perfect identification to approximately eight or nine signals. Boucek et al. (1977) state that no more than nine signals should be used if varied only on one dimension. TVA (1982) also recommends that a maximum of nine auditory signals be used. We recommend that a maximum of nine auditory signals be used when coded in two or more dimensions. This maximum includes auditory signals used outside of the control room (e.g., fire alarm or site emergency alarm). If variation is by frequency only, no more than five frequencies should be used.

The natural "urgency" associated with an auditory signal by the operators should also be taken into consideration when selecting auditory signals for different priorities. For example, Berson et al. (1981) had airline pilots rate 12 auditory signals as to the priority sound of the signal. The natural priority of the signal from highest (top) to lowest (bottom) priority was:

- Mechanical bell
- High wailer
- Electronic bell
- Low wailer
- Clacker
- Low C-chord
- High horn
- Low buzzer

- High C-chord

- Low chime

- Low horn

- High chime

While these findings may be different for reactor operators, the data indicate that sounds elicit natural priorities in humans. These tendencies should be capitalized upon when using auditory coding techniques for prioritization. This will help to ease the information processing requirements of the operators.

Design Principles Two, Three, Five, and Six are relevant to informing the operator of the priority of a deviation:

Design Principle Two. The annunciator should intervene in, but not disrupt, control room activities. When an easily discriminated indication of priority is supplied to them, operators are able to assess the need for immediate action. If immediate action is not required, they could continue more important tasks before responding to the lower priority condition and their activities are therefore not disrupted.

Design Principle Three. The annunciator should assist monitoring by control room operators, but should not encourage undue reliance. Indicating levels of priority assists in monitoring control room activities. However, quantitative data and indications that important process or system deviations are being approached should be read from other displays.

Design Principle Five. The annunciator should guide appropriately timed action by control room operators. Indicating the priority of the deviation allows operators to set priorities on their responses and therefore time their actions appropriately.

Design Principle Six. The annunciator should provide information, but should not increase the workload of control room operators. When the annunciator system provides information about the priority of the problem, the operators are provided with information about how to time their responses and thus do not have to process information to decide priority for themselves.

3.3.2 Nature of the Problem

After being alerted and apprised of the priority of a problem, the operators must be informed about the nature of the problem (see NUREG-0700, Sections 6.3.3.4 and 6.3.3.5). There is some disagreement among the various industries utilizing annunciators as to the amount of information that can be supplied. It is theoretically possible to provide a great deal of information by coding the visual displays and accompanying auditory signals. However, the aerospace industry, for example, finds this trend particularly disturbing. The number of unstandardized alerts in modern cockpits, where coded visual displays and auditory signals have a variety of meanings depending on the model of plane, cannot all be retained with confidence by a pilot, especially under conditions of high workload or stress (Randle et al., 1980). Up to 20 different auditory signals have been used in airplane cockpits. However, the use of such a large number of auditory signals has been largely avoided in the nuclear industry.

The manner in which information is presented is critical to an annunciator's ability to perform. Research by Boucek et al. (1980; 1981) for the aerospace industry indicates that the nature of the problem should be presented last, and that the order of presentation of the system and subsystem involved should be determined by operator familiarity. For example, "Left Engine Fire" is preferable to "Engine Left Fire," while "Pump A Auto Trip" may be preferable to "A Pump Auto Trip." TVA (1982) suggests a format in order to achieve legend uniformity that includes: (1) alarm condition on the first line; (2) general location on the next line or two; and (3) specific equipment, process, or instrument number on the bottom line. The example that they provide is:

HIGH SMOKE
MCR INTAKE
TRAIN A

VA-IAA-9070

NP-2411 suggests a standard 3-line nomenclature for legend uniformity (see Problem 4.4--Message Displays Nomenclature). The top line should contain the system in which the abnormal condition occurred; the middle line should contain the component in which the abnormal condition occurred; and the bottom line should contain a description of the condition. NP-2411 also discusses the use of set points on tiles (see Problem 4.6--Message Displays Set Points). However, we do not favor using set points on tiles for three reasons. First, the set point values are going to change and temporary labels will be used. This does not meet the human factors principle of labels being as permanent as the equipment to which it is attached. Second, the set point information only gives partial information (i.e., condition is above or below some set point), and the operator could assume that the condition is near the set point limit when in fact it is well above it or below it. Third, adding this type of information goes somewhat against the design principle of annunciators assisting operators but not encouraging undue reliance.

The most important aspects of legend format are that the information be presented in a uniform manner and in a way that is familiar to the operators. Extensive information cannot be provided on annunciator tiles, so that operators will still have to rely on other control room displays and procedures for additional information.

Computer systems offer the ability to increase greatly the amount of information presented about the nature of an annunciated condition. More information about the problem can be presented on a CRT or printer than on an annunciator tile. While the message should still be short and concise, as is the case for the message on the annunciator tile, there is much more flexibility for message length. Computers also offer the ability to present different levels of information. For example, a condition such as "HPI PUMP 1 TROUBLE" may be annunciated for a variety of reasons (e.g., low oil pressure or no suction). While these reasons probably should not be annunciated separately on the conventional, hard-wired system because too many annunciated conditions would result, the computer offers more flexibility in this area, allowing, for example, the message "HPI PUMP 1 TROUBLE" followed by the specific out-of-limit condition (e.g., "OIL PRESSURE LOW"). The computer could also be used in conjunction with the hard-wired system. For instance, the tile could still be illuminated and could present a general level of information so that all of the operators become immediately aware of the problem, and the computer could then be used to provide more specificity.

In addition to the information supplied by the tile legend, general information about the nature of the problem can be provided through grouping certain tiles and separating them visually from other tiles using lines of demarcation. For example, all of the tiles associated with the residual heat removal (RHR) system could be located together with a line of demarcation around the group to show that all the grouped tiles deal with the same system or subsystem. Then after the operators have become familiar with the grouping and its location, when one of the tiles begins to flash the operator will immediately know that there is a problem with the RHR system. NUREG-0700 recommends the grouping of alarms [see Section 6.3.3.3.d(2)], and a very good discussion of this concept can be found in NP-2411 (Problem 4.3--Message Displays Location and Grouping).

Another way of providing operators information about the nature of the problem is to present them with first-out information. When an event begins at a nuclear power plant, the sequence of events can occur in rapid chronology--on the order of milliseconds--making it impossible for the operators to determine the initiating event. A first-out design feature will provide them with this information. For the reactor system, NUREG-0700 (Section 6.3.1.3) recommends a first-out panel that indicates which of the automatic trip functions initiated the automatic plant shutdown; a similar first-out panel is recommended for the turbine/generator system.

Sequence-of-events information, as opposed to just first-out information, can also be useful to the operators during the course of the event and is very useful in later reconstructing the event and planning mitigation of future similar events. However, such information cannot be presented in enough detail by an annunciator system for event reconstruction and is therefore not discussed further in this report.

In order to keep from overloading the information processing capability of the operators, it would be very useful to be able to inhibit certain of the lighted tiles during an event through the annunciator logic. At the very least, inhibiting conditions like "TANK 1 LEVEL LOW" alarm when the "TANK 1 LEVEL LOW-LOW" condition is alarmed should be done. Other ideas on inhibiting alarms during an event are possible, such as inhibiting certain low-priority alarms when a higher order condition exists.

The information provided by a tile legend will not be useful to an operator unless it is readable. Readability involves considerations regarding operator workstation distance from the tile(s), typeface style and size, and legend contrast. These issues are adequately covered in NUREG-0700, Section 6.3.3.5.

Finally, the information provided by a tile legend will not be useful, after the alarm has been silenced and acknowledged, unless the operator can select the recently alarmed annunciator tiles from among the other tiles that are on (backlit) for known reasons. Thus, annunciator system philosophy requires that the annunciator tiles not be backlit unless a condition exists that needs to be attended to by an operator. This concept of keeping the tiles dark (unlit) unless operator action is needed is called the "black board" concept (i.e., no lights on). Unfortunately, there are typically numerous lit annunciator tiles at operating nuclear power plants. There are at least three methods for more closely approximating the black board concept.

First, some of the alarms should be made mode adaptive. Many alarms that are lit for long periods of time are lit because the alarm is inappropriate for a given mode of reactor operation (e.g., low oil pressure on the diesel generators). If the alarm is made mode adaptive through logic changes, then it will only alarm when the condition is relevant. NP-2411 discusses this backfit under Problem 4.13--Logic and Sequences Continuously On Windows.

Second, if it is too difficult to make the alarms mode adaptive through logic changes, then windows that are lit for accepted reasons should be denoted as such. One means of doing so would be to attach a symbol to the window to indicate why the window is lit (e.g., an "M" for maintenance or a "T" for surveillance testing). These symbols should affix so that they do not fall off easily, or they could slide in behind or in front of the tile itself.

A third suggested backfit to help meet the black board concept is to group acceptably lit tiles into a corner of the annunciator panel and to demarcate these tiles from the others. This concept is discussed in detail in NP-2411 (Problem 4.13--Logic and Sequences Continuously on Windows).

Design Principles Three and Six are relevant to informing the operator about the nature of the problem:

Design Principle Three. Annunciators should assist monitoring by control room operators, but should not encourage undue reliance. The printed information on an annunciator tile can provide the operator with immediate information about the nature of the annunciated deviation. However, annunciators cannot provide sufficient information on the tile face to replace monitoring of other displays by control room operators. Control room operators ultimately must rely on their interpretive skills and on quantitative instrumentation to become fully informed about the annunciated problem. Consequently, operators should be encouraged not to rely unduly on annunciators.

Design Principle Six. Annunciators should provide information, but should not increase an operator's workload. If the information provided by annunciators is not sufficiently clear, the operators' workload will in fact be increased because of the interpretation required. Thus, it is very important that the annunciated condition is stated clearly, that system, subsystem, component, etc. abbreviations are standardized and consistent with abbreviations used throughout the plant, and that the print size and spacing on the tile is sufficient to be read from the operator's work station.

3.4 Guiding the Operator

After informing the operator as to the priority and the nature of the problem, an annunciator should guide the operator's initial corrective action (Boucek et al., 1980; Berson, et al., 1981). In order to provide full guidance of the array of possible corrective actions directly, the aural and visual codes could become so complex and varied as to reduce the effectiveness of the annunciator system. Thus, the types of guidance that can be given by an annunciator system are somewhat limited.

