Online Supplement to "Informing Healthcare Alarm Design and Use: A Human Factors Cross-Industry Perspective"

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Appendix A. Guidelines (Exact Text) From the Automotive, Aviation, and Nuclear Industries Related to Alarming/Alerting

Below, we provide a comprehensive list of relevant guidelines from other industries. We have used language aligned with what is stated in the source documents. Many industries use the term "alert" in addition to "alarm" without differentiating between the two terms. Thus, the term "alert" appears below.

Automotive Industry
Minimize false/nuisance warnings: Deactivate a warning device automatically when it is not needed during a particular driving situation (i.e., require the shift lever to be in reverse gear to place a backup warning device in the active mode).
Allow the driver to reduce detection sensitivity to a restricted limit that minimizes false/nuisance warnings without significantly affecting the target detection capability of the device.
Present a warning only after a target or critical situation has been detected as continuously present for some specified minimum time.
Mitigate annoyance by allowing the driver to reduce warning intensity or volume.
Use redundancy across systems (e.g., steering and machine vision inputs to a lane departure warning) to increase the information available to the system and reduce the potential for false alarms.
Multiple, simultaneously activated signals are used to provide redundancy, maximizing the likelihood a driver will receive an alert.
Multiple signals are used to create a sequential change in modality for different stages of a graded system—e.g., less imminent stages of a warning can be represented using a less invasive signal like a static visual icon, and auditory can be used for more imminent alerts.
Non-attention-getting visual components of a multimodal message persist beyond the duration of other warning signals to provide post-alert information regarding the nature of the warning.
Consider using a one-stage warning: • For applications in which earlier-stage warnings of a two-stage system may be perceived as nuisance warnings. • If the rate of false alarms associated with a two-stage system significantly reduces driver trust in the system or increases driver frustration with the system. • In potential crash situations that evolve too rapidly for a cautionary warning to be effective (e.g., an FCW cautionary warning that rapidly or ambiguously transitions to an imminent stage). • With ICWs, as a reliable warning presented earlier may be more beneficial for safety than a later warning.
Consider using a two-stage warning: • When a key goal of the system is to promote a long-term modification of driving behavior. • In situations where hard braking could have an undesirable effect (e.g., lower customer satisfaction in buses and load shifts for heavy vehicles). Hard-braking may be more likely with one-stage systems that only activate for imminent situations. • For alerts related to vehicles in an adjacent lane (i.e., if the visual display is located in the far periphery—such as in the side mirror, on the A-pillar, etc.—when the driver is looking forward). Examples of such applications may include LCW and BSW systems).
Consider using a multi-stage graded warning system when the primary goal of the system is to provide continuous information (e.g., headway information in an FCW, continuous proximity to vehicle in BSW, LCW, or reverse collision warning (RCW), etc.).
Extraction: Can the driver see/hear/feel the message? Can it be fully and accurately perceived under a representative range of driving circumstances and conditions?
Recognition: How well do the parts of the message (especially for complex visual messages) relate to one another? Does the construction of the message support accurate understanding? Is the message easily confused with other messages that have different meanings?
Interpretation: How well does the message reflect its underlying meaning? Will it be understood when presented in the appropriate context? Does it require any special knowledge particular to a culture, language, or driver age?
In general, information is presented in as simple of a manner as possible while ensuring messages support and add value for the driver.
Visual Messages consist of simple icons and fonts with only the necessary detail included. In text displays, the number of lines of text per-message is minimized.
Auditory Messages are simple when an immediate response is required. This could be single or grouped frequencies presented simultaneously, such as a simple tone that consists of a square wave.
Visual messages are best for presenting more complex information that is non-safety-critical and does not call for immediate action, and can be used to: • Provide continuous (uninterrupted presentation of information over a trip segment, a trip, or even a longer period of time) lower-priority information such as navigation-related or cautionary information. • Provide spatial information. In this regard, head-up displays (HUDs) and high-head down displays (HHDDs) also have potential for presenting critical information, especially if the message has a spatial component (e.g., location in space relative to the driver's vehicle). • Provide redundant or supplemental information that accompanies a primary auditory or haptic message. • Provide primary warning information in a situation in which drivers can reasonably be expected to see the visual warning as part of the regular information-acquisition process (e.g., a visual imminent crash warning for an LCW system that is presented on the rear-view and side-view mirror, or on an A-pillar).

Auditory messages are capable of quickly capturing the driver's attention and can be used to:

- Present short, simple messages requiring quick or immediate action.
- Present high priority alerts and warnings (e.g., imminent collision warnings); in this instance, can be used in conjunction with visual (or haptic) messages to provide redundant cues to the driver.
- Provide an important message to drivers in situations in which they may be distracted or looking away from a visual display (note: this may apply to haptic messages as well).
- Draw attention directly to the location of a potential crash threat.
- Indicate the onset of a system malfunction or limitation.
- Augment a visual warning in a non-time-critical situation.

Symbolic or iconic representations can be used to add meaning to critical analog displays and do not require reading to interpret.

Critical displays for continuous vehicle control or critical warnings related to vehicle forward path are located within ± 15 degrees of the central line of sight but as close to the central line of sight as practicable. Messages that require immediate detection should be located within 5 degrees of the forward view when possible [1], and 5 degrees to the right and 5 degrees down for messages on a HUD.

Displays are placed in locations that are generally compatible with established expectations or with location cues from other warnings, such as auditory or haptic.

The display location is compatible with the desired response, such as a display in the mirror for alerts for looking to the blind spot; a HUD that is used to direct attention to the forward view for critical warnings.

The design and location minimizes glare from external sources or other displays in the vehicle (e.g., in the instrument panel or under a protective cover).

The color is associated with the level of warning:

- Red is normally associated with danger or critical situations
- Yellow is normally associated with caution
- Green is normally associated with normal operation; however, other considerations about warning conspicuity may necessitate using a different color (see Design Issues on the next page)

The colors that are used are compatible with symbols based on prior association, such as red for octagonal stop signs, and yellow for triangular or diamond warnings.

The quantity of colors used to code information is minimized; do not exceed 4 color codes.

Color is used to create a "pop out" effect in forward collision warnings to show the area of concern more distinctly from the background scene.

The following color contrast combinations are avoided: green/red, green/blue, yellow/red, yellow/blue, violet/red.

Select sizes for text and icons in warning messages that support rapid legibility of the message.

A higher flash rate is used for more urgent situations—optimal rate is 3-4 Hz.

Multiple flash mode (rapid pulses of flash for each flash cycle) is used for more urgent situations.

Flash rate and duty cycle are adjusted as needed to ensure driver comprehension of warning content.

Warnings are presented in appropriate temporal proximity to the dangerous situation to elicit desired response but not a nuisance alarm.

Flashing is used for important, suddenly occurring situations.

Other motion cues such as bouncing or zooming are not used as they may unnecessarily increase driver eyes-off-road time.

Provide sufficient display luminance and use high contrast display technologies to ensure adequate contrast.

Simple tones: Single or grouped frequencies presented simultaneously (e.g., Sine wave or square wave)

- High flexibility for conveying various levels urgency
- Can be highly salient and obtrusive
- Can be annoying
- Meaning is not inherently known and must be learned

Suggested uses:

- Highly time-critical messages, such as imminent collision warnings
- Situations that require immediate action

Ear cons: Abstract musical tones that can be used in structured combinations to create auditory messages. Sometimes referred to as complex tones (e.g., "Ding" or two-tone chimes)

- Friendlier and less obtrusive sounds
- Meaning is not inherently known and must be learned

Suggested uses:

- Cautionary warnings
- Drawing attention to visual status information

Speech messages: Voice messages that add information beyond pure sound (e.g., "Danger")

- Meaning can be easily understood
- Takes time to receive the complete message
- Can be highly annoying if presented frequently

Suggested uses:

- Less time-critical messages
- Conveying complex information
- Situations that require more detailed information

To increase the perceived urgency: • Use faster auditory signals (e.g., 6 pulse/sec) • Use regular rhythms (all pulses equally spaced) • Use a greater number of pulse burst units (e.g., 4 units) • Use auditory signals that speed up • Use high fundamental frequencies (e.g., 800 Hz) • Use random or irregular overtones • Use a large pitch range (e.g., 9 semitones) • Use a random pitch contour • Use an atonal musical structure (random sequence of pulses) • Use fast onset ramp • Use more urgent words (e.g., "Danger")
To decrease the perceived urgency: • Use slower auditory signals (e.g., 1.5 pulse/sec) • Use irregular rhythms (pulses not equally spaced) • Use a fewer number of pulse burst units (e.g., 1 unit) • Use auditory signals that slow down • Use low fundamental frequencies (e.g., 200 Hz) • Use a regular harmonic series • Use a small pitch range (3 semitones) • Use a down or up pitch contour • Use a resolved musical structure (from natural scales) • Use slow onset ramp • Use less urgent words (e.g., "Caution")
The perceived urgency of a sound is matched with the urgency of its referent. Drivers who perceive the benefits of an obtrusive signal will be less likely to be annoyed by it.
Low annoyance sounds are used for benign situations.
Minimize the rate of false or nuisance alarms to reduce the potential for annoyance.
Systems use sounds with characteristics that promote perceived urgency more than perceived annoyance
The amplitude of auditory signals is in the range of 10–30 dB above the masked threshold (MT), with a recommended minimum level of 15 dB above the MT (e.g., [1, 2, 3]). Alternatively, the signal is at least 15 dB above the ambient noise.
The signal does not exceed a maximum intensity of 90 dBA.
Designers avoid presenting auditory warnings at more than 30 dBA above the MT to avoid startling or annoying drivers.
The auditory warning signal includes frequency components in the range of 500-2500 Hz, and the signal includes at least two dominant components in the subset range of 500-1500 Hz.
The intensity of cautionary warning signals is less than the intensity of the imminent collision warning signals; however, if doing so will limit the ability of drivers to perceive the cautionary warning, other signal characteristics could be used to convey lower urgency.
Other sounds produced by the vehicle (e.g., radio or HVAC fans) are muted or disabled while the warnings are presented, to enhance the audibility of warnings.
Auditory warnings use distinctive sounds that are easily distinguished from other sounds in the cab.
Vehicles that are equipped with more than one collision warning system (CWS) use auditory signals that are distinguishable between the individual CWS applications and their associated alerts.
Auditory cautionary warning signals are distinctive from imminent warnings (although the auditory modality is discouraged for cautionary warnings).
If simple tones are used, no more than four distinct tones are used to discriminate between warnings.
Too many distinctive warnings are avoided, as this may confuse drivers. Strategies such as functionally- grouped warnings may help minimize delayed reactions and driver confusion.
For Cautionary Warnings Use: • Lower urgency characteristics • Continuous tone or intermittent with long interval. • Low signal (or pattern) repetition rate • Low intensity • Low fundamental frequency • Small frequency oscillations within auditory patterns • Pleasant, "friendly" sounds • Gradual onset and offset rates
For Imminent Warnings Use: • Higher urgency characteristics. • Intermittent with short intervals • High signal (or pattern) repetition rate • High intensity • High fundamental frequency • Large frequency oscillations within auditory patterns • Obtrusive sounds • Rapid onset/offset rate (but not enough to startle)

