OPERATOR PERFORMANCE and ANNUNCIATION SOUNDS

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ABSTRACT

This paper discusses the audible component of annunciation found in typical operating power stations. The purpose of the audible alarm is stated and the psychological elements involved in the human processing of alarm sounds is explored. Psychological problems with audible annunciation are noted. Simple and more complex improvements to existing systems are described. A modern alarm system is suggested for retrofits or new plant designs.

AUDIBLE ALARMS

The Purpose of an Audible Alarm

Annunciations, or alarms are used to attract the attention of a person to a particular situation that may need to be addressed immediately or in a very short time. Typically, an annunciation consists of an audible portion, the sound that attracts the operator's attention, and a visual portion. Over the years, the visual portion or component of the annunciation has evolved from flashing lights to back-lit printed messages, to cathode ray tube monitors displaying messages; first in black and white or green on black, then in colour, then printed messages; first black on white, then colour. The audible portion has remained basically unchanged. No progress has been made in this area since power stations were first built. The purpose of the audible alarm as used today is to direct the operator's attention to the visual component of the annunciation.

Examples of Audible Alarms

Many sounds are used to alert us to situations that need attention. Sounds may warn us of dangerous situations that have just developed (a change of state), or they may inform us of a particular state of affairs. Both of these uses of sound have been well developed in areas other than nuclear plant warning systems. Through the use of some examples it will become clear how nuclear plant warning systems could be improved by adapting some of the existing technology.

Some pedestrian crosswalk signals are equipped to signal states to enable a visually impaired person to know when sighted people see the walk light ON and it is 'safe' to cross the street. These signals range from a simple alarm on the busiest crosswalk in uptown Saint John, N.B. that has the sound of a loud electro-mechanical coocoo bird, to a sophisticated signal in Saskatoon, Saskatchewan that voices the message, "the cross walk at twenty-second street and third avenue is okay to walk." Both are adequate to signal a safe walking condition for the visually impaired persons who have adequate knowledge. That is, they understand the purpose of the simple alarm in Saint John or they understand the language in Saskatoon.

Observations. No such situational occurrence as this is ever presented in a Nuclear Power Plant.

Klaxon Technology

The word klaxon probably brings to mind the sounds from an old war movie featuring a submarine going into a crash dive. The word klaxon is actually a trademark used now to mean an electrically operated horn or warning signal. The annunciation alarm sound that power plant people are familiar with can rightly be included in the klaxon sound group. This sound can be heard in all of NB Power's generating stations and most or many of the Ontario Hydro generating stations. Energy Control Centres and Switching stations are armed with similar sounds. A study could very possibly reveal that one or two manufacturers are responsible for the technology for all of these annunciation systems. The klaxon sound can be described as a blaring or irritating or even an offensive sound. Electronic warbles and shrill sounds from speakers have been introduced in some applications; but the principle is the same. Many operators would agree, perhaps begrudgingly, that the first thing that enters their mind when they hear an alarm sound is not to address or acknowledge the situation, but to "stop the noise." An observer cannot measure whether the operator responded promptly because they were keen, eager and alert, or because they wanted to stop the noise. Just possibly the acknowledging of the horn should be a performance factor that operators are measured against. The parameter would be the response time to silence the horn. The units would be in seconds.

A check of six(6) reputable suppliers of alarm and control systems for commercial and industrial environments yielded one supplier who supplies equipment for voicing alarms. All suppliers provided equipment that used the klaxon technology. Most systems provided beeping signals to attract the operator's attention to a CRT screen where the alarm message is displayed in text or graphical form. One supplier of Fire Alarm equipment does supply a voiced message system that takes dry contacts as inputs.

Observations. The distinctions between generally alerting individuals and having them focus their attention on something specific have not been well explored in nuclear warning systems. If operators first attempt to mute an alarm they are not directing their immediate attention to the problem that triggered the alarm. If the alarm does not indicate the specific problem, then operators have to search for the problem before dealing with it.