Several types of guidance can be provided in nuclear power plants. First, the annunciator tile should be located above the related displays and controls that are required for diagnostic and corrective actions (see NUREG-0700, Section 6.3.3.1 and NP-2411, Problem 4.1--Audible Signal Localization). A supplement to guiding the operator via the location of the individual tiles is to provide visual localization cues by using summary displays. Two methods of accomplishing this are presented in NP-2411 (Problem 4.1--Audible Signal Localization). One method is to place above each major panel division a single large indicator light that flashes whenever a single annunciator light on the panel flashes. Then the operator can scan the major lights to determine which panel is annunciating a specific problem. The second method is to place in the control room a summary annunciator display that mimics the overall control panel layout. Then, when an individual annunciator activates, the analogous control panel section on the summary display would also start to flash. These concepts are similar to the central master alert system (Boucek et al., 1980) for the aerospace industry (see Section 3.2 of this NUREG/CR). However, such a master alert in the nuclear industry would appear not to be as useful as it might be in time-critical aerospace applications, and therefore is not necessary to meet the functional criterion of guiding the operator's initial corrective actions. In addition to the visual cues, the auditory signal associated with the annunciated condition should provide localization cues to direct operators to the relevant control/display panel (see NUREG-0700, Section 6.2.2.1 and NP-2411, Problem 4.1--Audible Signal Localization). Thus, the auditory localization cues and tile visual signals can be used to guide the operators to the relevant panel locations. It should be noted, however, that the number of distinct auditory signals for localization, prioritization and other alarms should not exceed nine.

Second, the annunciator tiles or the axes of the tile matrix should be labeled (see NUREG-0700, Section 6.3.3.3 and NP-2411, Problem 4.7--Procedure Reference) as a guide to the relevant annunciator procedures. For example, most tiles are located with other tiles in some sort of matrix arrangement (e.g., a 6 row by 8 column matrix of 48 annunciator tiles). In this case the rows of the matrix could be labeled A through F and the columns could be labeled 1 through 8. Then, if tile "A6" were lit, the operator could go to the annunciator response procedures to section A6, where the relevant information for that annunciated condition would be located.

Third, the annunciator legend could be used to provide simple written commands, as is proposed in the aerospace industry, to guide operator actions that are absolutely and immediately required. However, this concept is not likely to be very useful in the nuclear industry.

Design Principles Five and Six are relevant to guiding operator actions:

Design Principle Five. The annunciator should guide appropriately timed action by the operators. If some operator tasks (e.g., reactor protection) require relatively fast actions, then the localization cues of the auditory and visual signal can help to improve the timing of the operators' responses.

Design Principle Six. The annunciator should provide information, but should not increase the workload of control room operators. If the auditory or visual signal is not located over the relevant control/display panel, then the information processing requirements on the operator are increased, not reduced. Also, if the labeling of the tiles did not unambiguously guide the operators to the correct annunciator procedure, the workload of the operators is increased unnecessarily. Simple commands would also reduce the decision-making requirements on the operators if such commands are feasible.

3.5 Confirmation of Correction

While annunciators are not able to specifically guide the corrective action(s) of an operator, they can confirm, in a timely manner, whether the operator action(s) brought the deviation that was annunciated back within normal operating parameters. There are two design features to be considered here. The first design feature deals with clearing an alarm. The following three questions must be addressed. Should the annunciator point self-cancel immediately after the parameter limit returns to normal range? Should the annunciator point lock in and cancel only after the visual signal (flashing light) has been acknowledged by the operator, the parameter level has returned to normal range, and the reset button has been activated? Or, should the annunciator system be a hybrid of the two prior features with the annunciators' reset process dependent on some variable such as priority of the annunciated deviation (see NUREG-0700, Section 6.3.4.1)? The second design feature deals with determining whether a ringback feature should be paired with the cleared condition or whether the cleared condition should simply be signalled by the visual tile going to the unlighted (off) condition. NUREG-0700 (Section 6.3.1.5) recommends that a ringback design feature be incorporated in the annunciator system. Both of the choices are discussed below.

First, a decision has to be made whether to have an automatic cancellation of the visual signal or whether the signal should be cancelled only after activation of the reset button. Arguments in favor of each system can be made. The aerospace industry has decided upon a self-cancelling annunciator system (Berson et al., 1981), while other industries that use annunciators--e.g., liquefied natural gas facilities, fossil power plants, and nuclear power plants--do not typically have a self-cancelling feature. The most obvious advantage of a self-cancelling system is that it provides immediate indication of results following operator action(s), thereby reducing information processing demands on the operator.

On the other hand, the lock-in and manual reset method of cancellation has one major desirable feature--the operators will always know which annunciator point was alarmed. Therefore, nuisance alarms, which are caused by incorrect set points or set point drift, and phantom alarms (alarms that go on for no readily apparent reason) could be determined more easily with the lock-in and manual reset feature. Both nuisance alarms and phantom alarms should then be eliminated. Nuisance alarms that are caused by momentary, and unimportant, parameter excursions beyond the set point limit should be corrected through signal conditioning. In addition, when an operator pushes the reset button to see if a condition has cleared, his attention will be focused directly on the illuminated tile, although it is possible for other annunciator points at that panel also to clear at this time. With an automatic cancellation feature, the alarm point can clear when no operator is attending to the tile.

Another way to focus the operator's attention on a tile when it clears is to use the ringback design feature, which is recommended in NUREG-0700 (Section 6.3.1.5). Although "ringback" implies an auditory signal, a ringback signal can be both auditory and visual. The ringback could be incorporated with the automatic cancellation feature or the manual reset feature. In addition, the auditory and visual ringback signals could automatically cancel, cancel only after the reset button was depressed, or a combination of both (probably an automatic cancellation of the auditory signal and a manual cancellation of the visual signal).

The obvious advantage of the ringback feature is that it would present to the operator unambiguous confirmation that a process or system deviation had cleared thereby fulfilling the functional criterion. One possible disadvantage of the ringback design feature could be manifested during a major transient. That is, as some of the annunciator parameters that had exceeded their set point (thereby causing the condition to be annunciated) came back within acceptable limits, the auditory ringback signal and, to a lesser degree, the visual ringback signal could add to the information overload that the operators would already be experiencing. With single alarm events, however, this would not be a problem. Thus, in almost all respects the ringback feature is desirable. This is especially the case for the visual ringback feature, since it is specific to the annunciated condition of interest, while the auditory ringback signal would only be specific to a single control/display panel, which might have up to several hundred annunciator tiles located on it. NP-2411 discusses backfits for annunciator systems that lack ringback (see Problem 4.11--Lacks Ringback).

Design Principles Four and Six are relevant to confirmation of whether operator action corrected the annunciated condition:

Design Principle Four. Nuisance alarms should be minimized without endangering the generation of valid alarms. If an annunciator is expected to provide useful feedback on the actions of the operator, it must be reliable.

Design Principle Six. The annunciator should provide information, but should not increase the workload of control room operators. Feedback on corrective action should be provided without requiring significant actions or interpretation by control room operators.

4. RELATIONSHIP OF DESIGN FEATURES TO THE FUNCTIONAL CRITERIA

This chapter explains how the various design features that were defined in Section 2 may be employed to satisfy the four functional criteria for annunciators. The design features relevant to each functional criterion will be individually identified and discussed. The design principles implicit in a feature's application to a functional criterion are listed in the parenthetical expression at the end of the paragraph discussing the feature. This information is summarized in Table 1.

4.1 Design Features Relevant to Alerting the Operator

The following design features can assist in the realization of the functional criterion to alert the operator. The specific design principles (D.P.s) relevant to each design feature a.e referred to in the parenthetical phrase at the end of the paragraph discussing the feature.

TABLE 1: Design Features Relevant to the Functional Criteria and Design Principles of Annunciator Systems

DESIGN FEATURES	FUNCTIONAL CRITERIA: ALERT	INFORM: Priority	INFORM: Nature	GUIDE	CONFIRM	DESIGN PRINCIPLES: 1 ALERT NOT STARTLE	2 INTERVENE NOT DISRUPT	3 ASSIST NOT REPLACE	4 MINIMIZE NUISANCE ALARMS	5 GUIDE APPROPRIATELY TIMED ACTION	6 INFORM NOT OVERWHELM
Auditory Device	X	X	X	X	X	X		X		X	X
First Out	X		X					X			X
Grouping	X		X								X
Inhibitor	X	X				X	X		X	X	X
Lock-In	X		X	X		X		X		X	X
Operator Control											
Acknowledge	X						X				
Reset					X					X	
Silence	X						X				
Test	X					X					
Re-Alarm	X					X					
Reflash	X					X					
Ringback					X					X	X
Signal Conditioning	X								X		
Tile	X	X	X	X	X	X		X		X	X

Auditory Device. An auditory signal--such as a horn, buzzer, or bell--can be used for the basic alerting purpose. The type of signal--loudness, frequency, bandwidth, modulation--if carefully chosen, can enhance an auditory device's alerting power. Care must be taken, however, to ensure that the auditory signal does not startle the operators. (D.P. 1)

First Out. The first out feature will allow operators to identify quickly the initial source of the problem, guide their monitoring of the reactor, and minimize the increase in workload that an annunciator system might otherwise produce. (D.P.s 3 and 6)

Grouping. Grouping can allow control room operators to become aware of the general nature of a problem and the more important subsystems, components, and parameters that are involved. (D.P. 6)

Inhibitor. In order to alert operators to true deviations, inhibiting certain alarm points during specific modes of reactor operation could be beneficial. (D.P. 1)

Lock In. If the operators want to be alerted to even temporary conditions, a lock in feature would be necessary for the visual and/or auditory alert. (D.P. 1)

Silence and Acknowledge. In order to avoid disrupting the control room, it is important that the auditory and visual alert be terminated after the alerting purpose has been fulfilled. The silence and acknowledge controls, respectively, serve these purposes. (D.P. 2)

Test. In order for the annunciator system to alert the operator to the fact that a deviation from operating conditions has occurred, the auditory signal and flasher for the tiles must be working. The test design feature is needed to check for such conditions. (D.P. 1)

Re-alarm. Without the re-alarm design feature, an alarm condition can occur without an audible warning and/or visual indication (flashing tile), for example, when the alarm point is in the ringback state. Thus, in order to alert the operator to the fact that a set point has again been exceeded, the re-alarm design feature is necessary. A good discussion of how to backfit annunciator systems that lack re-alarm is provided in NP-2411 (Problem 4.11--Logic and Sequences Lacks Ringback). (D.P. 1)

Reflash. If an annunciator monitors several alarm points, a reflash feature is necessary to alert the operators to deviations occurring after one of the alarm points has already tripped and has therefore already illuminated the tile. A good discussion of how to backfit annunciator systems that lack reflash is provided in NP-2411 (Problem 4.10--Logic and Sequences Lacks Reflash). (D.P. 1)

Signal Conditioning. Signal conditioning should be employed to eliminate nuisance alarms that are due to transitory deviations. (D.P. 4)

Tile. Illuminating the annunciator tile can act to alert the control room operator. A flashing light is a better attention getting signal than a steady light and can be used to alert without unnecessarily alarming the control room operator (D.P. 1). In addition, locating the tile within the line of sight of the control room operators can enhance the ability of the annunciator to alert. (D.P. 1)

4.2 Design Features Relevant to Informing the Operator

The two components of informing the operator about the priority and the nature of the problem are discussed separately below.