The semantic content of directional speech alert messages is used to improve hazard detection and reduce reaction time.
The spatial localization of an auditory alert is congruent with the semantic meaning of the message (response times are generally improved)
High-bandwidth signals with high signal to noise ratio (SNR) are localized in the horizontal plane (azimuth). Avoid signals that are localized in the median plane (elevation).
Speech is used in conjunction with a textual visual warning; the speech and visual messages need to be redundant.
Speech messages used in time-critical applications are kept to a single word or a short phrase with the fewest number of syllables possible.
Cautionary warnings are limited to three or four information units* (e.g., “Vehicle ahead—merge right”).
The gender of the voice is either male or female; however, a female voice may more readily convey urgency than a male voice.
Speech is a natural voice or synthesized. Synthesized speech must be clear and intelligible, particularly when pronounced at high word rates.
A word rate of 150 to 200 words per minute is used to convey the urgency of the warning.
Speech is not preceded with an alerting tone unless a benefit for doing so can be demonstrated.
Aviation Industry
False alarm rates should not be so frequent as to cause the user to mistrust the automated system.
Users should be informed of the inevitable occurrence of automation false alarms particularly when base rates are low.
If equipment is not regularly monitored, an audio alarm shall be provided to indicate malfunctions or conditions that would cause personnel injury or equipment damage.
Alerting and warning systems shall be unambiguous, with a clear indication of the cause for the alert.
Alarms systems should a. alert the user to the fact that a problem exists, b. inform the user of the priority and nature of the problem, c. guide the user’s initial responses, d. confirm in a timely manner whether the user’s response corrected the problem
Alarms/alerts should indicate the degree of malfunction or emergency.
When a parameter value represents a fault in some modes and not in others, it should only be alarmed in the appropriate modes.
When alarm signals are based on user defined logic, the system should allow the users to access current alarm settings that are specified in terms of dimensions (variables) covered and which values (categories) are established as critical.
An alerting and warning system or signal shall provide the user with a greater probability of detecting the triggering condition than his or her normal observation would provide in the absence of the alerting or warning system or signal.
When necessary, users shall be able to request help and related information for the operation and processing of critical and non-critical alarms, messages, and signals.
Auditory as well as visual alarms shall be provided when the users work in an area with a high degree of ambient illumination.
All nonverbal audio signals shall be accompanied by a visual signal that defines the condition.
When used in conjunction with a visual display, an audio signal shall be supplementary or supportive, alerting and directing the user's attention to the appropriate visual display.
Alarms should be automatically organized and presented to the users in prioritized form, with the most significant alarms receiving the highest priority.
The display of alarms with higher current operational significance should automatically override the display of alarms with lower current operational significance.
When two or more incidents or malfunctions occur simultaneously, the one generating a message of higher priority shall be presented first followed by the remaining messages in descending order of priority.
The number of priority levels for alarm messages should be limited to four.
A message priority system shall be established so that a more critical message overrides the presentation of any message having a lower priority.
Warning signals shall be used to indicate the existence of a hazardous condition requiring immediate action to prevent loss of life, equipment damage, or a service interruption.
Caution signals shall be used to indicate conditions requiring awareness but not necessarily immediate action.
Caution signals shall be readily distinguishable from warning signals.
Alarm signals and messages shall be distinctive and consistent for each class of event.
Processed alarm information should be simple enough that users can easily evaluate the meaning or validity of the resulting alarm messages.
System status indication generally should be presented on a separate display from the alarm indicators.
Filtering should only be used for alarms that have no current operational significance.
When a single alarmed event invariably leads to subsequent alarmed events, the primary alarmed event should be shown with the subsequent events suppressed, as long as it does not interfere with the user’s tasks.
When an alarm is suppressed, users should be able to access the alarm information that is not shown.
The method for accessing information on suppressed alarms should not be excessively complex.

Training techniques should be devised to ensure that users are exposed to all forms of alerts and possible combinations of alerts and that they understand how to deal with them.

The design of audio display devices and circuits shall preclude false alarms.

The audio display device and circuit shall be designed to preclude warning signal failure in the event of system or equipment failure and vice versa.

Alarm system inputs (such as sensors) should be validated to ensure that spurious alarms are not presented to the user.

Alarm systems should have the capability to filter out noise signals to eliminate unnecessary alarms.

Audio signals should be provided, as necessary, to warn personnel of impending danger, alert a user to a critical change in system or equipment status, and to remind a user of critical actions that must be taken.

Auditory signals shall only be used when such signals contribute to understanding of and appropriate responses to the operational and task environment.

Auditory signals shall not result in user or operator confusion, errors, or inefficiencies in response.

An audio signal should be provided when any of the following conditions apply.

a. The information to be processed is short, simple, transitory, and requires immediate or time-based response.
b. The use of a visual display might be inappropriate because of overburdening of the visual modality, ambient light variability or limitation, user mobility, degradation of vision by vibration, other environmental considerations, or anticipated user inattention.
c. The criticality of a response to a visual signal makes supplementary or redundant alerting desirable.
d. It is desirable to warn, alert, or cue the user for subsequent or additional responses.
e. Custom or usage has created anticipation of an audio display.
f. Voice communication is necessary or desirable.

The intensity, duration, and source location of audio alarms and signals shall be compatible with the acoustical environment of the intended receiver.

Auditory alarms should not be used to indicate normal conditions.

When an audio signal is used, the particular type of signal (tone, complex sound, or speech) should be the best for the intended use as indicated in Exhibit 5.5.2.1.7.

Auditory signals shall be tested and evaluated for usability, operational suitability, and user acceptance using representative users in as near to a realistic operational environment as possible before the signals are incorporated into a system.

When appropriate to the task, a system or application should allow a user to set the parameter or condition that results in a software-generated alarm, alert, or status message.

User setting of parameters should not be allowed when:

(1) the settings by one user might affect the reception of alarms by another user;
(2) the settings might affect the safety of systems, equipment, or personnel; or
(3) alarm parameters are determined by functional, procedural, or legal requirements.

Signals with high alerting capacities should be provided when the system or equipment imposes a requirement on the user for concentration of attention.

Signals should not be so startling that they preclude appropriate responses or interfere with other functions by diverting attention away from other critical signals.

The most common auditory feedback, the system beep, should be used with other forms of notification such as flashing or message dialogs.

When absolute identification is required, the number of signals to be identified should not exceed four.

When relative discrimination is required, the number of alarm signals should not exceed 12.

A single audio signal should be used in conjunction with multiple visual displays only if immediate identification of the appropriate visual display is not critical to personnel safety or system performance.

Auditory signals that require different user responses should be easily distinguishable from one another.

Audio alarms intended to attract the user's attention to a malfunction or failure shall be different from routine signals such as bells, buzzers, random noises generated by air conditioning and other equipment and normal operation noises.

Audio alarms intended to attract the user's attention to a malfunction or failure shall be different from routine signals such as bells, buzzers, random noises generated by air conditioning and other equipment and normal operation noises.

Auditory signals should not be used if they resemble sounds that can occur in the actual operational setting.

Audio warning signals shall not interfere with any other critical functions or warning signals or mask any other critical audio signals.

The meaning of audio warning signals selected for a particular function in a system should be consistent with warning signal meanings already established for that function.

Standard signals shall not be used to convey new meanings.

Established signals should be used provided they are compatible with the acoustic environment and voice communication systems.

Auditory signals should be intermittent rather than continuous.

Audio warning signals should consist of two elements, an alerting signal and an identifying or action signal.

Modulated warning signals should either be modulated from 1-8 beeps per second or warbling with a pitch rise and fall of 1-3 cycles per second.

When reaction time is critical and a two-element signal is used, an alerting signal of 0.5 seconds duration shall be provided followed by an identifying or action signal with all essential information being transmitted in the first 2 seconds of the identifying or action signal.

When reaction time is critical, signals shall be of short duration.

When a single-element signal is used, all essential information shall be transmitted in the first 0.5 seconds.

Audio warning signal duration shall be at least 0.5 seconds and may continue until the appropriate response is made.
Signals that persist or increase progressively in loudness shall not be used if manual shutoff may interfere with the corrective action required.
Completion of a corrective action by the user or by other means shall automatically terminate the signal.
An alarm/warning signal shall provide an audio level in at least one octave band between 200 and 5,000 Hertz such that the signal is at least 10 dBA SPL (sound pressure level) above the ambient noise level, or 20 dBA SPL above the amplitude of the masked threshold, or at such a level that assures personnel are adequately alerted to the danger or status so as to take the appropriate response, when measured within 1 foot of the responder's ear, or at more than 2 feet from the alarm.
The frequency range of a warning signal shall be between 200 and 5,000 Hz, preferably between 500 and 3,000 Hz.
When a signal must be audible at a distance of 300 m (985 ft) or more, the frequency shall be below 1,000 Hz.
When the signal must be heard around obstacles or through partitions, the frequency shall be below 500 Hz.
The selected frequency band shall differ from the most intense background frequencies.
The frequency of a warning tone shall be different from that of the electric power employed in the system to preclude the possibility that a minor equipment failure might generate a spurious signal.
Mid-frequencies (1500-3000 Hz) should not be used for auditory alarms that require localization.
The intensity, duration, and source location of an auditory signal should be compatible with the acoustic environment of the intended receiver as well as with the requirements of other personnel within acoustic range of the signal.
When the audio alarms and signals must be heard and understood through equipment or garments (e.g., parka hoods and hearing protective devices covering the ears of a listener), audio signals shall be loud enough to compensate for the attenuation characteristics of the garments without exceeding 115 dB(A) for emergency signals and 90 dB(A) for other signals.
Auditory signals shall exceed the prevailing ambient noise level by at least 10 dB(A) or any maximum sound level with a duration of 30 seconds by at least 5 dB(A), whichever is louder, without exceeding 115 dB(A)for emergency signals or 90 dB(A) for other signals.
The intensity of evacuation and emergency signals shall not exceed 115 dB(A).
The intensity of signals other than emergency or evacuation signals shall not exceed 90 dB(A).
The user, the sensing mechanism, or both shall control the volume (loudness) of an audio warning signal depending upon the operational situation and personnel safety.
Volume control movement shall be restricted to prevent reducing the volume to an inaudible level or increasing it to an unacceptably high level.
Auditory coding should be used: a. to alert users to critical conditions or operations; b. to supplement visual signals; c. to present information in situations in which visual presentation is not feasible; and d. to provide feedback for control actuation, data entry, or the completion of timing cycles and sequences
Auditory coding should not be used when ambient noise prevents effective listening.
When a user must acknowledge a special or critical alarm in a unique way (e.g., with a special combination of keystrokes), this special acknowledgement shall not inhibit or slow the response to the condition initiating the alarm.
A system or application shall provide users with a simple means for turning off non-critical auditory alarms without erasing any displayed message that accompanies the auditory signal.
A system or application shall provide users with a means of acknowledging alarms and of turning off alarm signals once the alarms have been acknowledged or the condition generating the alarm has been corrected.
Procedures for acknowledgment and termination shall not decrease the speed and accuracy of operator reaction to the alerting situation.
A simple, consistent means of acknowledging auditory signals shall be provided.
When the signal is non-critical, the acknowledgement action shall also turn the signal off.
Users shall be able to acknowledge an alarm signaling the loss of redundancy, with the lack of available redundancy continuously displayed until the redundant system, equipment, module, or component becomes operable again.
If an audio signal is designed to persist as long as it contributes useful information, a shutoff switch controllable by the user, the sensing mechanism, or both, shall be provided consistent with the operational situation and personnel safety.
An automatic reset function for audio signals shall be provided, whether the signals are designed to terminate automatically, manually, or both.
Automatic reset functions shall be controlled by a sensing mechanism that recycles the signal system to a specified condition as a function of time or the state of the signaling system so that the warning device can sound again if the condition reappears.
Volume controls may be ganged to mode switches to provide maximum output during operational phases in which intense noise can occur and to provide reduced volume at other times. This ganging shall not be done if there is a possibility that intense noise could occur in an emergency situation during a phase in which the volume would be decreased below an audible level.
Audio caution signals shall be provided with manual reset and volume controls.
Voice signals should be used a. to supplement visual displays when communication flexibility is necessary, b. when coded signal meanings are numerous or may be forgotten, c. for presentation of complex directions or instructions, d. when ambient noise may mask simple tonal signals, e. in conjunction with tonal signals, and f. for presentation of continuous information when the rate of change is low.
Voice signals shall consist of a brief, standardized speech signal (e.g., a verbal message) to identify the specific condition and suggest an appropriate action.