Airbus

Signal systems in Airbus aircraft specifically signal states and warn of danger. I have taken the flight deck tour of these planes to find out as much as I could about the Airbus cockpit and the human factors considerations that were designed into it. I now have three landings and one take off experience to my credit. On my first trip I was invited to stay for a landing. The captain and first officer provide me a great explanation of features of the A320 and then I just sat in the third seat, strapped in, and took in the view and the surroundings. As we approached the field some 20 kilometers away, a voice warned "traffic, traffic." Wow! I couldn't believe it. It talks. The captain and the first officer knew immediately what to do and strained out of their seats looking for

planes in the vicinity of the Airbus. None were found on first try; but the radar showed that a plane was directly below us. Sure enough a small plane appeared. There was no klaxon; although they have them. As we dropped altitude and approached the runway, that same voice said "five hundred, five hundred" and not very much later it said, "four hundred, four hundred." Still no klaxons. All it was doing was announcing the altitude. To that moment in time I had heard a machine speak with at least a three word vocabulary. It didn't natter away at the captain and first officer as the first talking cars did to their drivers. It seemed to be very precise and very appropriate in its annunciations.

On one of the flights, the First Officer demonstrated the klaxons. There were about five distinctly different sounds; but all klaxons. The clearest and most typical sound was the 'alarm' from the steward. It can be an alarm or just a phone call. The captain said it was the best sound. It was certainly the loudest of the five that I heard. The more weird sounds were allocated to equipment problems and various aircraft systems. I suppose one of them is for the fire alarm.

Observations. The Airbus is yet another example of the up-to-date use of technology; again beating the nuclear plant annunciation systems designs. Attention is called to a specific problem amongst a potential variety of problems by verbal information or klaxons dedicated to limited subsystems. Perhaps the next version of cockpit annunciation will voice the location of the traffic.

Sounds from Micro Soft Windows

Micro Soft Windows seems to annunciate a problem that you have created or that it cannot handle by simulating the ding of a bell. It is usually just one crisp ding. If you have the amplifier on your speakers turned on, you will get a louder crisp ding. The ding adequately calls your attention to the screen; it is not a continuous dinging; not really a klaxon; just a ding; more of a musical note. It is crisp, clear and loud enough. This is an alarm that most of us hear at least once or twice a day. In fact, you can set any sound you want for your Micro Soft Windows alarms.

Observations. Clear voiced alarm messages are so meaningful, especially if they express in your own words what your computer alarm means to you.

Printer Alarms - Old and Modern

I have a Lexmark Color Ink Jet Printer and it is a marvel to behold. I kid you not, I just about fell out of my chair the first time the printer ran out of paper. I wasn't paying attention to the printing process and a voice says, "please load the paper or envelope tray." Do you still have or remember the dot matrix printer with its various beeps or single beep tone to notify you of some printer problem? Once you get the beep, you have to diagnose the lights and/or look for the probable cause. It is not hard; but "please load the paper or envelops in the automatic sheet feed" leaves no doubts, no questions, no quandary. Just grab more paper and put it in and away it goes. I found that the machine conveyed information to me. It didn't just 'cry' for attention with a beep,

it told me what I needed to do, skipping the annunciation horn step, my diagnostic step and my deduction step, straight to the instruction step. This is definitely a new approach to annunciation.

Observations . There are seven (7) voiced alarms with the Lexmark Printer. They express everything you want to know about user problems with the printer. They are clear, distinctive, relevant, not nattering.

Talking Car

"All systems monitored are okay." That is one of the first messages you hear after you start some models of automobiles equipped with voiced messages. Not many models with voiced messaging are found on the market. Only the more expensive luxury vehicles seem to be so equipped. A check of three auto dealers yielded zero cars available on their lots with voiced messages.

Observations. Drivers are motivated operators of their cars. They will readily respond appropriately to messages about the state of the car and to warnings about danger. These warnings do not have to be disruptive or aggravating.