4.2.1 Design Features Relevant to Informing the Operator About the Priority of the Problem

The following design features can help to inform the control room operator about the priority of the deviation.

Auditory Device. An auditory signal can be used to designate priorities. For instance, a klaxon could be used for a highest level priority, with other sounds being used for lower level priorities. Such a system is used in the aerospace industry and could also be used in the nuclear industry in conjunction with the priority system(s) in which priority is indicated by the color and/or location of the annunciator tile. Auditory signal frequency and modulation can also be used to indicate priority. (D.P.s 3, 5, and 6).

Inhibitor. During certain stages of reactor operation, it would be useful to inhibit the annunciation of lower priority deviations in order to preclude the annunciator system from disrupting control room activities, increasing the workload of the operators, or encouraging inappropriately timed action by the operators. (D.P.s 2, 4, 5, and 6)

Tile. Different colors for tile windows can be used to designate the various priorities of the information being annunciated. Consequently, colored tiles or colored lights behind the tiles can assist the monitoring of reactor functions, encourage appropriately timed action, and readily provide information without increasing workload. This method of indicating priority does have several shortcomings. Where a tile monitors several alarm set points, those alarms will necessarily have to be of the same priority unless, for example, multicolor backlighting is used. The color prioritization of a specific window also must be constant over the operating stages of the reactor, unless the tiles are changed.

The location of the tile also can be used to designate priority. For instance, an annunciator tile at the top of the annunciator panel could be used to designate the highest priority warnings while those tiles located below could be used to designate warnings of lesser importance. A master warning panel could also be used for the highest priority deviations. This method of designating priority is probably the least desirable, since it requires some interpretation by the operator and thus does not provide information as readily without increasing workload. Also, it may be difficult to retrofit in some control rooms. (D.P.s 3, 5, and 6)

4.2.2 Design Features Relevant to Informing the Operator About the Nature of the Problem

The following features can assist in the realization of the functional criterion to inform the operator about the nature of the problem.

Auditory Device. A different type of auditory signal for each major control room panel could be used to provide immediate information as to which system is involved. It should be noted, however, that if auditory signals are used for this purpose they would not be available to designate priorities. Providing a separate auditory source of the same type at each major control room panel would be another means of informing the operator of which system is involved through location cues. (D.P. 3 and 6)

First Out. The first-out feature will allow operators to identify quickly the initial source of the problem, guide their monitoring of the reactor, and minimize the increase in workload that an annunciator system might otherwise produce. (D.P.s 3 and 6)

Grouping. Grouping can allow control room operators to become aware of the general nature of a problem and the more important subsystems that are involved. (D.P. 6)

Lock In. If it is necessary to inform operators of the nature of a temporary deviation, the lock-in feature is needed. (D.P. 3)

Tile. The inscribed legend on the annunciator tile is the most important design feature for informing the operator about the nature of the deviation. The legend design determines the distance from the tile that the information can be read, and it determines the amount of information that can be conveyed. As already discussed, the extent of detailed information that an annunciator can supply is limited. However, by locating the annunciator tile above the relevant control/display panel, the annunciator tile will provide some immediate information as to which system is involved. (D.P.s 3 and 6)

Sometimes an annunciator tile will be illuminated for a long period of time for a known reason (e.g., for maintenance or because of the plant mode of operation), during which time the operator cannot or is not expected to take any corrective action. In order not to increase the operator's workload, it is important to designate in some way that the tile is illuminated for a known and accepted reason. For example, the letter "M" could be affixed to the tile to indicate that the tile is illuminated because maintenance is being done on the system or component. (D.P. 6)

4.3 Design Features Relevant to Guiding the Operator

The following design features can assist in the realization of the functional criterion to guide the operator's initial response to the deviation.

Auditory Device. An auditory signal could be used to direct the operator to the correct control panel. Such a feature can be used in conjunction with the flashing tile as a location aid. (D.P. 5)

Lock-in. An annunciator system with a lock-in feature can encourage appropriately timed action by providing guidance to operators on an emerging problem that might otherwise go undetected. It can readily provide information to an operator by suggesting a course of action where, without the feature, an operator would have to refer to other instrumentation to discover there was a problem and then independently determine a possible course of action. (D.P.s 5 and 6)

Tile. The legend can significantly enhance an annunciator's ability to guide control room response to a deviation. For instance, a carefully designed code on a corner of the visual display could reference the operator to the series of abnormal or emergency operating procedures that would be relevant to the announced deviation. Or the relative location of the annunciator tile could guide operators to the correct annunciator procedures. For instance, where the annunciator tiles are in a matrix arrangement, a tile's position within the matrix could be cross-referenced to a specific procedure. For certain conditions, the tile legend could also guide operator actions by telling the operator what to do as opposed to providing information about the nature of the problem. The tile should be located above the relevant displays/controls, so that it guides the operator to the appropriate panels. (D.P.s 5 and 6)

4.4 Design Features Relevant to Confirming Whether the Problem Was Corrected

The following design features can assist in the realization of the functional criterion to confirm whether operator actions corrected the deviation.

Auditory Device. A distinct auditory signal can confirm whether the annunciated problem has been corrected. (D.P.s 5 and 6)

Reset. The reset design feature can provide feedback to the operator on whether his corrective action was successful and thus encourage appropriately timed action. However, since this feature is not automatic, it does increase the operator's workload somewhat in order to obtain this information. (D.P. 5)

Ringback. A ring-back feature quickly allows an operator to know whether corrective action was successful and the alarm point has cleared without increasing the workload of operators. The ring-back can be visual, auditory, or both. (D.P.s 5 and 6)

Tile. The tile can provide confirmation whether the annunciated problem has been corrected by flashing at a defined rate (slower than the alarm rate), by a change in color, or by a change in illumination intensity. (D.P.s 5 and 6)

5.0 REFERENCES

American Nuclear Society (ANS). 1977. "Criteria for Safety-Related Operator Actions." ANS-51.4, ANSI N660.

Andreiev, N. 1976. "Annunciators Hold Ground Against the CRT." Control Engineering, 23(3):46-48.

Berson, B. L., D. A. Po-Chedley, G. P. Boucek, D. C. Hanson, M. F. Leffler, and R. L. Wasson. 1981. Aircraft Alerting Systems Standardization Study, Vol. III - Aircraft Alerting Systems Design Guidelines. DOT/FAA/RD-81/38, II. National Technical Information Service, Springfield, VA.

Boucek, G. P., J. E. Veitengruber, and W. D. Smith. 1977. Aircraft Alerting Systems Criteria Study, Vols. 1-2. ADA042328, ADA043383, National Technical Information Service, Springfield, VA.

Boucek, G. P., J. P. Erickson, B. L. Berson, D. C. Hanson, M. F. Leffler, and D. A. Po-Chedley. 1980. Aircraft Alerting Systems Standardization Study, Phase I Final Report. FAA-RD-80-68. National Technical Information Service, Sprigfield, VA.

Boucek, G. P., D. A. Po-Chedley, B. L. Berson, D. C. Hanson, M. F. Leffler, and R. W. White. 1981. Aircraft Alerting Systems Standardization Study, Vol. I - Candidate System Validation and Time-Critical Display Evaluation. DOT/FAA/RD-81/38, 1. National Technical Information Service, Springfield, VA.

Cooper, G. E. 1977. A Survey of the Status of and Philosophies Relating to Cockpit Warning Systems. (NASA CR-152071). NASA Ames Research Center, Moffett Field, CA.

DeSteese, J. G., P. J. Pelto, W. L. Rankin, T. B. Rideout, and R. Shikiar. 1983. Human Factors Affecting the Reliability and Safety of LNG Facilities: Volume 1. Control Panel Design Enhancement. (GRI-81/0106.1). Gas Research Insitute. Chicago, IL.

Finlayson, F. C., Hassman, T. A., Jr., K. R. Smith, Jr., R. L. Corlius, and W. W. Willis. 1977. Human Engineering of Nuclear Power Plant Control Rooms and Its Effects on Operator Performance, ATR-77(2915)-1. The Aerospace Corporation, El Segundo, CA.

Kemeny Commission Report (J. G. Kemeny, Chairman). 1979. The Need for Change: The Legacy of TMI. Report of the President's Commission on the Accident at Three-Mile Island. Washington, D.C.

NP-2411. 1982. Human Engineering Guide for Enhancing Nuclear Control Rooms. Electric Power Research Institute, Palo Alto, CA.

NUREG-0660. 1980. NRC Action Plan Developed as a Result of the TMI-2 Accident. National Technical Information Service, Springfield, VA.

NUREG-0700. 1981. Guidelines for Control Room Design Reviews. National Technical Information Service, Springfield, VA.

NUREG-0737. 1980. Clarification of TMI Action Plan Requirements. National Technical Information Service, Springfield, VA.

NUREG/CR-1270. 1980. Human Factors Evaluation of Control Room Design and Operator Performance at Three Mile Island-2. National Technical Information Service, Springfield, VA.

NUREG/CR-2147. 1981. Nuclear Control Room Annunciators: Problems and Recommendations. National Technical Information Service, Springfield, VA.

Pollack, I. 1953. The information of elementary auditory displays. Journal of the Acoustical Society of America, 25, 745.

Randle, R. J., Jr., W. E. Larsen, and D. H. Williams. 1980. Some Human Factors Issues in the Development and Evaluation of Cockpit Alerting and Warning Systems. NASA-RP-1055. Ames Research Center, Moffett Field, Sunnvale, California.

Rogovin Commission Report (M. Rogovin, Chairman). 1980. Three Mile Island: A Report to the Commissioners and to the Public, Volume I, Nuclear Regulatory Commission Special Inquiry Group. U.S. Nuclear Regulatory Commission, Washington, D.C.