Verbal signals should be preceded by an initial non-speech alerting signal to attract the user's attention if the verbal warning signals are used for other types of information as well as warnings.
The system should require that users acknowledge spoken warning signals.
Verbal signals for critical functions shall be at least 20 dB above the speech interference level at the operating position of the intended receiver without exceeding 90 dB(A).
Speech intensity should be appropriate to the expected ambient noise environment, with a signal to noise ratio of at least 5:1.
The words used in verbal signals shall be concise, intelligible, and appropriate to the task and the information presented.
Word selection priority should all be intelligibility, descriptiveness, and conciseness, in that order.
To the extent possible, words that rhyme with other words or that sound similar in other ways should be avoided if these other words might be used in the same context and, therefore, possibly be confused with the original words.
Formal or correct words should be used instead of slang, jargon, and colloquial words.
Alphabetic information should be presented using a phonetic alphabet that uses words like alpha, bravo, and Charlie rather than the letters A, B, and C.
Spoken messages should sound like an average talker from the user country without a regional dialect.
When different categories of voice signals are used, a different, distinctive voice should be used for each category of data.
Spoken messages should be brief, informative, and to the point.
The voice used in recording verbal warning signals should be mature and distinct enough not to be confused with voice communications including radio and intercom communications.
Voice signals shall be presented in a formal, impersonal manner.
Critical warning signals shall be repeated with not more than a 3 sec pause between messages until the condition is corrected or overridden by an operator or user.
Verbal warning signals shall be processed only if necessary to increase or preserve intelligibility, for example, by increasing the strength of consonant sounds relative to vowel strength.
Visual indicators shall be coded by color, size, location, shape, or flash coding as applicable.
Visual coding shall be consistent within a system or unit of equipment and between similar units of equipment.
Visual signals should be coded to indicate the priority level of the signal.
Flashing red shall be used to denote emergency conditions that require immediate user action to avert impending injury, equipment damage, or both with an approximately equal on and off time flashing rate from three to five flashes per second.
A visual alarm, with the exception of master caution, warning, and advisory indicators, shall be singular in purpose yet comprehensive in meaning without referring the user to other alarm indicators for other warning information.
Transilluminated displays should be used to provide qualitative information that requires immediate attention or an immediate response or to draw attention to important information.
Master caution lights, master warning lights, master advisory lights, and summation lights used to indicate the condition of an entire subsystem shall be set apart from lights that show the status of subsystem components, except as required in Paragraph 5.4.2.2.1.8.
The use of flashing lights shall be minimized and used only to call a user's attention to a condition requiring immediate action.
The flash rate shall be not less than three and not more than five flashes per second, with the on and off times being approximately equal.
When more than one flashing indicator is located within a user's field of view, their flashes shall be synchronized.
Flashing red to indicate an emergency condition that requires immediate action to avert impending injury, equipment damage, or both red to indicate that (1) the system or a portion of the system is inoperative, or (2) successful task completion is not possible until appropriate corrective or override action is taken, yellow to indicate (1) a marginal condition, (2) an unexpected delay, (3) that caution is necessary, or (4) that rechecking is necessary, green to indicate that (1) equipment is in tolerance," (2) conditions are satisfactory, or (3) it is all right to proceed, white to indicate system conditions that do not have "right" or "wrong" implications
Emergency controls and visual indicators shall be located where they can be seen and reached quickly and easily.
When a window contains task-critical information, that information should be displayed in a way that users can identify easily, (for example, separating it from other information by a blank space).
Information that is particularly important or that requires immediate user response shall be displayed in the user's primary viewing area.
The most important information and controls associated with a task should be located in the upper left part of its window and the least important at the bottom.
Text-background luminance contrast ratios for a variety of tasks and conditions shall not be less than those given in Exhibit 5.6.2.2.1.
Brighter or more saturated colors should be used to draw a user's attention to critical data.
When color is used to emphasize information, the brightest color should be used for the most important information.
Green, yellow, and red should be avoided as comparison colors for application information requiring important or frequent discriminations.
Flash or blink coding should only be used to indicate an urgent need for the user's attention and response, or to indicate the active location for data entry.
The rate of flashing shall be in the range of two to five Hertz (flashes per second) with a minimum ON interval of 50 percent.
When two flash rates are used, the higher rate should apply to the more critical information, with the lower rate less than two flashes per second.
When flash coding is used, users should have a means of acknowledging the flashing, which, when appropriate, automatically stops the flashing.

Data or text that the user must read should never blink or flash because a blinking object is, by definition, not displayed continuously and can be read only when it is displayed.
When a displayed object is to be flash coded, a flashing symbol adjacent to the object should be used rather than flashing of the object itself.
When a user must read a displayed item that is flash coded, an extra symbol should be used to mark the item, such as an asterisk or arrow that flashes rather than having the item itself flash.
When flash coding must be used on text, the flash rate should be 1/3 Hz to 1 Hz with an on/off cycle of 70%.
A hazard alerting or alarm device shall be provided to warn personnel of impending danger or existing hazards such as fire, radio frequency or radiation, or the presence of combustible or asphyxiating gas.
Hazard alerting or alarm devices shall be located where the people who must take corrective action can easily distinguish them.
Redundant hazard alerting devices of different types, for example, a light and a bell, shall be required if ambient noise could mask the audible alarm, or if the warning light could not be seen in the ambient illumination.
Critical messages warning users of destructive consequences of actions should be displayed in warning message windows.
When a warning message window appears, processing should be suspended until a user responds to the message.
Warning message windows should contain a warning symbol (!), a message, and one of the following sets of push buttons below the message in the order listed: {Yes, No, and Help} or {OK, Cancel, and Help}.
Warning messages should be accompanied by an audible signal.
Messages or alarm signals shall be provided to warn users and system administrators of potential threats to data security.
The number of false alarms shall not be such that they negate the effectiveness of alarms.
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Advisory messages should be distinctive. Additional Information: The salience of the message presentation should be appropriate to its content. For example, messages regarding potential data loss might be marked with a blinking symbol or displayed in red, or both, and be accompanied by a distinct auditory signal. Error messages might be marked with a different special symbol or displayed in yellow, or both.
Important information should be presented through both visual and auditory means. Additional Information: The visual display of important information should be redundant, using pictures, schematics, color, and text. An auditory alerting tone should accompany such information.
Alarm set points should be determined to ensure that the operating crew can monitor and take appropriate action for each category of alarms (e.g., respond to out-of-tolerance conditions) in a timely manner. Additional Information: Alarms are established to help ensure that the plant remains within SAR and technical specification limits. To achieve this, the setpoints may be specified at conservative levels that are well within the actual limits to allow sufficient response time for operators and plant systems. Thus, where practical, alarm setpoints should be determined such that the operator is alerted before a major system or component problem results in a condition that causes a loss of availability (e.g., plant trip), equipment damage, violation of SAR and technical specification requirements, or other serious consequences. Other criteria are acceptable if they do not compromise these factors.
The determination of alarm setpoints should consider the tradeoff between the timely alerting of an operator to off-normal conditions and the creation of nuisance alarms caused by establishing setpoints so close to the “normal” operating values that occasional excursions of no real consequence are to be expected. Additional Information: When determining setpoints, consideration should be given to the performance of the overall human-machine system (i.e., operator and alarm system acting together to detect process disturbances). If setpoints are established such that many false alarms occur, operators become less likely to respond to the alarm, especially when their tasks become cognitively demanding. Processing techniques are applied to prevent normal variation from producing alarms. Under some circumstances, however, preventing such alarms may deprive operators of needed information. In 4-12 cases where raising an alarm’s setpoint or delaying its presentation is not acceptable, more sophisticated techniques (e.g., alarms based on rate of change of the parameter or the time at which the parameter is projected to exceed a setpoint) should be considered.
Alarms and setpoints should be designed so that only parameters and conditions that fall outside the normal and expected range and that require operator attention or action are in the alarm state. Additional Information: This has traditionally been referred to as the dark board concept and is applicable when at full-power operation. In practice, it may be difficult in some plants to completely achieve a dark board but that should be the goal. If the alarm system does not have this capability for all operating conditions, it should be in effect when all systems are lined up in their most typical configuration for full-power operation. This concept has implications for the plant’s operating philosophy as well, including issues such as (1) repairing failed equipment expeditiously, (2) taking corrective actions for instrument drifts that cause alarms, and (3) correcting conditions that frequently lead to repeat alarms.
The alarm processing system should ensure that alarms that require immediate action or indicate a threat to plant critical safety functions are presented in a manner that supports rapid detection and understanding under all alarm loading conditions. Additional Information: Alarm processing should be provided to ensure that alarm functional criteria are not lost under any operational or accident conditions. The alarm system should provide the capability to reduce the number of concurrent alarm messages so that during off-normal conditions, the alarm system does not overload the operator’s cognitive processes. Special attention should be given to the problem of detecting subsequent malfunctions following the presentation of alarms related to an initial disturbance.
The number of alarm messages presented to the crew during off-normal conditions should be reduced by alarm processing techniques (from a no-processing baseline) to support the crew’s ability to detect, understand, and act upon all alarms that are important to the plant condition within the necessary time. Additional Information: Since there is no specific guidance on the degree of Alert reduction required to support operator performance, the designer should evaluate the system with operators to assess the effectiveness of the Alert reduction process. This assessment should include evaluations that simulate the operation of the alarm system under situations that activate multiple alarm conditions or generate increased operator workload, or both. The use of dynamic mockups and prototypes of the alarm system and dynamic control room simulators should be considered when developing these assessments.
Sensor and other input signals should be validated to ensure that spurious alarms are not presented to plant personnel because of sensor or processing system failure. Additional Information: Instrumentation failure is not a common problem in NPPs. However, when such failures as a failed sensor occur, biased or false signals are generated. The use of these signals by the alarm system may result in the presentation of either false or nuisance alarm messages. Such alarm messages are misleading and may interfere with the crew’s situation assessment or reduce the crew’s confidence in future alarm messages. Signal validation is a set of alarm processing techniques by which signals from redundant or functionally related sensors are compared and analyzed to determine whether a true alarm condition exists. The purpose of these techniques is to prevent the presentation of false alarms to the operator caused by malfunctioning plant instrumentation. Hence, an advanced alarm system should include signal validation.