HOW THE ANNUNCIATION SOUNDS ARE HANDLED IN THE NUCLEAR PLANT

Talking Radiation Monitor at PLGS

The talking radiation monitors at Point Lepreau GS are absolutely fascinating. They were installed back in 1987. From the first time one is introduced to these machines you become enamored and a smile appears on your face when you think of the job these machines are doing and how they do it. The machine is used to monitor your feet and hands and your front and back for detectable amounts of radiation before you proceed from the Zone 2 Service Building to the Zone 1 Buildings of the typical CANDU nuclear generating station. When you step into the machine, which looks like a closet with the front and back doors removed, an infrared detector detects your presence and the machine requests you to "insert hands." Either the female voiced machine or the male voiced machine will startle you at first if you have never heard it before; it does not welcome you or attempt to put you at ease. It just says "insert hands"; and no 'please' either. If you are not close enough it says "come closer." When satisfied, it starts to count, "three, two, one" then it says "turn please." Now it gets polite. Again, it has vocabulary to help you get into the correct position to be properly monitored and it starts to count the instant that you do get into the proper position. When the count down is complete, it simple says "clean, clean." No 'thankyou' either. Can you imagine the bells and whistles that it would require to accomplish the same job with hard wired electronic technology? The radiation monitoring people surely gained the upper hand in annunciation technology with this equipment. The nuclear plant control room is not that far advanced, even yet.

Observations. Klaxons are general, they do not instruct. Attention can be gained through voiced signals that instruct, diagnose and guide operators through procedures.

Fuel Handling System Alarms

The Fuel Handling system for a CANDU plant has two fueling machines; one for each end of the reactor. One fueling machine pushes new fuel into a channel while the downstream fueling machine accepts the used fuel from the channel. The two machines are usually designated north and south or east and west. They are controlled from six(6) control panels in the main control room with one operator assigned to each fueling machine. There is a dedicated CRT on the panels for each machine. The annunciation is provided by one klaxon beeper hardwired in the panels for each machine. There is no deliberate attempt to make the two sounds different. The frequency is quite high; higher than that from a pc generated speaker alarm.

Observations. The sounds could be at different frequencies and different amplitudes.

Safety System Monitoring Computer

There are approximately 300 window alarms on 20 panels in the main control room of a CANDU nuclear power station. 5000 CRT alarms plus Fuel Handling alarms. Not all of the alarms in the main control room of a nuclear plant are routed to the main annunciator system. Especially when add-ons are made to the control room equipment. This is the case with the Safety System Monitoring Computer at the Point Lepreau Generating Station. It was installed after the plant startup to give the operator warning of power level nearing the trip setpoint. The new monitor had just nicely been installed in the Main Control Room and placed under the watchful eye of the Control Room Operator. The station manager walked into the control room, one of his stops on his twice daily tour of the station, and inquired about the performance of the new monitoring system. The Control Room Operator reported the equipment's status and proceeded into the Control Equipment Room to show the rack mounted gear to the station manager. After just a few minutes of discussion and explanation, the Control Room Operator heard an alarm, quite different from the normal alarm klaxon, abruptly excused himself and rushed back into the control room to clearly hear the beep, beep, beep coming from the Safety System Monitoring Computer's small speaker mounted inside the computer chassis. He quickly executed a preset power reduction using a Control Computer display and an execute button on the console which he had previously planned because they were fueling the reactor. The Safety System Monitor had alerted the Control Room Operator to a low margin to trip situation that occurred during the fueling exercise on one channel or maybe two channels of the two safety systems that were being monitored. There are over fifty (50) flux detectors being monitored by the Safety System Monitor. Needless to say, if he had not executed the power reduction, the Safety System would possibly have tripped. It was the shrill but pleasant sound coming from the Safety System Monitor's speaker that alerted him to the need for attention at the Safety System Monitor. If this alarm had been tied into the main annunciation system, the familiar klaxon alarm would have sounded and would not have drawn the operator's attention as soon as the beep, beep, beep sound did.

The low margin-to-trip alarm was the only alarm from the Safety System Monitoring Computer. There was no question in the operator's mind what the alarm was indicating and warning him about. Fueling is performed five (5) days each week on a twelve (12) hour shift. About 20 to 25

channels are fueled each day, making about 250 channels per year. It is easy to conclude that a unique alarm is indeed required to annunciate low margins that can cause safety system channel trips and very possibly completed reactor trips. This uniqueness cannot be provided with the main annunciation system because it only has two sounds; the alarm sound and the return-to-normal sound. The low margin to trip alarm is a good application of voice alarms. The message would simply say; "Low margin, Low margin."

Observations. This incident graphically illustrated the need for different annunciation sounds in the Main Control Room.