Seminara, J. L., W. R. Gonzalez, and S. O. Parsons. 1976. Human Factors Review of Nuclear Power Plant Control Room Design, EPRI NP-309 and EPRI NP-309-2Y (Summary), Lockheed Missiles and Space Company for the Electric Power Research Institute.

Shikiar, R., W. L. Rankin, and T. B. Rideout. 1982. Applications of Human Factors Engineering to LNG Release Prevention and Control. PNL-4090. Pacific Northwest Laboratory, Richland, WA.

Siegel, A. I. and K. Crain. 1960. "Experimental Investigations of Cautionary Signal Presentation." Ergonomics, 3:339-356.

Singer, J. G. and G. Reeder. 1982. A Human Factors Review of a Nuclear Plant Control Room. Paper presented at the ISA Power Instrumentation Symposium, May 24-26, 1982. Los Angeles, CA.

Society of Automotive Engineers, Inc. 1980. "Flight Deck Visual, Audible, and Tactile Signals." ARP 450D. Warrendale, PA.

Tennessee Valley Authority. 1982. Human Factors Engineering in Alarm Systems, Electrical Design Guide, DG-E18.1.13.

Van Cott, H. P. and R. G. Kinkade (eds.). 1972. Human Engineering Guide to Equipment Design. Washington, D.C.: U.S. Government Printing Office.

Visuri, P. (ed.) 1981. Minutes of the HPG Subcommittee Meeting on Alarm Handling. OECD Halden Reactor Project (HWR-43), Erlagen, Germany, September 28-29, 1981.

APPENDIX A

CONSIDERATIONS FOR UPDATING NUREG-0700

Introduction

The following is a discussion of possible modifications to sections 6.2.2 through 6.3.4 of NUREG-0700. The remarks are grouped by topic and keyed to the NUREG-0700 guidelines to which they apply.

Auditory Signal Coding

Number of codes: Guideline 6.2.2.3 recommends means by which auditory signals can be coded, but does not recommend a maximum number of different auditory codes. Recommending a limit of 9 different auditory signals associated with all control room systems, including the annunciator system, may be a reasonable trade-off between giving too little information with the auditory alarm and having more signals than the operator can readily discriminate or so many signals that the operator cannot remember the information that is paired with the signal. (See Section 3.3.1 of this report for a defense of this criterion.)

Urgency of sound: Independent of pitch and intensity, some sounds are naturally more attention-getting than others. Obviously a klaxon conveys more urgency or priority than a telephone ring, which is more urgent-sounding than a chime. These differences can be used to clarify signal meaning to the operator, which is discussed in Section 6.2.2.2, without using signals that could startle the operator. (See Section 3.3.1 of this report.) The design constraint of alerting without startling should probably be stated in guidelines 6.2.2.6 even though it is covered in guidelines 6.3.2.1.c.

Visual Signal Coding

Re-alarm: Guideline 6.3.1.2.c (3) recommends the need for reflash capability. However, we have also discussed the need for the re-alarm capability, which causes a given alarm point (with either single or multiple inputs) to re-alarm (auditory signal and flashing tile) whenever the set point that caused the alarm point to go off in the first place is again exceeded. Re-alarm is needed when the alarm point is in the ringback sequence, because at that time the operator believes that the deviation has been corrected when in fact it has not. Report NP-2411, published by the Electric Power Research Institute (EPRI), recommends that the alarm point be able to re-alarm at any time in the alarm sequence. However, we do not see the need for re-alarm capability when the alarm point is in the silence or acknowledge state, since the operator should be operating under the assumption that there is a deviation at that time anyway.

Priority: Guideline 6.3.1.4.b. recommends four different methods of priority coding for visual annunciators: color, position, shape, or symbolic coding. It is suggested that prioritization of visual signals always be by color and/or position while the less readily identifiable indicator, such as shape or symbolic coding, be used as an adjunct to the primary methods. In addition, there is a possibility that the color coding for alarm tiles will be taken directly from Section 6.5.1.6, where the uses of red (unsafe), green (safe), and amber (potentially unsafe) are defined. Green should never be used on the annunciator tiles for priority coding, because if green is used to signify a safe condition, then that condition should not be on the annunciator panel in the first place since an annunciator is used to signal unsafe conditions. Thus, we suggest that this be made explicit in Section 6.3.1.4.b. We recommend the use of red, amber, blue, and white for annunciator tile colors. The only possible use for green would be for use as a ringback color to signify that the condition has cleared.

Mimic panels: Guideline 6.3.3.3 recommends a matrix organization of visual alarm tiles. While a matrix organization, especially if labeled according to 6.3.3.3.c. is an effective organization scheme, the guideline may unintentionally preclude the use of mimic panels with alarms which can readily convey information about the nature of the deviation and to guide operator action. If the guideline is rewritten to allow mimic panels as well as matrix panels, specific guidelines for the proper design of mimic panels will be needed.

Annunciator System Operation

Ringback: Guideline 6.3.1.5 recommends that all alarms have a ringback feature, but guideline 6.3.4.1.c. discusses reset of annunciators without ringback. If ringback is not recommended or possible for all annunciators, it may be in order to discuss where ringback is more important or where it may not be needed. (See Section 3.5 of this document.)

Guideline 6.3.1.5.a. recommends a distinctive audible signal for ringback. Additionally, it should be recommended that the signal be a chime or other low-priority type of sound. Because of the type of reasoning discussed in Section 3.5 of this report, it may be that an auditory ringback is not a good idea in every case, so a visual (but not necessarily an auditory) ringback signal might be suggested.

Guideline 6.3.1.5.b.(1) recommends a special flash rate for ringback and suggests half or twice the alarm flash rate. Twice the flash rate is in opposition to population stereotypes, because a faster flash rate is likely to be interpreted as signalling a more important condition and therefore should not be recommended.

Audio Silencing: During a major transient or event, many out-of-limit conditions will develop in rapid succession, resulting in many auditory and visual alarms. The continued sounding of auditory alarms can reduce the ability of the operating crew to cope with the problem or even communicate with one another. One means of dealing with the problem has been to have one operator dedicated to the silence control so the others can work, but this arrangement is not an efficient use of personnel. It would be beneficial in a major transient if the operators had some way of silencing the alarms completely or could set the auditory alarm to cancel automatically after a short period of activation. One utility has installed on the silence control an adjustable timer, which is used only during times of heavy alarm activity, to silence automatically each new alarm after a specified time period has elapsed. One suggestion is to use the time-out silencer when a major event begins and to have the capability of turning off the auditory alarms entirely until after the event has been successfully mitigated. These ideas might be considered for a modification to guideline 6.3.4.1.a.

Alternate mode adaptation: Guideline 6.3.3.2.f. discusses lights that must remain on for extended periods of time. Obviously, it would be best if the annunciator system could adapt to the mode of plant operation and not light any unnecessary annunciators, but in the near term, most annunciator systems will not be mode adaptable. One possibility in the near term is to provide a means of temporarily attaching a symbol (for instance, a large "M" for maintenance) to annunciator tiles that must remain lit, so that their non-alarm status will be easily noticed. Some utilities are using small paper stick-on dots to do this, but they tend to fall off and are hard to see from a distance.

Control Placement: Guideline 6.3.4.2.a. states that repetitive groups of annunciator controls should have the same control arrangement and relative location in order to facilitate "blind reaching." This section should probably have the last sentence deleted, since good human factors practice does not encourage blind reaching.

Annunciator System Design

Coverage: Guideline 6.3.1.2. One way to improve many annunciator systems in existing nuclear reactor control rooms is to eliminate unnecessary alarms. The trend in control room design has been to alarm everything that can be alarmed, even if the information presented is not necessary or is intended to be used by someone other than the operator. Many of the resulting "nice-to-know" and status alarms should be eliminated.

Alarm Delay: One means of reducing nuisance alarms is to have a built-in time delay between the receiving of an alarm indication by the annunciator, and the activation of the auditory and visual alarms. If the condition clears during the delay, the alarm will not activate. Obviously, this feature must be applied only where it would not prevent the operator from receiving information needed promptly. One example would be current monitors on electric motors, designed to warn of motor overload. If the starting current trips the alarm every time the motor starts, it is nuisance. If the alarm delays long enough for the motor to reach operating speed, it will eliminate the nuisance alarms and still warn the operator when the motor overloads. Guideline 6.3.1.2 could be amended to recommend the judicious use of alarm delays and other types of signal conditioning.

Information Content: An exception to guideline 6.3.3.4.c., which deals with specificity of information, is that if an operator performs the same response to two or more conditions without needing to know which condition specifically exists, they can share a common alarm.

A larger issue in information content is the probable trend toward computer-assisted annunciator systems. Total elimination of hard-wired annunciators will not occur in the near future, if ever. But computer presentation may be used for an increasing number of lower priority alarms. A display on a CRT, especially if it is in color and uses a combination of graphics and alphanumeric information, can give an operator a more detailed and accurate assessment of a situation than a matrix of small annunciator tiles. Section 6.3 of NUREG-0700 could benefit from a redrafting to ensure that it is amenable to the installation of computer-based annunciator systems, although this may be a part of a longer term program.

APPENDIX B

PILOT ASSESSMENT OF PROPOSED ANNUNCIATOR SYSTEM IMPROVEMENTS

INTRODUCTION

Purpose

The purpose of the Appendix is to discuss a pilot assessment of the impact of implementing the design improvements discussed in the body of this report on nuclear power plant (NPP) annunciator systems in terms of quality, feasibility, cost, and implementation time.

Data Sources

There are several different sources of data that were used in writing this Appendix. First, the NRC provided comments regarding the annunciator systems of license applicants. Second, additional plants were contacted to discuss possible changes in their annunciator systems and in some cases some of the NRC-audited plants were recontacted for additional information. Information from a total of 30 different plants has been gathered from these two data sources. Third, we have contacted four annunciator system manufacturers, including: U.S. Riley Corporation (Panalarm), Ronan Engineering Company (Ronan), Beta Corporation (Beta), and Technology, Incorporated. Fourth, we have contacted Nuclear Steam Supply System (NSSS) vendors and architect-engineering (A-E) firms to get input. These groups included: Bechtel, General Electric (GE), Ebasco Services, and Combustion Engineering (CE).