Status indications, messages that indicate the status of plant systems but are not intended to alert the user to the need to take action, generally should not be presented through the alarm system display because they increase the demands on the users for reading and evaluating alarm system messages. Additional Information: While status information is important to operators, status indications are not alarms and should be presented to operators by a nonalarm display (e.g., on process displays). If the presentation in the alarm display of status indications is justified based on the unique aspects of the design, such status messages should be designed so that operators may readily distinguish them from true alarm messages.

If a single event invariably leads to subsequent alarmed events that are the direct consequence of this event, only the alarm message associated with the main event may be presented and the other alarm messages suppressed, so long as this does not interfere with the user's situational awareness. Additional Information: For example, logical consequences processing may be used to suppress alarms that follow as a logical consequence of trip or isolation conditions. When implementing logical consequences processing, the designer should ensure that messages associated with the "consequence" alarm conditions are not needed for other operational tasks and that operators are aware that the associated "consequence" alarm conditions were generated but not presented. This guideline only suggests suppression of these alarms not their complete elimination (i.e., filtering).

The system should notify the user when unexpected alarms occur. Additional Information: A related feature that may also be considered is to annunciate the absence of expected alarm patterns (i.e., the system can notify the operator when "expected" alarms do not occur. Such analyses may apply, for example, during certain transients (e.g., reactor scram) where the expected alarm pattern is well known.

The alarm system should provide functions that enable users to evaluate the meaning or validity of the alarm messages resulting from alarm processing; for example, it should be possible to view the inputs to the alarm processing system. Additional Information: Complexity of the processing affects the operator's ability, as the system supervisor, to understand the results of alarm processing and its constraints and limitations. Since the alarm system is the operator's first indication of process disturbances, and operators will confirm the validity of alarm signals before acting, it is essential that operators easily comprehend the meaning of alarm data, how they are processed, and the bounds and limitations of the system. An alarm system that combines multiple processing methods should not be so complex that it cannot be readily understood and interpreted by the operators who must rely on the system's outputs. If operators are unaware of the relationships among displayed alarms and how those relationships might depend on the processing being

applied, they may draw incorrect conclusions about the state of the system or the reliability of the alarms. For example, operators may need to view sensor data and values that result from alarm system processing under certain circumstances, such as if the pattern of alarm messages appears to be contradictory, or if operators suspect that there is a problem with the processing system such that the results of alarm processing are incorrect.

Alarm messages should be presented in prioritized form to indicate urgency (immediacy of required action) and challenges to plant safety. Additional Information: Additional alarm priority dimensions, such as challenges to plant productivity or investment protection, may also be implemented. The selected prioritization scheme should be logical such that those alarms of the highest safety significance receive the highest priority and such that the prioritization appears reasonable to operators.

When alarm suppression is used, the user should be able to access the alarm information that is not displayed. Additional Information: Suppressed alarms are not presented to the operators, but they can be accessed by operators upon request. The method for accessing suppressed alarms and the scheme for their presentation to the operators should not be excessively complex.

Alarms should be routed to appropriate destinations based on their intended use. Additional Information: Alarms that require operator action are routed to operator displays or workstations. The system provides the capability to route only a subset of the alarms to one or more workstations if the operators using those workstations have responsibility only for a portion of the plant. Alternatively, all operator alarms can be routed to all operator workstations. Alarms that are responded to by maintenance personnel should be routed to maintenance workstations. For example, detailed information on a fault in the I&C systems or the alarm system itself would be provided to maintenance technicians for troubleshooting and repair.

An alarm log should be maintained. Additional Information: An alarm log supports event analyses. Alarms may be recorded in a separate alarm log or integrated into a more comprehensive record of plant information. Section 4.2.5, "Alarm Contents," identifies the types of information that can be included in the alarm log.

The alarm display should support the user's ability to rapidly discern the following:

a. priority (e.g., urgency for action and importance to plant safety)
b. distinct alarm states: new, acknowledged, and cleared
c. the first-out alarms for reactor trip
d. the need to access other displays to verify or clarify the alarm state
e. the difference between alarms that can be cleared through ongoing corrective actions (i.e., by operations personnel) and alarms that require significant maintenance intervention

Additional Information: Multiple alarm display formats, such as dedicated tile-like displays, alarms embedded into process displays, and message lists, may be necessary to satisfy all alarm information needs.

When alarm alerts are displayed separately from detailed alarm information, the design should support rapid transitions between alerts and detailed information. Additional Information: In conventional annunciator tile-based alarm systems, the annunciator tile performs both the alerting function (i.e., providing a salient indication of the presence of an alarm condition) and the informing function (i.e., providing information that describes the nature of the alarm condition). In advanced alarm systems, the alerting and informing functions may be separated. For example, an alarm tile display may alert the operator to the presence of an alarm condition while an alarm message list display may provide detailed information, such as the alarm parameter name and setpoint value. The presentation of the alerting and informing information should be coordinated so the operator can rapidly access detailed alarm information associated with the alarm condition alerts.

When alarm alerts are displayed separately from detailed alarm information, the detailed alarm information display should indicate the priority and status of the alarm condition. Additional Information: The operational significance of the detailed alarm information, such as the parameter name and the exceeded setpoint value, may be more readily apparent to the operator when accompanied by an indication of the alarm's priority and its status (e.g., whether it is acknowledged or unacknowledged).

Alarms for any shared systems in multiple-unit plants should be duplicated in all control rooms. Additional Information: Multiple-unit NPPs may contain systems that are shared by two or more units. The status of any such equipment should be provided in all control rooms. When an item of shared equipment is being operated from one control room, a status display or signal should be provided in all other control rooms where the condition of the equipment is operationally relevant (e.g., other locations from which the equipment could be controlled).

Alarms that have higher importance or greater safety significance should be given greater priority in their presentation than less important alarms. Additional Information: The priority of presentation should be part of an overall process for alarm management, which may include coding for the level of importance or priority, and alarm processing, filtering, and suppression.

For nonspatially dedicated alarm presentations such as VDU message lists, a sufficient display area should be provided for the simultaneous viewing of all high-priority alarms. Additional Information: Non spatially dedicated alarm displays, such as message lists, should generally not be used as the primary method of presenting high-priority alarm messages. If non spatially dedicated alarm displays are used, they should have sufficient display space available for simultaneous presentation of all high-priority alarms under the worst credible conditions. Operators should never have to page or scroll a display to view high-priority alarms.

A method of coding the visual signals for priority should be employed. Additional Information: Acceptable methods for priority coding include color, position, shape, and special symbols. Color and position (top to bottom) are especially effective visual coding methods.

Unacknowledged, acknowledged, and cleared alarm states should have unique presentations to support the users' ability to rapidly distinguish them.

Unacknowledged alarms should be indicated both by visual (e.g., flashing) and audible means. Additional Information: When unacknowledged alarm messages are presented on a VDU, the message text itself should not flash. Rather, an adjacent flashing symbol should be used to indicate the unacknowledged message.

After the user has acknowledged an alarm (e.g., pressed the acknowledge button), the alarm display should change to a visually distinct acknowledged state.

When an alarm clears (i.e., the parameter returns to the normal range from an abnormal range), the return to normal conditions should be indicated by visual and audible means. Additional Information: Ring back, alerting the operator when a parameter returns to normal, should not be required for all alarms but should be required when it is important that the operator know immediately when the deviation has cleared, or when the deviation is not expected to clear for some time. Such cleared alarms should provide a positive indication by initiating audible and visual signals. Techniques that may be employed include a special flash rate (one-half the normal flash rate is preferred, to allow discrimination), reduced brightness, or a special color. Cleared alarms should have a dedicated, distinctive audible signal, which should be of finite and relatively short duration.

If an alarm has cleared but was not reset and the parameter reenters the abnormal range, then the condition should be presented as a new alarm. Additional Information: When an alarm clears, the operator is informed by the ring back feature that the value is now in its normal range. Since the operator might expect the parameter to remain in the normal range, the alarm system should alert the operator when the parameter deviates from the normal range. If the parameter again enters the abnormal range, the alarm system should behave as it does for new alarms, by producing visual and auditory signals to alert the operator. For cases in which a parameter might move (e.g., oscillate) in and out of the normal range, alarm processing should be used to prevent the frequent reoccurrence of the alarm from becoming distracting to the operator. One technique might be to require the parameter to move further into the normal range before the alarm clears. Another technique might be to require the parameter to remain within the normal range for a particular amount of time before allowing the alarm to clear.

Alarms that are triggered by any one of an aggregate of individual alarms (e.g., "Pump Trouble") and that require the operators to perform additional actions to determine the cause should be limited. Additional Information: This guideline does not apply to the use of alarm processing through which individual alarms are logically processed to provide more operationally meaningful, higher level alarm messages. By contrast, shared alarms are defined by the activation of one or more of a set of different process deviations. For example, a "trouble" message may combine several potential problems associated with a single plant system or component, or it may address the same problem for a group of similar components (e.g., a bearing temperature alarm may address bearings from more than one component). When shared alarms are used, an inquiry capability should allow the operator to obtain specific information about which of the ganged parameters exceeded its setpoint. Table 4.2 gives the criteria for the use or avoidance of shared alarms. In traditional (i.e., tile-based annunciator) alarm systems, shared alarms imposed additional workload on the operator compared to single alarms because the operator had to identify the deviant parameter(s). Advanced alarm systems should minimize this type of shared alarm. Some advanced alarm systems automatically present information related to the deviant parameter when the shared alarm is initiated. This reduces the operator workload associated with retrieving alarm information and minimizes the negative effects of shared alarm.