Annunciation during an Upset

A Safety System trip, a reactor Stepback, a reactor Setback, a Turbine Trip, a large change in power level all constitute a system upset that the control room operator must promptly address. All of these upsets will cause the sounding of the alarm horn. From the onset of the upset, until a new stable operating region is attained, the alarm horn will sound frequently. So frequently that it is utterly annoying to everyone in the control room. A 'primary objective' of the control room operator is the silencing of the alarm horn. After all, s/he is now standing in front of the stand to operate panels. The aggravation is so much so that an assistant operator is designated to take up the seat at the control room operator's desk and acknowledge the horn, silencing the aggravating noise for a moment. The control room operator then can assess the flashing annunciator windows and the new CRT alarms. Upon the okay from the control room operator, the assistant operator acknowledges the alarm windows and the CRT alarm messages. This type of action is indication of a problem; a coping with the equipment; an adapting of the human operator to the equipment design. As is most often the case, human beings can work a 'work around' around almost any problem; but that doesn't make it right.

Some control room operators expressed the desire for accessible annunciation acknowledge and reset pushbuttons at the stand to operate panels since the pushbuttons on the operator's desk were the only push buttons in the control room that would acknowledge and reset all alarms. A compromise was made at Point Lepreau GS in 1993 in that two zones of acknowledge and reset were set up on the control panels. Panels 1 through 7 can be acknowledged and reset from any one of two locations at the panels as well as Panels 8 through 19 can be acknowledged from any one of three locations at those panels.

Over a dozen alarm reduction measures have been implemented in Point Lepreau GS over its operating life to date. CRT alarms during upsets have been greatly reduced using strict rules for the classification of major and minor alarms. Only major alarms are permitted on screen during the three minutes following an upset. Then the minor alarms are unsuppressed and allowed to appear on screen. On screen, they have to be acknowledged and acknowledged upon the return to normal state. This action has greatly reduced the occurrence of alarms during the first minutes of the upset. Another major reduction in alarms with the reactor shutdown was the correction of a logic problem in the channel temperature monitoring program. The logic to suppress the channel temperature alarms with reactor power less than 2% was incorrect. This caused many alarms as the individual channel temperatures compared to neighboring channels spread outside their

temperature limits. Of course with each of those alarms the klaxon sounded. Continuous improvement is the only way to handle problems like these that only surface when conditions are just right for the manifestation of the problem.

Observations. Alarm systems themselves add to disruptions and aggravation on the job without giving proper information about the problem. Operations personnel cope with existing designs. Management and supervision develop workarounds.

Emergency and Alert Signals

I truly have an identifiable behavioral response when I hear the Emergency or Alert Signals. There are two (2) very important klaxon signals used in most CANDU power stations. One is the alert signal and the other is the emergency signal. The alert signal is a distinctive pulsating sound played through the station public address system. There are redundant powerful speakers placed in rooms throughout the plant and around the plant site. On a clear day, the signal can be heard possibly four kilometers from the station. Heard individually, most people cannot tell one signal from the other. You have to wait for the announcement. The ALERT signal requires no action on behalf of the majority of the station staff. The EMERGENCY signal requires that all station staff report to their respective muster station. After the requisite 15 to 30 seconds of sounding the ALERT alarm, the control room operator announces his/her instructions, prefaced with information on what the ALERT is about. The instructions usually request the Response team to proceed to the incident area. There are some five alert notices that the staff expect to hear. These include situations involving medical, chemical and radiation conditions. The EMERGENCY SIGNAL is processed the same way as the alert signal but it is a distinctive continuous sound for the duration of its activation. You just know that something terrible has happened. You hope that it is an equipment test or that the operator may have actuated the signal while training another operator. You might hope it is just a drill, although you would have to vacate your office or work place and proceed to a designated emergency station to be counted and await further instructions. A drill can be called in the winter time. I would say you are definitely hyped up during this time. That signal gets the adrenaline going. Unfortunately, you must wait the prerequisite 15 to 30 seconds of the sounding of the EMERGENCY SIGNAL before you are informed by the control room operator about the nature of the EMERGENCY.

Do we need an alert or emergency type of signal for general annunciation in the main control room of a nuclear plant or any process plant for that matter? Is the designer trying to change the physiological characteristics of the operator and raise the adrenaline level to get him/her primed to respond? I think not. The noise level in the Point Lepreau GS main control room is 45 db; lower than bird sanctuary level. Designers must now properly assess the real needs of the operator and determine the signal(s) requirements to get the operators attention; better still, to inform the operator that a condition or threshold has been reached that s/he should know about.