The cost estimates provided in this appendix need to be discussed briefly. During phone calls and personal visits to the second through fourth data sources listed above, some cost estimates for specific annunciator system improvements at specific plants were obtained. These estimates, and extrapolations from these estimates, served as the main data source for cost estimates in this appendix. The estimates are generally for hardware changes and for a technician's time to make the specific hardware changes. The estimates do not include other staff costs, paperwork costs, etc. Given that the estimates are extrapolations from specific cost data and that several costs are not included in the estimates, the estimates provided in this report are likely to be underestimations and should be used with care.

Appendix Organization

The remainder of this Appendix is organized in the following manner. The next section discusses our findings on the need for, feasibility of, cost of, and implementation time for various annunciator system improvements. These improvements include controls, first out, ringback, reflash, inhibit, prioritization, and other upgrades. The Conclusions section presents a brief summary of the improvements and sets priorities on the need for the improvements.

PILOT ASSESSMENT

This section presents findings and recommendations on several design features of annunciator systems, including controls, first-out panels, reflash, ringback, inhibit, and prioritization. As a general finding, however, we must reiterate the need for a systems analysis to determine the design of the annunciator system. The systems analysis needs to address the following questions: (1) Which conditions really need to be annunciated? (2) Of these conditions, what basis should there be for prioritization and which conditions should be assigned which priority? (3) What operator actions are necessary for a given condition (needed for the alarm response procedures)? (4) Which conditions need immediate feedback and which do not? The need for this, and possibly other, information will become clear in the following sections.

The basis for discussing the need for the various design features was the functional criteria and design principles. That is, we asked the question, "How necessary is it to have this feature in order to meet the functional criteria, and what different ways could the present-day systems be changed if they do not meet the functional criteria?" However, the selection of a specific feature to meet a specific functional criterion must be determined within the context of the whole system, since individual features are not necessarily compatible with all other features.

Controls

The NUREG-0700 preferred control arrangement for an annunciator system is a four-function system with four separate controls for silence, acknowledge, reset, and test (abbreviated SART). None of the NSSS vendors or A-Es contacted disagreed with the need for a SART control arrangement. However, in reviewing manufacturers' products, it is clear that many of the alarm sequences that they sell do not include the four-function arrangement. In most of these cases, however, the switch to four separate functions can be made via a change in logic cards. The primary deviation from the arrangement is to combine the silence and acknowledge functions in the same control. Of the 30 plants for which we have data, three do not have separate silence and acknowledge controls. The reason for separating these two functions is so that the operator can silence the auditory signal while still allowing the annunciator tile to flash until the operator has time to identify positively the annunciated condition. This is important, because the operator's first response following an annunciated condition is to silence the auditory. If the auditory is silenced before the flashing lighted tile is perceived, the operator could have trouble distinguishing the newly alarmed condition from previously alarmed conditions and therefore not be apprised of the nature of the deviation.

How likely is this to happen? If the operator only knew that the condition came from a specific panel (from the directional cue of the auditory signal), the probability of not responding to a given annunciated condition is a function of the number of lighted tiles.

NUREG/CR-1278 gives a range of human error probabilities (HEPs) from 0.0006 (for failing to respond to 1 out of 2 conditions) to 0.25 (for failing to respond to 1 out of 40 or more annunciated conditions). Assuming approximately 10 lit tiles, the HEP is 0.05. However, missing an annunciated condition might not always be a serious error of omission. Missing the annunciated condition would be most serious if it were a high-priority condition. Since the serious events would cause numerous alarms to go off, they would be less likely to require a response on a one-by-one basis. Thus, missing a single annunciated condition because of the lack of separate silence and acknowledge functions would most likely happen following the deviation of a single parameter from an acceptable level.

Utilities not presently having SART may consider one of the following alternatives for achieving the functional goal. First, they can add another function and its related control so that SART is achieved. Many present-day annunciator systems can be ordered with or without both functions and the changeover can be affected by replacing the logic cards. Such a cost could run $30 to $50 per card plus I&C technician time to make the changeover. If such a logic card changeover were not possible, external logic would be required, which would be more costly. In either case, the changeover could be as much as $30,000 to $50,000 and could take several months to accomplish.

A second option would be to use a time-out relay to silence the auditory signal after a few seconds. This is currently against NUREG-0700 guidance but could be acceptable if the time-out function were permitted only following a major event (e.g., SCRAM) and if the auditory signal were presented for a long enough period of time so that it would not be missed. Since a signal that is 10 dB(A) above background noise would be perceived by an operator on the order of 50 to 100 milliseconds and processed within a second or two, an auditory signal duration of 3 to 10 seconds should be adequate. This could be an inexpensive solution to the problem on some systems, or it could require a logic card changeover as in the first solution above.

First Out

Of the 30 reactors on which data are available, six did not have first-out annunciator panels for the reactor or the turbines. Some of these utilities claim that a multi-pen event recorder or alarm printer performs the same function adequately. Individuals from utilities that had both first-out panels and alarm printers expressed the opinion that the printer alone was insufficient because it could become overloaded and get behind. One NSSS vendor observed that a first-out indication is not that useful if emergency procedures are symptom-oriented rather than event-oriented. Some utilities have first-out panels that do not satisfy a strict interpretation of NUREG-0700 guidelines, which state that only the tile indicating the initial trip event shall be lit and no other. Their first-out panels either show a different color of light for the first out or have a flashing light for the first out with subsequent alarms appearing as steady lights. One annunciator manufacturer sells a sequential display panel which is similar in appearance to a standard annunciator panel except that an LED digital display in the upper right corner of each window indicates the sequence of the first ten alarms received. Thus, there are several functional ways of providing first-out information to the operator.

Our opinion is that first-out information on the cause of a reactor trip or a turbine trip is helpful but not immediately necessary to the operator. As stated by one NSSS vendor, procedures are symptom-oriented, so first-out information, per se, is not needed to mitigate the event but is more useful in analyzing the sequence of events, once the situation is under control. On the other hand, while attending to symptoms, the operators are also thinking about cause. In addition, many of the reactor trip conditions on the first-out panel are also entry conditions into the emergency operating procedures. This information is very important to the operator. But it is the fact that this is entry condition information, more than the fact that it is first-out information, that makes it important.

Thus, it is our opinion that the NRC should focus its attention on a reactor trip and turbine trip panels, on which first-out information can also be provided, rather than on first-out (only) panels. Otherwise, we believe that the function of providing first-out information can be handled in one of several ways in the NPP. These include adding a reactor (turbine) trip panel with first-out indication, using a paper tape event recorder, or using a computerized printer as the recorder.

Reactor (turbine) trip panels are quite feasible (the main problem is panel space) and should not be very expensive to install. We estimate the cost at approximately $10,000 and the implementation time at several months.

Reflash

Reflash is an annunciator design feature that allows one alarm point to cover two or more functions. In this case, the logic circuit allows two or more process or system deviations to initiate or re-initiate the alarm point at any time. Nine of the 30 plants on which we have data do not have reflash capability on all of the alarm points that cover two or more functions. In some cases, the licensees have the reflash capability on some alarm points but not on others.

We feel that the need for reflash is clear-cut. If the annunciator system does not have a reflash capability, then it cannot always meet the first functional criterion, i.e., to alert the operator that a process or system deviation has occurred. The only time that reflash would not be needed is if the two or more conditions that are listed on the alarm point are mutually exclusive, i.e., they could not occur at the same time.

There are at least two ways of adding reflash. First, the licensee could move additional function(s) to a different alarm point(s) so that reflash is unnecessary. Several utilities have already done this, and it is totally feasible (in terms of logic, wiring, etc.) unless no extra windows are available in an appropriate location. The cost would be for new logic cards and the manpower to carry out the installation. It is our estimate, then, that the cost could range from $100 to $300 per change. Implementation might take several months from determining which points needed to be upgraded through order and receipt of the new logic cards to final installation. This improvement would reduce the operator's requirements for processing information on individual alarms and meets the sixth design principle of providing information without increasing workload. However, if the new alarm point(s) cannot be located over the relevant control/display panel (thereby violating the functional criterion to guide the operator's initial response), then a new problem is introduced. One drawback to this solution is that it increases the total number of annunciators when the NRC advocates a reduction in the number of annunciators to avoid operator sensory overload. Separating functions into more alarm points may result in a sensory overload to the operator during major events when many alarms are initiated almost simultaneously.

The second method of correcting the problem would be to add the reflash capability to the alarm point. This is also quite feasible, and some licensees are using this form of upgrading. Depending on the amount of design work required, new logic cards might cost between $50 and $100 per point. Implementation time should be faster than the other option listed above. In any case, reflash must be provided so that the first functional criterion of annunciator systems can be met.

Ringback

Ringback is a design feature that provides a distinct visual or auditory indication, or both, when a process or system condition that has tripped an alarm point returns to normal. Ringback is useful to help meet the fourth functional criterion of confirming whether the operator's response corrected the deviation. Twelve of the thirty plants on which we have data do not have any type of ringback. One plant has visual, but not auditory, ringback. The NRC has suggested to some license applicants that they have ringback automatically clear if they do not want to require an operator action (actuation of the reset control). We will discuss each of the three options below.

Opinions on the need for ringback run the gamut. Operators from NPPs that have ringback believe that the function is very useful and are glad that they have it. Operators from NPPs that do not have the function argue that it is not needed and that it would actually degrade control room conditions during a major transient by adding more auditory and visual signals to those already present. A representative from one company felt that ringback only acted as a "crutch" for operators and that they should be required to actuate periodically the reset control to determine whether the condition has cleared. This way they would have to keep aware of what they were monitoring.

First, let us state that the functional criterion of confirming in a timely manner whether the operator's response corrected the deviation does not necessarily require that the ringback design feature be available. That is, the standard operating sequence at many plants, i.e., actuating the reset control to see whether the lighted tile goes off, meets the functional criterion if it is done "in a timely manner." The timeliness of the confirmation suggests that ringback be required for at least two situations. The first type of situation for which ringback is needed is a situation for which it is important that the operator know immediately when the deviation has cleared (such as an entry condition into the emergency operating procedures). The second type of situation is that in which the deviation is not expected to clear for some time (e.g., refilling a tank) so that one would not expect an operator to remember to actuate the reset control intermittently during that period, and, in fact, where one would expect that the operator might forget that the condition was slowly being cleared.

Thus, our suggestion is that ringback should not be required for all alarm points but should be required for the two types of conditions discussed above (and others that may be determined during the systems analysis). When an operator is trying to correct other annunciated problems where immediacy of information or delay of information are not considerations, using the reset button to "ask" for feedback would appear to be acceptable because the information would still be provided in a timely manner.