The system should allow users to access the individual alarm information when a shared alarm activates. Additional Information: The information could be provided by means of alarm messages on a VDU, an alarm list on an alarm printer, or by other means. This information may be provided automatically or by operator action.

If a new parameter deviation has occurred before a preceding alarm has cleared, the shared alarm should return to the new alarm state (e.g., flashing). Additional Information: The alarm logic system should provide the capability to "reflash" (i.e., reactivate the visual and audible alert indications for the alarm) when subsequent alarm conditions occur after the initial alarm condition has been acknowledged.

Titles and legends should be clearly understandable, use standard terminology, and address conditions specifically. Additional Information: For example, specifically identify the parameter and state (e.g., HIGH PRESSURE) instead of using one legend for multiple parameters or multiple states (e.g., TEMPERATURE–PRESSURE or HIGH–LOW). Abbreviations can be used if they are clearly understandable (see Section 1.3.2, Abbreviations and Acronyms).

The format of messages on alarm tiles or tile-like displays should be consistent for all alarms. Additional Information: Information on a tile might be organized as follows: top line, name of alarmed parameter; middle line, alarm setpoint value; bottom line, indication of severity.

The content of each message should provide information that identifies the alarm source. Additional Information: Information should be available as to which specific sensor (or group of sensors) supplied the alarm signal.

Alarms should be time "stamped" with the time of occurrence and the time at which the condition clears (returns to normal). Additional Information: When multiple systems are detecting and time-stamping alarms, events, and data values, all time clocks should be synchronized to a common, correct date and time. Alarm time and the chronological sequence of alarms, events, and process data is critical to the ability of operators and engineers to diagnose plant upsets and perform other post event analyses. This is also important for correct implementation of "first out" capability.

An alarm message should indicate its priority.

The relevant setpoint limits should be readily available to users. Additional Information: This information can be provided, for example, by including it in the alarm message when alarm information is presented on a VDU, is printed, or is in the ARPs.

Immediate actions should be presented or made available directly upon request when alarm information is presented on VDU or printer displays. Additional Information: To support the general alarm system function of guiding the operator's response to an alarm, the immediate actions should be provided to the operator. For conventional alarm systems, the immediate operator actions should be available in ARPs that are clearly and simply keyed to an alarm tile and located nearby for easy and quick reference. In this case, the procedure would contain those items that could not be incorporated into the alarm display itself (e.g., alarm source, setpoint value, immediate actions, and follow-up actions). Advanced alarm systems may present the relevant alarm response procedure (e.g., through a nearby VDU).

Each level of a coding dimension should be easily and readily distinguishable from the other levels. Additional Information: For example, if color is used, the different colors should be easily distinguishable. Each color should have a single, precise meaning that is consistent with applicable population stereotypes. A formal coding scheme that encompasses all coding methods (e.g., color, shape, brightness, textures or pattern, and flash rates) and specifies that a hierarchic order should be established and formally documented. Alarms should be organized into categories according to priority. Coding should be systematically applied such that alarm information with the highest priority is also most prominent.
Each technique used to code alarms should represent only one dimension of the alarm classification. Additional Information: If a flash rate is being used to indicate alarm state (e.g., unacknowledged, acknowledged, or cleared), it should not also be used to indicate the need for user action (e.g., immediate action required, action required within 15 minutes, or no near-term action needed).
The number of different coding techniques should be kept to a minimum, so that the coding system does not become too difficult to use or understand.
A visual coding method should be used to indicate alarm importance and should be consistently applied throughout the alarm system. Additional Information: To be effective, an alarm system should attract attention and help the operator focus attention on more-important rather than less-important alarms. A flashing visual signal is a preferred means for directing attention and indicating alarm status (e.g., unacknowledged, acknowledged, and cleared-not reset) on SDCV and computer-based displays.
Redundant codes (e.g., color and location) should be used for alarms that require rapid action.
Flash rates should be from three to five flashes per second with approximately equal on and off times.
For transilluminated displays, such as lighted alarm tiles, the luminance of the dim state (if used) should be at least 10 percent greater than the inactivated state; the brightest state should not be more than 300 percent of the surrounding luminance. Additional Information: Transilluminated displays should have no more than three levels. Brightness of "on" alarms should not be annoying or distracting.
Low-intensity indications (e.g., dark red) in the periphery of the visual field should be avoided where color coding is used, since they may not be readily detected. Additional Information: If the display system has an area that is a specific focus of attention, then displays located in adjacent areas may be frequently in the periphery of the operator's field of vision.
Spatial coding may be used to indicate alarm importance.
If the visual codes indicating alarm status are automatically suppressed or delayed during high alarm volume conditions (or the presence of more important alarms), they should be automatically presented after the more important alarms have been addressed. Additional Information: Under high alarm volume conditions, the designer may consider suppressing or delaying the alerting indications (e.g., visual flashing) for those alarm conditions that (1) do not require immediate response, and (2) do not indicate a challenge to plant safety and technical specifications. This will assist operators in detecting the more significant alarm messages and reduce distraction from less important ones. Plant personnel should not be required to remember to request alarms that have been automatically suppressed.
An auditory signal should be used to alert the user to the existence of a new alarm or any other condition of which the user must be made immediately aware. Additional Information: Auditory cues should be provided for all new alarms under normal operating conditions.
Auditory coding techniques should be used when the workstation associated with the alarm is not in the main operating area. Additional Information: During off-normal conditions, the designer should consider the suppression of the auditory code for those alarms that (1) do not require immediate response, and (2) do not indicate a challenge to plant safety and technical specifications. This will prevent operators from being distracted by less important alarms while attending to more significant ones.
The auditory signal associated with an SDCV alarm should be easily distinguishable from the auditory signal associated with an alarm message displayed by other means (e.g., on a VDU message display).
The tones used for incoming alarms should be separate and distinct from tones used to signify "clearing" alarms.
If the tone associated with an unacknowledged alarm automatically turns off after an interval of time, a reminder tone should be presented to alert the user to the continued presence of an unacknowledged alarm. Additional Information: The same principle holds for alarms that may have had the auditory code suppressed because of high alarm conditions or the presence of more important alarms. When the more important alarms have been addressed, the alarm system should remind the operator, through visual or auditory signals, of the presence of the unacknowledged alarms.
The auditory alert mechanism should automatically reset when it has been silenced.
Audio alarm signals should not conflict with other auditory codes or signals. Additional Information: If continuous, relatively loud signals are used, they may render other codes and signals less audible. Thus, it may be necessary to consider the audibility of a signal not just in the presence of ambient control room noise but also in combination with other signals that might plausibly occur at the same time. To avoid mutual masking, the frequencies of tonal signals associated with alarms that may be active at the same time should be separated by at least 20 percent of the center frequency. Interference among alarm signals is less of a concern if the signals consist of several widely separated frequency components or of brief groups of pulses presented at intervals. Techniques are available that allow the audibility of signals in noise to be predicted.
The user should be able to quickly determine where to direct attention (e.g., which functional area of the plant or which station) from the characteristics of the auditory alert and the source from which the auditory alert originated. Additional Information: This guideline pertains to the use of auditory tones to direct the operator to the location of a spatially fixed alarm display device to expedite the operator's response to the alarm condition. The use of sound to indicate the location of the alarm display may be of less value if the advanced alarm system allows the same alarm message to be retrieved from multiple locations (e.g., from redundant VDUs) in the control room. It should also be noted that, in advanced control rooms that feature compact control consoles, the alarm display devices may not be physically separated enough to use sound localization as a cue. In this case, coded audio signals (possibly from a single source) would be used to direct the operators' attention. Thus, this guideline is most appropriate for advanced alarm systems that feature spatially fixed alarm display devices. It has been recommended that coded signals from a single audio source should not be used to identify individual workstations within the main operating area and that each major console should be equipped with a separate sound generator capable of producing a distinctive sound. If the direction of a source sound is to be used as a cue, the signal should not be a high-frequency pure tone, since such signals can be difficult to localize.
The signal intensity should be such that users can reliably discern the signal above the ambient control room noise. Additional Information: The intensity of an audio signal should be such that users are alerted aurally to an alarm occurrence under the most adverse anticipated background noise conditions. A signal level 10 to 20 decibels (on the A-weighted scale (dBA)) above average ambient noise, for quiet (below 45 dBA) and noisy areas respectively, is generally considered adequate. It has also been recommended that sound intensity be limited to a maximum of 95 dBA; however, signal levels of 115 dBA may be used if considered necessary to achieve required attention-getting reliability for alarms indicating extreme danger. Signal levels above 115 dBA should not be used. The tendency for designers to err on the side of conservatism results in many audio signals being more intense than is necessary to ensure reliable detection.