All of the conditions in the plant that require the operator's attention are not unexpected. A particular alarm may not occur in years of operation of a unit, but you can bet that the operator has been trained in some aspect of the system that enables him/her to make some assessment and take some action. S/he might have to get the technical people on shift to investigate the alarm and

in the worst case, s/he might call the system engineer responsible for the process system from which the alarm is coming, to get clarification. The required information is most likely found in the Action Following Alarms and Trips section of the Operating Manual.

One of the 7 habits of a highly effective control room operator is that of keeping his/her arousal level at a point for effective thinking and decision making; 'remaining cool.' And that means working in a 'cool' environment; keep the environment 'cool.' The klaxon technology that is used in plants today violates the operator's environment and creates a heightened level of arousal that may be detrimental to appropriate response from the operator. As arousal increases, attentional focus narrows. If the problem is complex, narrowed attention will result in an exclusion (either in monitoring the external environment or in the internal search of knowledge by the operator) of important elements in solving the problem. This could result in slowed problem solving or a failure to solve the problem.

Observations. Klaxons by design are meant to disrupt attention. If they continue during an operators attempt to solve a signaled problem they will adversely affect his/her cognitive abilities devoted to the problem. They will add to the operators arousal and may increase it to the point where thinking becomes apparently disorganized and ineffective.

Klaxon technology is appropriate for situations like the Alert and Emergency. The signals are seldom activated and a verbal announcement follows the alarm, clarifying the meaning of the Alert or Emergency.

PSYCHOLOGY SECTION

Psychological Problems with Present Alarm Systems in Plants

Sameness. The klaxon technology yields an alarm signal for an operator that has a high level of sameness. It is the same alarm sound frequency for over 5000 different specific problems. It is the same tone for both the alarm and return to normal state. It has the same volume for all alarms and return to normal actuations; it is always too loud and needs a sock stuck in the fluted horn. It has the same annoying effect on each operator. The sound may have been designed to get the operator out of his seat. And, worst of all, it has the same general information for each and every specific situation. In other words, there is a lack of information that borders on no information available for the operator. This sameness characteristic of klaxons can yield only one piece of information: There is something wrong with the plant. In actual fact, there may be nothing wrong with the plant. An operator may be doing a test that causes an alarm to annunciate in the control room. A alarm could simply be informing the operator that an auto filling of a tank has occurred or a standby pump has started. The operator may have started a pump and get an alarm indicating that the pump started. Why annunciate this action with the same sound as for all annunciation? Sound the alarm if the pump does not start. The annunciation system is being used to alarm a normal correct process system response. Even if there is something wrong with the plant that the operator was not previously aware of, there are different levels of problems in the plant requiring different responses from the operator. Some alarms are the result of poor design. Conditioning of

alarms should be a priority with designers. This has not been the case on present CANDU designs although much work has been done in some plants to condition out alarms in various process situations or configurations.

What information do the sounds of annunciation have that can be converted to neural and cognitive codes in the operator' brain and then compared with the mental models of process plants and systems, or mental models of the various expected upsets that s/he has been trained to respond to? Or, what information is contained in the sounds of annunciation that would trigger an automatic operator response that might be procedural (knowledge underlying skillful actions) or declarative (factual information that is somewhat static) in the psychological sense? Many of the operator's responses are automatic processes that encompass both the declarative and procedural types of information. However, the deliberate actions stem from controlled processes that can accommodate both declarative and procedural information.

Attention. Attention for the purposes of this paper will refer to a concentration of mental resources on a selected set of related stimuli. Attention may involve stimuli external and internal to the individual, or both simultaneously. The amount of attention devoted and the ability to sustain this attention are related to the outcome of mental processes such as memory, problem solving or decision making associated with the attentional focus. Attentive capacity is variable and limited. It is dependent upon internal factors such as choice, interest and arousal levels and external factors such as stimulus novelty, meaningfulness, attractiveness and intensity.

Alarms and Klaxons. Alarms, and klaxons alert individuals that attention should be focused. The alerting is done through the intensity of the stimulus. If a signal occurs in one and only one situation such as air raid sirens, it not only alerts but also conveys some information about the problem. If the same alarm is used for several situations 1) individuals are alerted, 2) mental resources are allocated to search for the problem (an attentive search) 3) mental resources (attention) are devoted to solving the problem and 4) a response is made.