In summary, our reasoning for taking this position (i.e., ringback is only needed for certain conditions) is as follows. First, operators can get confirming information via use of the reset control, so that the basic functional criterion can be met. Second, in a minority of cases the need for immediate confirming evidence is so important that one should not rely on the operator having to actuate the reset control--the operator may forget to do it or forget to do it often enough. In such cases, ringback is not a "crutch," but a necessary aspect of the operator's information requirements. Third, the added visual and auditory "noise," if all points had ringback, could have a negative effect during a major transient by adding even more (unnecessary) information to an already overloaded condition. However, for the near term, we do not recommend that plants which have ringback on all their points disconnect any of them, since in non-transient conditions the ringback is useful (but not necessary).

Should nuclear power plants have both a visual and an auditory ringback signal? On the basis of our previous logic, we believe that both types of signals should only be required when it is important that the operators be notified immediately after a condition has cleared. The auditory signal, which meets NUREG-0700 criteria, is the only way to ensure notification, since auditory signals are multidirectional. A visual ringback signal cannot ensure perception, although such a signal should be seen within a few minutes in a control room environment. Thus, the addition of the auditory signal would promote faster recognition.

Should the ringback automatically clear, or should it require some operator action (typically activating the reset control)? We believe that either situation is acceptable in most cases. The major reason for requiring an operator action is to ensure that the ringback signal was received by the operator. An auditory signal that meets the NUREG-0700 criteria should be easily heard, so an automatic clear would be acceptable, except for the cases where the operator must be immediately aware of the cleared condition to perform some related task. However, since the visual ringback may take several minutes to perceive, if a visual ringback signal is used alone (i.e., not in conjunction with the auditory ringback), then an operator action should be required to clear it.

Present-day hard-wired systems can be ordered with or without ringback. Systems without ringback can be changed to systems with ringback through a change in logic cards. A representative of one company estimated that it would cost less than $50,000 to add ringback to all annunciator points in a PWR that began operation circa 1980. This is the cost for the new logic cards only, so that all other costs would be additional and could add up to several hundred thousand dollars.

If ringback contacts are not in an existing system, a licensee could add external logic to provide ringback, as suggested by the EPRI report, NP-2411. Although specific cost data are not available, it would be considerably more expensive to install this system than the system that has ringback contacts. We estimate that it would cost $100 or more per alarm point to add ringback by this method.

In order to change the whole system, where only new logic cards were required, it would probably take several months to have the cards built, and several months to change over to the new system. Adding external logic to a whole system would take longer. Adding ringback only to those conditions that required it (by our criteria) would take proportionately less time.

Inhibit

During the event at TMI-2, the annunciators proved to be nearly useless because of the incessant occurrence of new alarms accompanied by auditory and visual signals. Zion has carried out an analysis of transient conditions and concluded that the auditory signals are the most serious distraction during the first few minutes of a transient. The question is whether an annunciator system can provide adequate alarm information during normal operations without causing unnecessary stress and distraction to the operator during a major transient. The optimum solution would be an intelligent system that would display only the number of alarms an operator could handle, selected on the basis of response priority for the existing situation. However, it appears that such a system is more within the scope of the long-term program than it is within the near-term program. Inhibit capability in current annunciator systems may be limited to administrative control over auditory alarms during a major transient. As new technology becomes available, other options can be considered.

Another facet of alarm inhibition is mode adaptability. One utility surveyed has a four-position rotary switch (run, bypass dump tank, refuel, and shutdown), which causes bypass of some alarms that do not apply for a given mode. Mode adaptabilty is a highly beneficial feature from a human factors standpoint. From a technical standpoint, the analysis required to support mode adaptive logic must be rigorous to assure that no event or combination of events in a given mode can bypass a critical alarm.

Adding mode adaptability to existing plants could be quite time consuming and very costly. While the benefits are attractive, they may not warrant the cost of adding any more than very rudimentary mode-adaptive systems to current hard-wired annunciator systems. If, however, a utility is planning to revamp its annunciators completely, it should consider some method of mode adaptability.

Still another aspect of alarm inhibition is the elimination of nuisance alarms. In addition to those alarms that might be bypassed by a mode-adaptive system, there are three distinct types of nuisance alarms. First, there are alarms for conditions that should not be alarmed. Any alarm that activates to show that an automatic system is working properly fits this category. Second, there are alarms that result from instrument drift, hysteresis, or alarm setpoints being unreasonably close to control setpoints. A third type of nuisance alarm results from equipment that is undergoing scheduled maintenance or test. Licensees should eliminate all three types of nuisance alarms, and the use of "inhibit" logic is one way to do so.

In summary, we recommend that operating plants have a quiet switch for auditory alarms to be permitted only during major transients. This should be an inexpensive alteration. We also recommend that mode adaptability be given consideration whenever an annunciator system is targeted for major modification. Elimination of nuisance alarms already seems to be a high priority item at most utilities. The cost of eliminating nuisance alarms depends on the number of such alarms and the method used to eliminate them.

Prioritization

Prioritization of alarm points is needed to meet a basic functional criterion. In situations where operators must deal with a major event, prioritization would allow them to focus their attention on the most critical problems and responses, leaving the less important alarms until the situation has stabilized.

More than half of the 30 plants reviewed lack a prioritization scheme for their annunciator systems. Possibly this is because a truly useful and effective prioritization scheme is not easy to generate. It requires a comprehensive systems analysis to develop a useful scheme. However, in our opinion, the need for prioritization is clear cut.

Implementation of a prioritization scheme, once it has been devised, can be relatively simple and inexpensive. Changing colors of annunciator tiles can ordinarily be accomplished by sliding a colored piece of plastic behind the window or fitting a colored filter over the light bulb. Other methods, such as spatial ordering, are also relatively easy to achieve.

In summary, prioritization is an essential annunciator design feature. All control room alarm points should be prioritized only after a thorough systems analysis is accomplished. The analysis will require several person-months of effort, but implementation of the prioritization scheme would cost approximately $10,000.

Grouping

Grouping is a design feature in which a number of alarm points are grouped within a general alarm tile. Grouping, in general, is a poor design feature from a human factors viewpoint and should be avoided. Two acceptable times for using this feature are: (1) when more detailed information regarding the individual alarm points is required to perform a manual action and this information is provided close to the general alarm tile, and (2) when an auxiliary operator's corrective action takes place at a local control panel and sufficient time is available for the operator to reach the panel and take the proper corrective action. If neither is the case, then more specific information needs to be presented in the main control room, or the controls for taking corrective action need to be moved to the main control room.

Fail-Safe

Normally, all annunciator functions can be tested by use of a test button. However, some variations in test button logic can diminish its usefulness. The preferred function sequence for a test button is as follows. First, when the button is pushed, the auditory alarm(s) sounds and all tiles covered by that test button flash in unison [burnt-out bulbs are much easier to detect if all flash in unison rather than with slight variations; solid illumination does not confirm correct operation of the flasher(s)]. Second, when the button is released, the auditory alarm(s) stops, and visual and auditory ringback signals are given for a short period by all tested tiles that have ringback. Third, at the end of the test sequence, the panel returns to its pretest state, except that any new alarms that occurred during the test should then provide the auditory and visual alerting signal and any ringback-equipped alarm points that cleared during the test should then provide the ringback signal. With this type of test button logic, the operator can detect all failures of the annunciator system.

One weakness in this test scheme is that it is normally accomplished only once per eight-hour shift. A bulb that burned out or a flasher that failed "off" immediately after the test could result in an alarm going unnoticed for eight hours or more. One approach to mitigating potential problems is to require testing of the annunciators two or more times per shift to shorten the time period during which an out-of-limit condition would go undetected.

A better and more commonly used system for improving annuciator system reliability is the use of two bulbs per window. The difference in brightness can be readily seen and the burned out bulb can be replaced. However, single bulb systems could not be retrofitted and would have to be replaced.

NUREG-0700 specifies that flashers should be designed so that failure will result in a steady on rather than steady off condition. On systems where each point has its own flasher, this would be expensive. On other systems where one flasher is used for up to 100 points, the expense would not be as great.

Systems that are not fail-safe may not meet the basic functional criteria for alerting or informing for some period of time. On the other hand, we are not aware of this having been a problem at plants, and certain electrical or logic solutions may be expensive to implement. Our recommendation is that existing systems not having dual-bulb windows and fail-safe flashers be tested more often (at least every four hours), and that dual bulbs and fail-safe flashers be incorporated into the specifications for any new or retrofit annunciator systems.

Flash Rates

NUREG-0700 recommends a flash rate of 3 to 5 cps. While a 3-to-5-cps flash rate is easier to perceive than a 1-cps flash rate, the difference in recognition time is still only on the order of a few seconds. This time savings is not enough, in our opinion, to justify any major or costly changes. If the flash rate is easily changed, such as on systems where one flasher unit drives one alarm panel, then the change may be worthwhile. On units where the change is difficult and/or expensive (because each point has a flasher unit, for instance), the the change may not be cost effective.

Auditory Signal Intensity

If the auditory signal cannot be heard, then there is a good chance that an annunciated condition will go unheeded for at least several minutes. This is especially true if the auditory signal is allowed to clear automatically. Thus, the first functional criterion for alerting the operator can only be met if the auditory signal is loud enough. If it is too loud, then it will startle the operator and not meet our first design principle. In summary, it is critical that the NUREG-0700 criteria for loudness [10 dB(A) above the ambient noise level] be met. Making this change should cost several thousand dollars.

Relocation of Tiles

In order to guide initial operator actions, it is important that annunciator tiles be located in such a way that they are easily visible from the relevant control/display panel. This is most important for annunciated conditions that require a quick response.

It is our opinion that the relocation of annunciator tiles to a position above the controls and displays is very important in the fast-response cases (i.e., necessary to meet the functional criterion for guiding initial operator actions and to meet the design guideline for not increasing operator workload), while in other cases, where an immediate response is not necessary, relocation of tiles is of less importance. Even in the less important cases, annunciator tiles should never be located in a different part of the control room, far from the related controls and displays. Such changes might cost from $100 to $200 per alarm point.

Tile Inscriptions

For the information inscribed on a tile face to be useful, the inscription must be legible from the operator's work position and it must be intelligible. If it is not, functional criterion two (inform operator of the nature of the problem) and design principle six (provide information but do not increase workload) would not be met. Thus, we believe that changing the legends for inscription consistency, abbreviation consistency, etc. is very important. It is also easy once standardized message formats and abbreviations are available. The cost could range from $10 to $50 per alarm point depending on the staff effort required.