Audio signals should be designed to minimize irritation and startle. Additional Information: Signals should reliably capture the user's attention but should not be unpleasant. Considerations include the selection of signal frequency and intensity, as well as the overall design of the audible alarm scheme.
Manual disabling or adjustment of auditory signal intensity (loudness) should be avoided. Additional Information: Signals should reliably capture the user's attention but should not be unpleasant. Considerations include the selection of signal frequency and intensity, as well as the overall design of the audible alarm scheme.
The number and placement of loudspeakers should be such that auditory signals are free of distortion and are equally audible at any workstation in the control room. Additional Information: Speakers should be oriented away from surfaces that could scatter or diffuse the acoustic wave. Speakers should not be located behind structures that could cause distortion, echoes, or sound shadows. When sound localization is used to direct the operator to particular alarm display devices, the loudspeakers should be oriented such that their location can be quickly discerned and should correspond to the location of the intended alarm display device. Loudspeakers for adjacent alarm display devices should have adequate separation to allow their individual locations to be discerned.
Each audio signal should be unambiguous and easily distinguishable from every other tone in the control room. Additional Information: Current sound generation technology allows the design of alarm signals that make better use of the operator's ability to process audio information. It is possible to design signals that are not only more distinguishable from one another than are conventional signals but also have the potential to carry more information. Signals should be composed of unique combinations of tone pattern and frequency.
When information is coded by the pitch of narrow-band signals (i.e., tones), no more than three frequencies should be used. Additional Information: The frequencies should not be in a ratio of 2:1 with one another since it can be difficult to identify pitches an octave apart. Although some sources recommend that no more than five separate frequencies be used, operators may not reliably distinguish among more than three pitch codes. For critical alarms with differing response requirements, the more conservative guidance should be followed. If more than three critical alarms are to be coded, it is preferable to combine pitch with another dimension to create more distinctive signals.
Center frequencies should be widely spaced within a range of from 500 to 3,000 hertz (Hz), although a wider range of from 200 to 5,000 Hz may be acceptable. Additional Information: It is recommended that tonal signals be broadband and widely spaced within the 200 to 5,000 Hz range.
No more than three pulse repetition rates should be used for coding purposes. Additional Information: Repetition rates should be between 1 and 8 pulses per second since faster rates may not be perceived as pulses. Repetition rates should be sufficiently separated (e.g., differ by a factor of 2) to ensure operator discrimination. Sounds with the same temporal pattern, including signals with similar duty cycles (on-off times), may be confused, despite having very different pulse speeds (i.e., periods). Such signals are therefore more appropriate for coding the level of urgency of a condition than for indicating different types of conditions.
No more than three modulated frequency codes for audible alarms should be used. Additional Information: Warbling sounds, with frequencies modulating from 1 to 3 times per second, are attention-getting as well as easily recognized, whereas slower modulation rates do not develop distinguishable characteristics rapidly enough to be appropriate for alerting applications.
If modulation of frequency (Hz) of a signal is used to denote information, the center frequencies should be between 500 and 1,000 Hz.
If sequences of tones are used to represent information, the patterns should be easily recognizable. Additional Information: Warning sounds consisting of "bursts" composed of five or more brief pulses (about 0.1 second in duration) with interpulse intervals of .15 to .3 seconds have been recommended. The pulses may be designed to be distinctive with respect to their onset and offset shaping, fundamental frequency, and harmonic structure. The bursts may vary as to the number of pulses, the tempo at which they are presented, and the rhythmic and pitch contours.
A maximum of nine auditory signals should be used when coded in two or more dimensions. Additional Information: When signals differ in two or more dimensions (e.g., pitch and temporal pattern), a greater number of signals can be reliably distinguished. This maximum includes auditory signals used outside of the control room (e.g., fire alarm or site emergency alarm).
Coding of auditory signals by intensity (loudness) should not be used. Additional Information: The range of intensities between the level required to ensure audibility and the level at which signals become aversive can be relatively narrow; the usefulness of this dimension for coding is therefore limited. If such coding must be used, no more than two levels should be defined. The signals should differ from each other by a minimum of 6 dBA. The lower intensity should be about 10 dBA above the ambient noise level, and the maximum signal-to-noise ratio should be 10 dBA for most applications of sound intensity coding. It is recommended that sound intensity should be limited to a maximum of 95 dBA but that signal levels of 115 dBA may be used if considered necessary to achieve required attention-getting reliability for alarms indicating extreme danger. Whether this coding would be effective would depend on the frequency spectrum of the ambient control room noise and the frequency of the signal.
Using speech alone for presenting alarm information is not recommended. Additional Information: Speech is an acceptable medium for presenting interface-related, and there may be advantages associated with using speech for presenting alarm information, as well. However, its appropriateness has been questioned for tasks where there is a memory component, there is likely to be some delay before the fault is attended to, there is likely to be more than one alarm presented at a time, and where the operator is required to assimilate information from a variety of sources using spatial reference. Therefore, it has not yet been shown that it is an appropriate method for presenting alarm information in process control contexts. Speech should only be used in conjunction with other methods of presenting alarm information.
Alarms within a display should be grouped by function, system, or other logical organization. Additional Information: Alarm elements should be grouped so that system functional relationships are readily apparent. For example, area radiation alarms should be grouped on one display, not spread throughout the control room. As much as possible, the alarms should be grouped with controls and displays of the same system.
Alarms should be ordered to depict naturally occurring relationships. Additional Information: Naturally occurring relationships (e.g., those derived from the physical process) include the following: • pressure, flow, level, and temperature alarms in fluid systems • alarms for a given thermodynamic parameter at different points within the system that indicate a progression (e.g., within a fluid system, a series of pressure alarms starting with the source tank and ending with the system discharge) • several alarms for the same parameter indicating levels of severity (e.g., tank level low and tank level low-low) • alarms related by cause and effect For example, pressure, flow, level, and temperature could be arranged left to right.
Alarm parameters (e.g., pressure, flow, level, and temperature) arranged in one order on one panel should be arranged in the same order on other panels. Additional Information: Circumstances may dictate different orderings for systems with very different functions. However, once an arrangement has been chosen, the arrangement should be used consistently within similar systems or alarm groups.

When process displays cannot show all alarms, those that are more important to plant monitoring and operator action should be selected for display. Additional Information: There is a tradeoff between showing alarm information and cluttering the display with too much information. Therefore, if space is limited, only the most important (highest priority) alarms should be presented. An alternative is to provide a high-level indication that a relevant alarm exists. For example, on a soft control display, a single alarm symbol could be presented to indicate to the user that an alarm relevant to the control actions exists.
An alarm acknowledgment function should cause the alarm's visual coding to change from that indicating an unacknowledged alarm to a visually distinct "not cleared" state. Additional Information: For example, the acknowledge function might cause an alarm to change from flashing to steady.
Acknowledgment should be possible only from locations where the alarm message can be read. Additional Information: If alarm information is available at multiple VDUs, then operators should be able to acknowledge the alarm from the VDU at which they are working. If alarm information is presented on a large control room overview display, operators should be able to acknowledge it from alarm control locations where it can be seen. This flexibility will minimize disruption caused by the alarm system interactions. It should not be possible to acknowledge alarms from locations where they cannot be read. If alarms can be acknowledged from multiple locations, then a means should be provided for ensuring that all operators for whom the alarm is important are aware that the alarm occurred. These means may include spoken, telephone, or computer-based communications among personnel.
The reset function should place an alarm in an unalarmed state after the condition has cleared. Additional Information: The reset function should silence any audible signal indicating clearance and should extinguish the light and return the alarm to an inactive state. Note that some alarms may have automatic reset, when it is not necessary that the operators specifically know the reset condition.
A manual reset sequence should be used where it is important to explicitly inform users of a cleared condition that had once been deviant.
An automatic reset sequence should be available where users have to respond to numerous alarms or where it is essential to quickly reset the system. Additional Information: An automatic reset sequence should not be used in this situation.
The reset function should be effective only from locations at which plant personnel know which alarm they are resetting.
If the alarm system provides user-selectable operational configurations, then these configuration changes
should be coupled with an indication of the present configuration. Additional Information: Alarm systems allow users to select alternative functional configurations of the alarm system under some alarm situations, such as automatic silencing of auditory alerts for lower priority alarms under high-alarm conditions. Another example may be operator selection of an alarm message suppression mode in which low-priority messages are not presented through the alarm displays but may be accessed through operator action. It is important for the alarm system to inform the operators that a requested change in system configuration has been successfully achieved. In addition, a prominent display of the present configuration should be available.
Acknowledgment (or confirmation) should be required if a significant alarm system configuration change is to be made by user selection. Additional Information: Alarm systems allow users to select alternative functional configurations of the alarm system under some alarm situations. An example may be operator selection of an alarm message suppression mode in which low-priority messages are not presented through the alarm displays but may be accessed through operator action. It is important for the alarm system to inform the operators that a requested change in system configuration has been successfully achieved. In addition, a prominent display of the present configuration should be available.
The alarm system may provide temporary, user-defined alarms and user-defined set points for specific conditions where such alarms are determined to be of assistance in selected evolutions (e.g., temporary alarms to support increased monitoring of a problem component, or at other times when the user wants to know of a parameter trend that is approaching a limit).
User-defined alarms and setpoints should not override or interfere with the existing alarms and setpoints.
The alarm system should provide a clear indication of user-defined alarms and setpoints, as distinct from the alarm and setpoints designed into the system.
The definition and removal of operator-defined system characteristics should be under administrative controls.
If the alarm system automatically changes operational configurations under some alarm situations, then these configuration changes should be coupled with an alert to the user and an indication that the configuration has changed. Additional Information: Alarm systems may provide automated functions under some alarm situations, such as automatic silence of auditory alerts for lower priority alarms under high-alarm conditions. It is important that operators be notified of the change in system functioning. In addition, a prominent display should be available to remind operators of the current configuration of the system.
Acknowledgment (or confirmation) should be required if a significant alarm system configuration change is to be made automatically. Additional Information: Alarm systems may allow users to select alternative functional configurations of the alarm system under some alarm situations, such as automatic silencing of auditory alerts for lower priority alarms under high-alarm conditions. It is important for the alarm system to inform the users that a requested change in system configuration has been successfully achieved. In addition, a prominent display of the present configuration should be available.
Separate controls should be provided for silence, acknowledgment, reset (acknowledging an alarm that has cleared and returning it to normal), and testing. Additional Information: A global silence capability, together with separate silence and acknowledge capabilities, can be useful during high-alarm situations by allowing the user to silence many distracting alarms and then acknowledge these alarms at their respective panels. A variety of controls is possible, such as pushbuttons, function keys, and onscreen controls.
Alarm system controls should be distinctively coded for easy recognition. Additional Information: The controls should be distinguishable from each other, by touch and sight, to prevent accidental operation of the wrong control. Such techniques as color coding, color shading the group of alarm controls, demarcating the group of alarm controls, or shape coding should be used.
Each set of alarm system controls should have the functions in the same relative locations. Additional Information: Consistent locations should be established for silence, acknowledge, reset, and test operating sequence controls.
Alarm system control designs should not allow the controls to be altered or defeated. Additional Information: For example, some pushbuttons for alarm silencing and acknowledgement can be held down by inserting an object in the ring around the pushbutton. While the controls should be designed to prevent their being defeated, the system should be designed to minimize the desire to do so.
The alarm system should be designed so that no single failure will result in the loss of a large number of alarms. Additional Information: Also, the failure of a single alarm system component should not result in the loss of an individual alarm important to plant safety.

In case of flasher failure, an unacknowledged alarm should assume a highly conspicuous state, such as a steady "on" (e.g., illuminated) state, rather than a less conspicuous state, such as "off." Additional Information: While it is preferable in the case of a flasher failure for the associated alarm element to remain on (e.g., illuminated) rather than off, a unique and highly conspicuous code is best. The code should be unique to prevent confusion between unacknowledged and acknowledged alarms. It should be salient to alert the operator to the malfunction of the alarm display system. In addition, other alerting mechanisms, such as warning messages, may be used to inform the operator of a malfunction in the alarm display system.

Test controls should be available to initiate operability tests for all essential aspects of the alarm system (including processing logic, audible alarms, and visual alarm indications). Additional Information: For those portions of the alarm system (such as audible alarms and visual indications), the test capability should be simple and available to the operators. The more complex portions (such as sensor inputs and logic processing) should also be testable but by I&C technicians and engineers. Advanced alarm systems, having the capability for continuous, online, self-testing, may satisfy some of these recommendations.