Assessment. It is obvious that alarms and klaxons are not very efficient if more than just general reactivity is required from the target individual. Use of klaxons results in two serious problems. They fail to convey specific information and depending upon their intrusiveness they disrupt the mental processes attempting to discover the signaled problem and orchestrate the correct responses.

Projection. A more efficient way to command attention for a problem is to use a signal that is meaningful to a motivated target. Meaningful signals to motivated individuals evoke rapid and appropriately directed responses. To use a wartime analogy, soldiers sleep through the intense noise of shelling yet will awake and react appropriately to the whispered words of the sentry that the enemy is sneaking up on them.

Psychological Problems. Klaxons disrupt ongoing attention so that attention can be redirected to a new more serious problem. They are designed to be so intrusive that they cannot be ignored. No person could continue to devote attention to previous operations. If klaxons continue beyond

the alert stage they will disrupt attention devoted to discovering the signaled problem and solution. Thus klaxons are actually an impediment to speedy problem solving.

Physiological Problems. A loud, continuous, annoying klaxon signal can change the operator's physiology in an instant. Heart rate goes up, palms start to sweat, the mind focuses on ridding itself of the sound; "Stop the noise!" Operators may wish to cover their ears.

Klaxons cause measurable physiological arousal. One of the oldest relationships in psychology that has been so often verified that it now has the status of a law is the Yerkes-Dodson Law (1908) [1]. The relationship between physiological arousal and problem solving performance is curvilinear. Using indices such as error rates or reaction time, at low levels of arousal task performance is usually poor. Performance increases as arousal increases but will begin to decline at high levels of arousal. Part of the explanation involves the narrowing of attentional focus (Easterbrooks, 1959) [2]. At low levels of arousal, attention is distributed over a broad range such that irrelevant thoughts and distractions readily intrude to disrupt performance. At moderate levels of arousal, the focus narrows to the stimuli important to the task. At higher levels, the focus becomes so narrow that information relevant to the task becomes excluded from attentional focus. For example, people died in fires against inward opening doors because the simple act of everyone standing back to allow the door to open could not be conveyed or negotiated with the group under the intense levels of threat from the fire. Students have blocked on exams but as soon as they give up and reduce their attentional efforts they think of how to answer the question. Unfortunately, but as a logical consequence of arousal and attention focus, this happens after they have handed in the exam.

Performance. Performance on simple tasks is robust across a wide range of arousal. For complex tasks the level of arousal is critical and limited to a narrow band for effective problem solving. Arousal has to be at a sufficient level to result in focused attention but not so high as to exclude elements critical to the problem. The answer to the question "Why didn't I think of that at the time?" is that you were in a state of overarousal. Given the potentially serious nature of a problem in nuclear plant operation, high levels of arousal may be inherent in some aspects of the job. Elevating already high levels of arousal through a klaxon may contribute to a serious inability to solve problems because allocated attention is so narrowly and intensely focused that important elements are excluded.

Observations. In summary, klaxon technology is primitive. We would not tolerate someone who had something to communicate but simply made a loud disruptive noise to prompt you to guess what was on their mind. We would demand they say directly, simply and clearly what they wish to communicate. Effective warning systems can be designed the same way. A klaxon based alarm alert system is effective if the alarm occurs for/in one and only one situation. On the other hand, a voiced alarm describing a problem can both alert and direct attention to the problem in one signal. A motivated, trained operator can immediately comprehend the gravity of the message and will devote the appropriate level of sustained attention to solving the problem and selecting the proper responses.

CUES

Situational awareness (SA) is the starting point for control room operator decision making in normal (a few alarms from operating systems), abnormal and emergency situations (grouped under the term upsets). S/he can not solve a problem unless s/he recognizes s/he has a problem and s/he understands the nature of the problem. Situational awareness is most critical when upset conditions are changing rapidly, dynamically evolving, possibly ambiguous and demand frequent updating.

Endsley in 1994 [3] proposed three levels of situational awareness: perception of cues; comprehension of cues; and projecting future developments. The initial perception of cues that signal a problem drives the situation assessment process to clarify the nature of the problem and primes the operator (crew) to monitor or seek further information. The updated situation model, including risk and time assessments, provides a grounding for decision making and action.