Black Board Concept

The black board concept (i.e., tiles are lit only when there is a real problem) is highly desirable but may be difficult to achieve. Even if the black board concept is not achieved, most functional criteria and design principles can still be met. The exception occurs when so many tiles are lit that the operator has difficulty distinguishing newly lighted tiles from the others.

Thus, it is important, first, that as many nuisance alarms as possible are removed from the system. Second, to help accomplish the function served by the black board concept (reduce operator memory and information processing requirements), the utilities need to develop a methodology for indicating the status of "acceptably lit" annunciator windows. This might be accomplished easily and inexpensively through use of stick-on labels. It could be better accomplished through the use of inhibit logic, discussed earlier, but this is still seen as costly and difficult to implement.

Keying Procedures to Tiles

In order to meet the functional criterion of guiding the operator's initial actions, the annunciator tiles need to be keyed to the alarm procedures. The method should be straightforward and should not increase operator workload. Thirteen of the 30 NPPs reviewed had a system of keying the tiles to the procedures in a manner that placed an excessive workload on the operator (e.g., needing to use an index). Modifications to avoid this are easy and would only cost several hundred dollars. Such changes are needed to meet the functional criteria and design principles.

CONCLUSIONS

The purpose of this appendix was to analyze the types of changes required in NPP annunciator systems to meet the guidance in NUREG-0700 and in this document and to estimate the feasibility, cost, and implementation time for these changes. This was accomplished through analysis of NRC control room audit reports and through telephone calls and visits to utilities, NSSS vendors, A-E firms, and annunciator system manufacturers. In addition, the importance of the upgrades was reviewed in terms of meeting annunciator system functional criteria and design principles.

In this section we prioritize the upgrades and present a brief rationale for the prioritization. Finally, we will discuss the overall impact of the upgrades on the annunciator system.

The improvements, the priorities assigned to them, and the ease of making the changes are presented in Table B1. The meaning of the priority and ease-of-implementation ratings is presented at the bottom of the table.

First, several of the upgrades are needed so that the annunciator system can meet the basic functional criteria and design principles. They are given a priority rating of 1 and include: reflash, prioritization, fail-safe, auditory signal loudness, tile legibility and intelligibility, relocation of tiles, keying procedures to tiles, and relocation of tiles. In addition, inhibit was given a priority rating of 1 because of its relationship to the original TMI-linked concerns, and the first-out panel was given ratings of 1 and/or 3 depending on its implementation. These are discussed more fully below.

The first-out panel is given a priority rating of 1 or 3. If it is truly to be a plant-wide first-out panel, we would assign a rating of 3 because first-out information is not crucial for mitigating the event. We would assign it a priority of 1 if it were simply a reactor (turbine) trip first-out panel because of the way that it directly relates to information needed to accomplish emergency operating procedures. The rating for ease of change is a 1 to 2, since it is easy but moderately ($10,000) expensive, by our estimate.

The need for reflash is paramount, and the change should be relatively easy and inexpensive to make. Inhibit is given a priority of 1, because it directly relates to the problems at TMI. However, we are only recommending that the inhibit be required for the auditory signal (ease of change of 1). Changing the logic to inhibit specific points is judged to be a longer-term fix because it is largely infeasible on present-day systems (ease of change of 3).

TABLE B1.

Priority of the Upgrades and Ease of Implementing the Upgrades

Upgrades	Priority	Ease of Implementation
First-Out Panel	1,3	1-2
Reflash	1	1
Inhibit	1	1,3
Prioritization	1	1,3
Fail-safe	1	1,3
Auditory signal loudness	1	1
Tile legibility, intelligibility	1	1
Keying procedures to tiles	1	1
Relocation of tiles	1	2
Controls (separate silence and acknowledge)	2	1-3
Ringback	2	1,3
Black board for normal operation	2	2-3
Grouping	3	3
Flash rate	3	1,3

Priority

1 = Needed to meet functional criteria
2 = Helps to meet functional criteria, but is not essential
3 = Helps minimally in meeting functional criteria

Ease of Implementation

1 = Relatively easy/inexpensive to implement
2 = Moderately hard/expensive to implement
3 = Hard/expensive to implement

Prioritization must be accomplished to meet the functional criteria. The analysis to determine priority levels could be expensive (hence the ease of implementation of 3), but actually carrying out the prioritization on the windows (using color coding, for instance) is relatively easy (rating of 1).

Having a fail-safe system is important in order to know that a deviation has occurred. On some systems where only several flasher units are involved, the change could be relatively easy (rating of 1); on other systems where more flasher units are involved, it could be hard (rating of 3). Requiring more system tests via administrative procedures is an acceptable temporary solution in cases where the changes would be expensive. The full design change should be accomplished if an extensive control room update is anticipated.

Auditory signal loudness is important and is easy to change (rating of 1) to meet NUREG-0700 criteria. The same is true for tile legibility and intelligibility, and for keying procedures to the tiles. Relocation of tiles was given a priority rating of 1 because it is important to maintain good functional relationships between controls and displays, including annunciators. The changes required to have tiles moved to locations above the relevant panel are moderately easy.

Second priority was given to separating the silence and acknowledge functions, adding ringback, and achieving the black board concept. The need to separate the silence/acknowledge functions stemmed from the fact that the operator might be in so much of a hurry to silence the alarm that he would not notice which tile was flashing. We argue that this is unlikely to happen very often and, if it did, would probably be of little importance. Ease of change in separating the silence/acknowledge functions ranged from 1 through 3 because of the ways that the separation might be accomplished, which ranged from changing logic cards to allowing the auditory signal to time out.

Ringback was given a priority of 2 because it is our opinion that ringback is only truly needed on a few of the alarm points. The ease of change was rated as a 1 if a simple change in logic cards would suffice, and as a 3 if external logic were required. Achieving the black board concept was given a rating of 2, since having a few of the tiles "acceptably" on would not create a heavy information search or processing demand on the operator. Although it is important to eliminate nuisance alarms, it may be difficult to achieve a full black board concept.

Finally, lowest priority was assigned to the elimination of grouping and for changing the flash rate. Although grouping should be avoided, conditions do exist under which it is an acceptable practice. Elimination of grouping might be expensive because new information would have to be supplied to the control room and because additional space would have to be provided for new annunciators. A priority of 3 was given to changing the flash rate, because it would only save a few seconds in the operator's search time and in some cases could be quite expensive. If this change is easy to make, it should be accomplished.

In summary, it is our opinion that the changes given a priority of 1 will improve present-day annunciator systems and will begin to address the concerns that resulted from the TMI accident. These changes will ensure that annunciator systems meet the basic functional criteria of a warning system, will reduce the auditory and visual noise in the control room in both normal and emergency operations, and will reduce the information processing required of the operator. The cost of making such improvements is, of course, dependent on how many changes would need to be made at a specific plant. If a plant already met most of the functional criteria, the costs could be below $50,000. If a plant needed to make major improvements, the costs could range above half a million dollars. Staff time requirements would add to these costs. Similarly, implementation times would vary depending on the number of improvements. In cases where numerous improvements are needed, it could take over a year for full implementation.

APPENDIX C

BIBLIOGRAPHY ON ANNUNCIATOR SYSTEMS

American Nuclear Society (ANS). 1977. "Criteria for Safety-Related Operator Actions." ANS-51.4, ANSI N660.

Andreiev, N. 1976. "Annunciators Hold Ground Against the CRT." Control Engineering, 23(3):46-48.

Arnesen, K., O. Falmyr, T. Hueding, M. Pehrsen, and T. Palmtran. 1981. Trends in Distributed Process Control Systems: Data Communication Strategies, Process Interface Techniques, and Graphic Operator Communication Systems. OECD Halden Reactor Project (HWR-28), Halden, Norway.

Atomic Energy Commission (AEC). 1972. "Annunciators for Control Systems." RDT Standard C 17-8T. Washington, D.C.

Bagchi, C. N. and S. C. Gottilla. 1981. "Application of Human Engineering Criteria to Annunciator Display Systems in a Large Fossil Power Station." IEEE Transactions on Power Apparatus and Systems PAS-100(6):2759-2765.

Bate, A. J. 1969. Cockpit Warning Systems Comparative Study. AMRL-TR-68-193. Defense Technical Information Center, Alexandria, VA.

Berson, B. L., D. A. Po-Chedley, G. P. Boucek, D. C. Hanson, M. F. Leffler, and R. L. Wasson. 1981. Aircraft Alerting Systems Standardization Study, Vol. III - Aircraft Alerting Systems Design Guidelines. DOT/FAA/RD-81/38, II. National Technical Information Service, Springfield, VA.

Binford, J. R. and M. Loeb. 1966. "Changes Within and Over Repeated Sessions in Criterion and Effective Sensitivity in an Auditory Vigilance Task." Journal of Experimental Psychology 72(3):339-345.

Boucek, G. P., J. E. Veitengruber, and W. D. Smith. 1977. Aircraft Alerting Systems Criteria Study, Vols. 1-2. ADA042328, ADA043383, National Technical Information Service, Springfield, VA.

Boucek, G. P., J. P. Erickson, B. L. Berson, D. C. Hanson, M. F. Leffler, and D. A. Po-Chedley. 1980. Aircraft Alerting Systems Standardization Study, Phase I Final Report. FAA-RD-80-68. National Technical Information Service, Sprigfield, VA.

Boucek, G. P., D. A. Po-Chedley, B. L. Berson, D. C. Hanson, M. F. Leffler, and R. W. White. 1981. Aircraft Alerting Systems Standardization Study, Vol. I - Candidate System Validation and Time-Critical Display Evaluation. DOT/FAA/RD-81/38, I. National Technical Information Service, Springfield, VA.

Cooper, G. E. 1977. A Survey of the Status of and Philosophies Relating to Cockpit Warning Systems. (NASA CR-152071). NASA Ames Research Center, Moffett Field, CA.

Crawford, A. 1963. "The Perception of Light Signals: The Effect of Mixing Flashing and Steady Irrelevant Lights." Ergonomics 6(3):287-294.

Curry, R., D. Kleinman, and W. Hoffman. 1977. A design for control/display systems. Human Factors 19(5):421-436.

Danchak, M. M. 1980. "The Content of Process Control Alarm Display." Advances in Instrumentation 35:101-109.

Danchak, M. M. 1981. Techniques for Displaying Multivariate Data on Cathode Ray Tubes with Applications to Nuclear Process Control. (NUREG/CR-1994 and EGG-2086). Idaho National Engineering Laboratory. Idaho Falls, ID.