Periodic testing of the alarm system should be required and controlled by administrative procedure. Additional Information: Simple functional tests are normally required once per operating shift. Reliability analyses of the alarm system may be used to determine appropriate intervals and degree of testing to be performed on the alarm system.

The alarm system should be designed so that maintenance activities can be performed with minimal interference with the activities of the users. Additional Information: Desirable design features may include built-in test capabilities, modular components that can be rapidly removed and replaced, and rear access panels that prevent maintenance activities from obstructing the users' view of controls and displays.

Tagging out an alarm (taking it out of service) should require disabling of the associated visual and audio signals. Additional Information: A tagged-out alarm should never be lit or flashing and should never cause any audible device to sound.

Cues for prompt recognition of an out-of-service alarm should be designed into the system. Additional Information: Tagging out an alarm should not prevent its identification and should not obscure any other alarm or interfere with operations.

Aids should be provided, if needed, to assist personnel in performing alarm system maintenance. Additional Information: Aids include instructions and specialized tools. For example, aids may be needed to support changing the light bulbs in the alarm system.

Users should be given prompt indication of a failure of the alarm system or its major subcomponents.

Alarm response procedures (ARPs) should contain the following information:

a. the system or functional group to which the alarm belongs
b. the exact alarm text or legend
c. the alarm source (i.e., the sensor(s) sending the signal, processors and signal validation logic, and the actuating device(s) for the alarm with a reference to a schematic diagram on which such devices can be found)
d. alarm setpoints
e. priority
f. potential underlying causes for the alarm (e.g., low water level, inadequate feed flow)
g. required immediate actions, including actions that can be taken to confirm the existence of the alarm condition
h. actions that occur automatically when the alarm occurs (and which should be verified as having taken place)
i. follow-up actions
j. explanations of relevant alarm processing (e.g., comparisons and combinations of plant parameters; alarm filtering and suppression; alarm setpoints that are conditional, such as setpoint values and time delays used to prevent the occurrence of nuisance alarms when a parameter oscillates in and out of the alarm range)
k. pertinent references

Information contained in the ARPs should be consistent with information on control boards, in the alarm system, in I&C procedures used to calibrate alarm setpoints, in controlling documents that determine setpoints (e.g., technical specifications and accident analyses), in piping and instrumentation diagrams (P&IDs), in emergency operating procedures, and in other plant procedures.

The terminology, conventions, standards, and codes used to present the ARPs should be consistent with the rest of the HSI. Additional Information: The ARPs should use the same conventions, such as terminology for plant systems and equipment, identification codes for plant components and parameters, and measurement units, that are used in the main HSI displays and procedures. Defined values, such as alarm setpoints, should be consistent. In addition, information coding schemes used in the ARPs should be consistent with the rest of the HSI. For example, if graphical displays are used to present the ARPs, then coding conventions, such as symbols, icons, and color, should be consistent with the rest of the HSI, such as information presented in plant displays and computer-based systems for emergency operating procedures. For example, if color codes are used to indicate priority, it should have the same meaning across all displays of the HSI.

The ARP format should do the following:

a. highlight the ARP identifier on each page of the procedure
b. highlight important items
c. locate information categories in the same position on each page
d. consistently present information throughout the ARP
e. minimize the need for paging back and forth to obtain the information

Visible alarm indications should be located within about 60 degrees on either side of the direct line of sight of the user's normal work position.

Alarm displays and controls should be located so that the display can be read while operating the controls.

Alarm displays and controls should be arranged and located such that those in the control room who must respond to an alarm can access the alarm information in sufficient time to respond adequately.

Visual alarm panels should be located near the controls and displays that are required for corrective or diagnostic action in response to the alarm. Additional Information: If displays and controls associated with an alarm are on different panel segments, the alarm displays should be located near the process display segment. If they are presented on a VDU, easy access to supporting controls and displays should be provided in the display.

Indicator lights or other nonalarm illuminated displays should not be located so close to alarm displays that they could be mistaken for an alarm or mask an alarm.

Appendix B. Analysis of Guidelines From Other High-Risk Industries (Automotive, Aviation, and Nuclear) Related to Alerting, Organized by Alert Guideline Topic

Alarm Reduction

Guidelines Applicable to Visual and Auditory Modalities. All three industries recommend filtering, suppressing, and reducing detection sensitivity to minimize false or nuisance alarms and reduce annoyance, engender trust in the system, and bolster alarm effectiveness. The nuclear and aviation industries recommend that alarm system inputs be validated to ensure that sensors are not faulty to avoid triggering false alarms. The nuclear and aviation industries also recommend that if a single event leads to subsequent related alarms, only the alarm that triggered the event should be presented.

The automotive industry recommends that alarm systems use redundant inputs to increase alarm accuracy. This industry also recommends turning off warning sensors when they are not needed (e.g., backup warning device turned off when the car is in drive). It also recommends that higher priority alarms override alarms of lesser priority to reduce interference. The nuclear industry recommends testing various alarm reduction strategies and system sensitivities to make informed decisions about what works.

Guidelines Applicable to the Auditory Modality. The automotive industry recommends that non-alarm noises produced by the system (e.g., radio or heating, ventilation, and air conditioning fans) be muted in the presence of auditory alarms. The aviation industry recommends that systems filter out environmental noises that could produce false auditory alarms.

Guidelines Applicable to the Visual Modality. The automotive and nuclear industries recommend that visual alarms be sensitive enough to warn users before a critical event occurs but not so sensitive that they produce frequent nuisance alarms.

Appropriateness

Guidelines Applicable to Visual and Auditory Modalities. All three industries recommend using bimodal alarms for critical information. The automotive industry provides guidelines for multistage alarms (i.e., alarms that occur sequentially over time) indicating graded warning levels. One-stage alarms should be used when immediate action is required or if a two-stage alarm may be considered a nuisance. Two-stage alarms are recommended to promote long-term behavior change or when urgency is less preferred (e.g., suddenly braking a vehicle in icy conditions is not the preferred response). Multi-stage alarms are recommended to provide continuous information (e.g., directions). The automotive industry also recommends that alarms be deployed after a trigger condition has been present for a predetermined time.

The aviation industry recommends bimodal alarms be used in environments with high ambient illumination, when auditory signals are nonverbal, and as needed to attract attention to visual alarms. This industry also recommends a single audio signal be used with multiple visual displays if locating the correct visual display quickly is not critical. The nuclear industry recommends the user be notified (modality not specified) when parameters are unexpectedly outside of normal conditions or when an expected parameter (e.g., status alarm) is absent. Additionally, once the user has cleared an alarm, the system should alarm (modality not specified) the return to normal conditions if it is important for the operator to know a deviation has been cleared. The nuclear industry also recommends that unacknowledged alarms be presented bimodally.

Guidelines Applicable to the Auditory Modality. All three industries agree that auditory alarms should indicate when immediate action must be taken and should be used when the system is not regularly monitored (e.g., when a workstation is not located in the main operating area of a plant). The automotive and aviation industries recommend that auditory alarms be used when the information is simple and short, when there are too many existing visual alarms for a particular workflow, and when the environment makes a visual alarm difficult to see. The automotive and aviation industries recommend that the type of auditory alarm (e.g., tone, speech) be chosen based on the specific situation. For the most part, the industries provide different, though not conflicting, recommendations; the automotive and aviation industries agree that tone alarms should be used in situations that require immediate action and speech alarms should be used to convey complex information.

The automotive industry recommends using earcons (e.g., "ding," two chimes) to draw attention to cautionary alarms. Speech alarms should be used in situations where time is not critical since delivery of the alarm is longer than a tone; however, speech alarms may improve hazard detection and reaction time.

The aviation industry recommends using auditory alarms to remind users of actions to be taken, but not using them to indicate normal conditions. The aviation industry states that tone alarms are appropriate when used in combination with other alarms (e.g., flashing, text). Speech alarms are appropriate when a tonal alarm may be forgotten, when the ambient environment may mask a tonal alarm, or when presenting continuous information. The aviation industry recommends using auditory coding (i.e., alarm information that is conveyed by sound characteristic, such as high-pitch sounds for urgent alarms and low-pitch sounds for nonurgent alarms) for critical alarms, supplementing visual signals, providing feedback, and presenting information when a visual alarm is not possible.

The nuclear industry recommends using auditory alarms to indicate when a visual alarm is presented and a reminder tone to attract attention to the visual alarm that is unacknowledged. The nuclear industry recommends against using speech alarms to present complex information, when there is a memory component, when there are multiple alarms, or when special information is important.

Guidelines Applicable to the Visual Modality. The automotive industry recommends that visual alarms be used to deliver complex, lengthy messages in noisy locations or locations with frequent auditory alarms that the user continuously monitors. The automotive industry suggests that visual alarms are best at delivering information that needs to be referred to later or acted on immediately, or that deals with locations in space.

Context-Dependence

Guidelines Applicable to Visual and Auditory Modalities. The automotive industry recommends that auditory and visual alarms be easily perceivable in an environment. The nuclear industry recommends that alarms appear in locations where users who can address the alarm are likely to reside (e.g., send maintenance alarms to maintenance stations) and if an alarm type is relevant to more than one user group, it should be routed to all relevant group locations. Also, only users with visibility to the alarm and alarm information should be able to reset alarms. This industry also recommends that if alarms are separated from their source information (e.g., a red light indicates an alarm and an alarm log indicates the reason for the alarm), the alarm and the information should be physically close together.

Guidelines Applicable to the Auditory Modality. The automotive and aviation industries recommend that auditory alarms be distinguished from environmental noise. The aviation industry specifically recommends distinguishing auditory alarms in intensity, duration, source location, and frequency from the environment and recommends that auditory coding not be used in noisy environments. The aviation industry recommends that any speech alarms are distinct from other recorded speech in the environment (e.g., intercom communication). It also recommends that auditory alarms be compatible with clothing and equipment (e.g., headgear, hearing protection) and that alarms do not mask important feedback from the environment. The nuclear industry recommends that auditory alarms be audible and duplicated in any relevant workstation.

Guidelines Applicable to the Visual Modality. All industries recommend that visual alarms are physically located within the users' workflow and line of sight, especially critical alarms (e.g., blind spot detection alarms on side mirrors). The aviation and nuclear industries recommend presenting system status indicators and alarms in different locations. These industries also recommend placing visual alarms near controls required to respond to the alarm.

Design Characteristics

Guidelines Applicable to Visual and Auditory Modalities. The automotive industry recommends designing all alarms in a simple and understandable way and making bimodal speech and text alarms redundant (i.e., speech and text to provide the same information).