Situation ambiguity, whether due to inherently vague cues, conflicting cues, or contextually uninterpretable cues, requires a lot of cognitive effort to determine the true state of affairs and produce effective decision making. Information gathering and diagnosis are fundamental to making major operating decisions. Tripping the reactor, tripping the turbine, transferring station service are tasks simply done once the final situational awareness state is reached that permits an action decision and then the action to be made. Most of the activities in an upset situation are concerned with information gathering and diagnosis. An estimate of the percentages of information gathering, diagnosis and actions can be made from the analysis of video tape sessions of upsets performed on nuclear plant simulators. The estimate should be done with the present audible annunciation and with a modified, improved audible system. Sometimes simulator exercises are done with the horn off! This is not truly representative of the environment the operator will face in the real situation.

Possibly the most important factor in the Situational Awareness Process is the cue(s). Cues, of course are first provided by the annunciation system: the horn, flashing windows, visual display unit (VDU) messages, instrument meter movements, VDU trends changing and indicating lights changing state all follow the sounding of the horn. We won't concern ourselves with the sequence and the actual millisecond timing between each of these events at this time.

The cue sets the whole situational awareness process up. The cue is the entry point to the process and the reentrant point of the process as a dynamically evolving upset progresses. The cue must be meaningful. It must be informative. If the cue is adequate, it can trigger an automatic response. In the nuclear plant upset cues are produced almost continuously. Each cue has the potential to alter the operator's course of action. Cues can be and often are the feedback result of actions taken. These would be confirmatory cues as opposed to problem onset alert cues that kicked off the whole process.

Cues should be verbalized by the operator. Verbalization reflects conditions that are seen as important, directs attention to critical information and prepares the crew for possible developments. The operator and each crew member can plan a course of action right from the

problem onset cues. NASA [3] found that verbalization, voicing awareness and voicing plans were behaviors of "high performing" flight crews. They vividly noted the connection between situation awareness, situation assessment strategies, planning and action in cockpit voice recorders of a flight that encountered a severe thunderstorm enroute and windshear at their destination airport.

Observations. Signals are communications. Their meaning depends on their message content, the actual situation and an operators model or interpretation of the situation. The less specific the message, the more likely the operator can interpret the message in terms of an erroneous model of the developing situation. An alerting signal or communication that is precise and accurate determines that the operators conception of the situation will correspond with what is actually happening.

From the forgoing, one can deduce that cues from the annunciation system should be verbal for maximum understanding in the situational awareness process. Voiced cues are more likely to prompt a correct and more timely response from the operator(s).

REQUIREMENTS

What are the requirements for a good annunciation signal that will adequately gain the operator's attention and inform him/her at the same time? The operator must feel s/he knows something by just hearing the sound; a mental model is activated and begins to form just by hearing the sound. The major requirement is that the sound is such that the operator direct his/her full attention to "the correct problem" as quickly as possible. An alerting signal that can :

1) inform, diagnose and accurately direct attention,
2) in as simple way as possible,
3) with as little disruption to clear thinking,

would provide a satisfactory solution to the annuciation problem.

An annunciation sound must have discernible frequency (pitch), enough intensity (loudness) and why not some quality to make it pleasant and even more unique to the ear. The sound should not be a noise for it has no discernible frequency, and being a noise, would not be welcomed at any intensity level. It of course has questionable quality.

IMPROVEMENTS

Everyone of us in the business of annunciation can think of various improvements that can be made to present day systems, now that we know more about the psychological implications of the alarm signal. Here are just a few suggested improvements that apply specifically to the CANDU 6 design. The improvements can be applied to any other process plant.

Simple Improvements

1. For the main annunciator, change the continuous sounding alarm signal to just two short bursts of sound. This will adequately gain the operator's attention and direct his/her attention to a flashing window alarm or CRT alarm message. This change does away with the 'horn acknowledge'. The operator will still have to acknowledge the flashing window or CRT message. The horn should be tuned to an appropriate frequency and just the right level of intensity. There is quality included with present horns, but it should be looked at critically. It should have a more distinctive and demonstrative sound than the return to normal alarm.

2. For the main annunciator, inhibit the return to normal alarm until the new alarming message has been acknowledged by the operator. The logic would simply not allow the return to normal alarm if a new alarm had not been acknowledged. This change prohibits the return to normal alarm sounding immediately after the alarm horn sounds. If one is not quite aware of this effect, it can be naturally assumed that the two sounds constitute the one alarming sound of the annunciator. Of course, this is not the original intention of the two alarm signals.