DeSteese, J. G., P. J. Pelto, W. L. Rankin, T. B. Rideout, and R. Shikiar. 1983. Human Factors Affecting the Reliability and Safety of LNG Facilities: Volume 1. Control Panel Design Enhancement. (GRI-81/0106.1). Gas Research Insitute. Chicago, IL.

DiSalvo, R. May 6, 1980. "Report of Travel to Johnson Space Center." Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, D.C.

Electric Power Research Institute. August 18, 1981. "Request for Proposal, RFP2011 'Development of an Alarm System Improvement Guide.'" Palo Alto, CA.

Electric Power Research Institute. 1980. Workshop on Date-Acquisition and Display Systems: Directions After TMI. (EPRI-NSAC-6). Technology for Energy Corporation, Knoxville, TN.

Elke, D. R., T. B. Malone, S. A. Fleger, and J. H. Johnson. 1980. Human Engineering Design Criteria for Modern Control Display Components and Standard Parts. ADA086139. National Technical Information Service, Springfield, VA.

Finlayson, F. C., Hassman, T. A., Jr., K. R. Smith, Jr., R. L. Corlius, and W. W. Willis. 1977. Human Engineering of Nuclear Power Plant Control Rooms and Its Effects on Operator Performance. ATR-77(2915)-1. The Aerospace Corporation, El Segundo, CA.

Hanes, R. L. 1980. "Understanding Annunciators: Characteristics and Types." Plant Engineering, March 8:239-241.

Hollow, E. 1977. Some Points of Advanced Alarm System Design, (RISO-M-1980). Research Establishment, Risoe, Roskilde, Denmark.

Honeycutt, F., W. T. Merten, G. M. Roy, E. Segraves, and G. P. Stone. 1981. Design and Hardware Alternatives for a Safety Parameter Display System. (NSAC-34). Electric Power Research Institute. Palo Alto, CA.

Instrument Society of America. 1979. "Annunciator Sequences and Specification." Standard S18. Research Triangle Park, NC.

Jervis, M. W. 1971. "CRT Displays of Graphs in CEGB Power Stations." In Conference on Displays, pp. 55-62. Institute of Electrical Engineers, London, England.

Johnson, C. B., F. S. Mollerus, and L. A. Carmichael. 1980. Fundamental Safety Parameter Set for Boiling Water Reactors. (NSAC-21). Electric Power Research Institute, Palo Alto, CA.

Joos, D. W., Z. A. Sabri, and A. A. Husseiny. 1979. "Analysis of Gross Error Rates in Operation of Commercial Nuclear Power Stations," Nuclear Engineering and Design, 52, 265-300

Jutila, J. M. 1981. "Guide to Selecting Alarms and Annunciators." InTech, 28(3):35-40.

Kemeny Commission Report (J. G. Kemeny, Chairman). 1979. The Need for Change: The Legacy of TMI. Report of the President's Commission on the Accident at Three-Mile Island. Washington, D.C.

Livingston, W. L. 1980. "The Impact of Three Mile Island on Process Control Computer Technology." Sixth Annual Advanced Control Conference, Purdue University, Lafayette, IN.

Lloyd, B. E. 1973. "Human Factors in Visual and Auditory Signalling Systems." Electrical Engineer 50(4):12, 15-16, 18.

Meister, D. and D. J. Sullivan. 1969. Guide to Human Engineering Design for Visual Displays. AD693237. Defense Technical Information Center, Alexandria, VA.

NP-2411. 1982. Human Engineering Guide for Enhancing Nuclear Control Rooms. Electric Power Research Institute, Palo Alto, CA.

NUREG-0660. 1980. NRC Action Plan Developed as a Result of the TMI-2 Accident. National Technical Information Service, Springfield, VA.

NUREG-0696. 1981. Functional Criteria for Emergency Response Facilities. National Technical Information Service, Springfield, VA.

NUREG-0700. 1981. Guidelines for Control Room Design Reviews. National Technical Information Service, Springfield, VA.

NUREG-0737. 1980. Clarification of TMI Action Plan Requirements. National Technical Information Service, Springfield, VA.

NUREG-0835. 1981. Human Factors Acceptance Criteria for the Safety Parameter Display System (Draft). National Technical Information Service, Springfield, VA.

NUREG-1270. 1980. Human Factors Evaluation of Control Room Design and Operator Performance at Three Mile Island-2. National Technical Information Service, Springfield, VA.

NUREG/CR-1278. 1980. Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications. NUREG/CR-1278. Sandia Laboratories, Albuquerque, NM.

NUREG/CR-2147. 1981. Nuclear Control Room Annunciators: Problems and Recommendations. National Technical Information Service, Springfield, VA.

OECD Halden Reactor Project. Report of the Workshop Meeting on Strategies for Handling Cautionary and Warning Alarms. Workshop held at Sarpsborg, Norway, February 18, 1982. OECD Halden Reactor Project (HWR-6), Halden, Norway.

Pollack, I. 1953. The information of elementary auditory displays. Journal of the Acoustical Society of America, 25, 745.

Pollack, I. and J. Tecce. 1958. "Speech Annunciator Warning Indicator System: Preliminary Evaluation." Journal of the Acoustical Society of America, 30:58-61.

Pope, R. H. 1979. "Power Station Control Room and Desk Design, Alarm System and Experience in the Use of Cathode-Ray-Tube Displays." In Nuclear Power Plant Control and Instrumentation, pp. 209-223. IAEA, Vienna, Austria.

Randle, R. J., Jr., W. E. Larsen, and D. H. Williams. 1980. Some Human Factors Issues in the Development and Evaluation of Cockpit Alerting and Warning Systems. NASA-RP-1055. Ames Research Center, Moffett Field, Sunnvale, California.

Regulatory Guide 1.23, Proposed Revision 1. 1980. Meteorological Measurement Programs in Support of Nuclear Power Plants.

Regulatory Guide 1.97, Revision 2.1980. Instrumentation for Light-Water-Colled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident.

Robinson, J. C., J. W. Allen, A. R. Buhl, F. E. Levert, and C. B. Oh. 1980. A Parameter Set for a Nuclear Plant Safety Console. (NSAC-10) Electric Power Research Institute, Palo Alto, California.

Rolfe, J. M. 1971. "The Secondary Task as a Measure of Mental Load." In Measurement of Man at Work, eds. W. T. Singleton et al., pp. 135-148. Van Nostrand Reinhold, New York.

Rogovin Commission Report (M. Rogovin, Chairman). 1980. Three Mile Island: A Report to the Commissioners and to the Public, Volume I, Nuclear Regulatory Commission Special Inquiry Group. U.S. Nuclear Regulatory Commission, Washington, D.C.

Rossiter, D. and S. Skolnic. 1980. Computer Systems Interface Guidelines for Nuclear Plants. (EPRI-NSAC-5). Macio Corporation, Fort Washington, PA.

Seminara, J. L., S. K. Eckert, S. Seidenstein, W. R. Gonzalez, R. L. Stempson, and S. O. Parsons. 1979. Human Factors Methods for Nuclear Control Room Design. EPRI Report NP-1118 (3 volumes), Palo Alto, CA.

Seminara, J. L., W. R. Gonzalez, and S. O. Parsons. 1976. Human Factors Review of Nuclear Power Plant Control Room Design, EPRI NP-309 and EPRI NP-309-2Y (Summary), Lockheed Missiles and Space Company for the Electric Power Research Institute.

Sheehan, D. J. 1972. Head-Up Display Warning Requirements Research. AD755736. National Technical Information Service, Springfield, VA.

Shikiar, R., W. L. Rankin, and T. B. Rideout. 1982. Applications of Human Factors Engineering to LNG Release Prevention and Control. PNL-4090. Pacific Northwest Laboratory, Richland, WA.

Siegel, A. I. and K. Crain. 1960. "Experimental Investigations of Cautionary Signal Presentation." Ergonomics, 3:339-356.

Simpson, C. A. and D. H. Williams. 1980. "Response Time Effects of Alerting Tone and Semantic Context for Synthesized Voice Cockpit Warnings." Human Factors, 22(3):319-330.

Singer, J. G. and G. Reeder. 1982. A Human Factors Review of a Nuclear Plant Control Room. Paper presented at the ISA Power Instrumentation Symposium, May 24-26, 1982. Los Angeles, CA.

Society of Automotive Engineers, Inc. 1980. "Flight Deck Visual, Audible, and Tactile Signals." ARP 450D. Warrendale, PA.

Swain, A. D. 1969. Human Reliability Assessment in Nuclear Reactor Plants, SCR-69-1236. Sandia Laboratory, Albuquerque, NM.

Tennessee Valley Authority. 1982. Human Factors Engineering in Alarm Systems, Electrical Design Guide, DG-E18.1.13.

Topliss, R. W. 1976. Alarm annunciators-what can they do for me? Automation, 11(1-2), 25-27.

Van Cott, H. P. and R. G. Kinkade (eds.). 1972. Human Engineering Guide to Equipment Design. Washington, D.C.: U.S. Government Printing Office.

Veitengruber, J. E., G. P. Boucek, and W. D. Smith. 1977. Warning and Alerting Systems Criteria Study, Volume I: Collation and Analysis of Aircraft Alerting Systems Data. FAA-RD-76-222, Federal Aviation Administration, Washington, D.C.

Visuri, P. and F. Owre. 1981. A Candidate Approach to a Computer-Based Alarm Handling System (HALO): Functional Description. OECD Halden Reactor Project (HWR-23), Halden, Norway.

Visuri, P. (ed.) 1981. Minutes of the HPG Subcommittee Meeting on Alarm Handling. OECD Halden Reactor Project (HWR-43), Erlagen, Germany, September 28-29, 1981.

Visuri, P. J., B. B. Thomassen, and F. A. Owre. 1981. Handling of Alarms with Logic (HALO) and Other Operator Support Systems. OECD Halden Reactor Project (HWR-24).

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16. ABSTRACT (200 words or less)

This report sets forth a basic design philosophy with its associated functional criteria and design principles for present-day, hard-wired nuclear power plant control room annunciator systems. It also presents a variety of annunciator design features that are either necessary for or useful to the implementation of the design philosophy. The information contained in this report is synthesized from an extensive literature review, from inspection and analysis of control room annunciator systems in the nuclear industry and in related industries, and from discussions with a variety of individuals who are knowledgeable about annunciator systems, nuclear plant control rooms, or both. This information should help licensees and license applicants in improving their hard-wired, control room annunciator systems as outlined by NUREG-0700.

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