The nuclear industry recommends maintaining an alarm log with time stamps to support event analysis. The nuclear industry also recommends designing alarm systems that are resilient, give prompt indication of system or component failure, can be regularly tested, have maintenance systems that minimally impact the performance of the user, require alarm signals to be disabled when taking an alarm out of service, and do not interfere with the user's ability to act on the alarm. It recommends requiring manual reset when it is important for the user to know the condition has cleared, and an automatic reset should be available when numerous alarms are present. The reset function should return the alarm to an inactive state. This industry recommends changing alarms to a distinct acknowledged state (e.g., auditory alarm turned off, visual alarm changed color) after the user acknowledges the alarm. If a new abnormal range occurs, the alarm should be presented and distinguishable as a new situation.

Guidelines Applicable to the Auditory Modality. The automotive and aviation industries recommend specific frequencies and loudness for auditory alarms in general, in comparison to ambient noise, at specific distances, and in the presence of obstacles. These industries also recommend speech alarms be short and use formal language. The automotive industry recommends that speech alarms not be preceded by an alarm tone; however, the aviation industry recommends preceding alarm tones to speech alarms. The aviation and nuclear industries recommend designing alarms that will not startle the user.

The automotive industry recommends using high-bandwidth signals with a high signal-to-noise ratio, and a few distinct tones to discriminate between auditory codes. The automotive industry recommends speech alarms be natural voice or an easily understood synthesized voice.

The aviation industry recommends creating auditory alarms with two elements: an alarming signal (i.e., catches attention) and an identification signal (i.e., relays information). Additionally, avoid using midfrequency auditory alarms when they require localization. The aviation industry also recommends auditory alarms be designed to be clear, unambiguous, and understandable to prevent alarm failure. The aviation industry recommends using intelligible and descriptive speech, avoiding words that sound like other words, digitally processing speech to increase intelligibility, and using the North Atlantic Treaty Organization (NATO) alphabet (e.g., Alpha, Bravo, Charlie) for alphabetic information. The aviation industry also recommends using auditory codes that differ in two or more dimensions (e.g., pitch, temporal pattern). The aviation industry also recommends using brief and intermittent auditory signals rather than a continuous one and recommends specifications for the duration of auditory alarms. The nuclear industry recommends automatically resetting auditory alarms when they are silenced.

Guidelines Applicable to the Visual Modality. The automotive and aviation industries recommend avoiding certain colors in visual alarms and designing visual alarms so they are highly visible. The automotive and nuclear industries recommend that visual alarms be designed with high intensity, contrast, and luminance. The automotive industry recommends adjusting the flash rate to ensure the alarm is comprehensible, avoiding bouncing or zooming in visual alarms, limiting the number of colors in visual alarms, and using simple fonts and icons as well as minimal text.

The aviation industry recommends brighter, more saturated colors to draw attention and specific luminance contrasts between background and foreground in typical settings and in a dim state. The aviation industry recommends specific flash rates and flash coding on visual alarms, and that visual flashing alarms synchronize with one another and flash a symbol, asterisk, or arrow as opposed to the text or the whole alarm. The nuclear industry recommends specific flash rates for visual alarms and that if a flashing alarm fails, it should fail to an "on" position as opposed to an "off" position.

Mental Model

Guidelines Applicable to Visual and Auditory Modalities. The automotive and nuclear industries recommend that related alarms should be grouped together. The automotive industry recommends that for multimodal alarms, visual components should be presented to the user longer to maintain situational awareness. The automotive industry also recommends designing alarms that are easy to recognize and understand based on the user's existing knowledge.

The nuclear industry recommends that alarm groupings should be based on naturally occurring relationships when possible. This industry recommends consistent formatting of alarms on all displays, including word order (e.g., title, value, severity), alarm arrangement (e.g., pressure placed above temperature), and alarm control arrangement (e.g., reset placed below acknowledge), as well as consistent terminology, symbols, and standards across alarm displays and procedure manuals. The nuclear industry recommends limiting aggregated alarms (e.g., single alarms that combine data from multiple sensors), but if aggregated alarms are used, users should be able to see which information is outside of normal conditions. This industry also recommends providing clearly labeled and usable aids for interacting with alarms and performing system maintenance, and a system design that enables user comprehension.

The nuclear industry recommends using minimal alarm coding strategies to make it easier to understand. It recommends separating controls for silencing, acknowledging, resetting, and testing alarms, and making these controls distinct.

Guidelines Applicable to the Auditory Modality. The aviation and nuclear industries recommend designing auditory alarms using few auditory codes, especially when users are required to identify the meaning of the alarm. The aviation industry recommends testing for system alarm usability using representative users. It also recommends avoiding operator confusion, errors, and inefficiencies when responding to auditory alarms and providing a consistent method for acknowledging alarms across the system. The aviation industry recommends keeping auditory alarms consistent across the system, using standard accents from the user's country, utilizing existing associations for auditory alarms, and avoiding the use of sounds with old associations to represent new concepts.

Guidelines Applicable to the Visual Modality. The aviation industry recommends using symbols and icons as well as colors that utilize existing associations (e.g., octagon stop sign, yellow triangle). It also recommends maintaining consistent visual coding of alarms within the system and equipment. The nuclear industry recommends standard terminology and abbreviations for visual alarm titles and legends, and a single display area for high priority alarms.

Prioritization

Guidelines Applicable to Visual and Auditory Modalities. The aviation and nuclear industries recommend designing an alarm management system that prioritizes urgent and important alarms, and when two alarms appear simultaneously, the higher priority alarm is presented and the lower priority alarm is suppressed. The aviation industry recommends alarms be categorized into a limited number of priority levels with distinguishable characteristics. The nuclear industry recommends that high priority alarms be detectable under any expected environmental conditions.

Guidelines Applicable to the Auditory Modality. The automotive industry recommends that auditory alarms reflect prioritization through sound intensity.

Guidelines Applicable to the Visual Modality. The aviation industry recommends that the most important alarm information be displayed on the top left of the screen and the least important on the lower right. The nuclear industry recommends that if visual alarm information is displayed separately from detailed information, the detailed information should show the priority and status of the alarm. In the context of multiple alarms where some alarms are suppressed to address the priority alarm, once the priority alarm has been acknowledged, this industry recommends that alarms that may have been suppressed reappear.

Specificity

Guidelines Applicable to Visual and Auditory Modalities. All industries recommend designing visual and auditory alarms that are easily distinguishable from one another. The nuclear industry recommends that each technique used to code alarms (e.g., color, pitch, placement) should represent one aspect of alarm classification (e.g., color only represents priority). It also recommends distinguishing alarms based on their system state (e.g., unacknowledged, acknowledged, cleared).

Guidelines Applicable to the Auditory Modality. All industries recommend designing auditory alarms that are easily distinguishable from one another. The aviation industry recommends auditory coding that distinguishes signals based on the necessary response. It recommends that tone alarms are distinguished using intensity, pitch, beats, and harmonics, and that speech alarms are distinguished using different, distinct voices. The nuclear industry recommends designing auditory alarms that are distinct from other sounds produced by the system. It recommends using auditory codes that differ based on specified repetition rates and frequencies, but auditory codes should not use loudness as a dimension.

Guidelines Applicable to the Visual Modality. All industries recommend consistent visual coding of alarms using color, size, location, shape, and flash. The aviation industry recommends that system status indicators should be visually distinct from alarms. It also recommends using individual visual alarms to convey a singular message, except for master warning/summation lights. Additionally, warning/summation lights that summarize a subsystem should be visually distinct from their subsystem components.

Urgency

Guidelines Applicable to Visual and Auditory Modalities. All three industries recommend that alarms should indicate the degree of the problem they are highlighting. The automotive industry recommends using different modalities to signal urgency (e.g., visual for low urgency, auditory for high urgency). The aviation industry recommends using warning signals to indicate conditions requiring immediate action, while caution signals be used to bring awareness to certain unsafe conditions that do not present immediate danger.

Guidelines Applicable to the Auditory Modality. The automotive industry recommends matching the perceived urgency of the auditory alarm with the true urgency of the system and minimizing perceived annoyance, especially for low urgency situations. This industry recommends increasing perceived urgency of auditory alarms by using short and simple tones, fast regular rhythms that speed up over time, high frequencies, random overtones, large pitch ranges, atonal musical structure, obtrusive sounds, and more urgent words (e.g., danger). For speech alarms, the automotive industry recommends using a female voice and specific word rate to convey urgency. The aviation industry recommends using alarms that capture attention when the system requires high concentration from the user and repeating urgent auditory alarms until they are corrected or acknowledged.

Guidelines Applicable to the Visual Modality. All three industries recommend the use of visual characteristics to convey urgency, such as specific flash rates, bright colors, and high contrast, to indicate urgent situations.

The automotive industry specifically recommends the use of displays lit from the back (e.g., car warning lights) to convey urgent qualitative information. It also recommends using flash rates exclusively for situations that require immediate attention and using high flash rates for more urgent situations. The aviation industry recommends providing critical alarms if a user begins an action that could lead to danger or compromised data security, and these alarms should be interactive (e.g., ability to select yes, no, help) and prevent the user from interacting with the system until the alarm is acknowledged. The nuclear industry recommends using special coding to indicate urgency (e.g., all urgent visual alarms placed at the top of the display).

User Control

Guidelines Applicable to Visual and Auditory Modalities. The aviation industry recommends that users be able to request help when needed, have access to current alarm systems and shutoff switches, and be trained on alarms. For example, this industry recommends that users should easily be able to access suppressed alarm information. In some unspecified cases, the aviation industry recommends allowing users to set their own alarm parameters, but users should not be allowed to set alarm parameters when one user might affect settings of a second user or when parameters are determined by functional, procedural, or legal requirements. The aviation industry recommends automatically terminating and resetting alarms when the user performs the appropriate corrective action. The aviation industry recommends that any acknowledgment actions should not interrupt the user's response to the alarm, and that users should be able to turn off noncritical alarms via the acknowledge button or turn off critical alarms once they have been acknowledged or corrected.

The nuclear industry recommends allowing users to access alarms that have been suppressed in favor of displaying high-priority alarms and subalarms that are nested in master alarms, and to see the current alarm parameters. Additionally, the user should be able to set temporary parameters that do not change the system parameters for specific conditions and should be required to acknowledge any changes they select. Parameters set by the system versus the user should be easy to distinguish, and system parameters should be under administrative control. Any automatic parameter changes made by the system should alarm the user and require user acknowledgement. The nuclear industry recommends designing alarms to prevent users from defeating the controls (e.g., intentionally placing a book on top of reset button).

Guidelines Applicable to the Auditory Modality. While both the automotive and aviation industries recommend that users control alarm volume and intensity, the aviation industry suggests that volume controls should be restricted to an extent to maintain minimum audible levels. However, the nuclear industry recommends no manual adjustment of alarm signal intensity.

Guidelines Applicable to the Visual Modality. The aviation industry recommends alarming the user if there is a loss of redundancy in the alarm system, and continuously displaying the lack of redundancy until the system is operable.