3. Designate one alarm signal for each panel grouping, Panels 1 to Panel 7, one alarm signal, one alarm signal for Panels 8 to 13, and one alarm signal for Panels 14 to 19.

This simple designation permits distinguishing by signal, the Reactor Systems alarms from the Balance of Plant alarms and the Service and Electrical Systems. This is not a quantum leap, but activates the operator's mental model and gives enough information to know location, where to look for the alarm, without having to scan the entire nineteen panels. This modification is actually worth a lot to the operator because alarms are more likely to be generated by the less redundant balance of plant systems than from the triplicated, high reliability Reactor Systems, and why sound the one and only present alarm when a lesser system is involved?

A real hazard with alarm systems is that the service systems, hence alarms, can greatly affect the reactor systems and yet they might not be assigned the priority they should be.

4. - Designate one alarm signal for the Hardwired Window Alarms, one signal for the Computer driven Window Alarms, and one signal for the alarms that appear only on the Annunciation Monitors.

This simple modification provides a welcome relief to the operator in that all of the Window Alarms are separated from the remainder of All of the Alarms in the station. There are over 300 Window alarms on the CANDU 600 out of a total of 5000 alarms on the entire Annunciation System. Window Alarms seldom operate. With this modification in place, a Window Alarm so presented would properly gain the Operator's attention. Conversely, for all other alarms, the operator could afford a reduced level of anxiety upon hearing the alarm sound.

5. - Designate one alarm signal for only the trip Window Alarms from all Station Systems, one alarm signal for all other Window Alarms, and one signal for all alarms that appear only on the Annunciation Monitors.

This modification reserves a special signal for major upset conditions resulting from trips of the reactor from Shutdown System 1 and 2, Containment button-up, Turbine trip and Electrical System trips. All other alarms are a relief to the operator; relatively speaking. A separate signal for the remaining Window Alarms and one signal for the Annunciation Monitor alarms. This modification has a lot going for it. Mental models are more readily formed from hearing the trip alarms as are those models formed after hearing alarms from the remainder of the hardwired Window Alarms. Alarms designated for the Annunciation Monitor are really of lower likelihood of indicating the onset of a major upset and the operator should have ample time to take effective action.

6. A change that is easily done is to voice the ALERT and EMERGENCY signals. The present signals seem to fulfill most of the criteria for a good alarm signal only because the explanation and instructions immediately follow the alarm. The Voiced alarms would simply say: "ALERT ALERT pause ALERT ALERT" and "EMERGENCY EMERGENCY pause EMERGENCY EMERGENCY." This change can be easily tried since both of these signals are processed over the station public address system.

More Elaborate and More Complex Improvements

1. For all the suggested changes made under simple improvements, Voice those alarms instead of sounding an alarm horn. The selection of the actual voiced alarm message is critical. For the panel grouping suggestion, the messages may be as simple as:

"Reactor System Alarm; Reactor System Alarm"
"BOP System Alarm; BOP System Alarm"
"Service System Alarm; Service System Alarm"

The suggestion that divides the annunciation by type could have messages such as:

"Window Alarm, Window Alarm"
"Computer alarm; Computer Alarm"
"CRT Alarm; CRT Alarm"

The suggestion that designates an alarm signal for trips could have messages such as:

"Trip; Trip"
"Window Alarm; Window Alarm"
"CRT Alarm; CRT Alarm"

2. Voice all of the major designated alarms. At some stations, there are less than 100 designated major alarms. Major alarms can occur at any time; but are of specific interest during an upset condition. The CANDU annunciation system has a feature that allows only the Major Alarms to appear on the CRT during the first 3 minutes (actually adjustable) of an upset. Alarms designated to be voiced should be high quality, properly conditioned and meeting all criteria set for choosing a major alarm. The alarms should not be nuisance alarms, generated by flaky, unreliable equipment. The alarm should be well developed logic in hardware or software so that when it

does alarm, the operator can be relatively sure that the alarm is valid. Alarms so developed certainly will not occur all together and busy the voiced message system unnecessarily. Too many messages occurring together would simply take too long for the voice system to verbalize.

3. Alarm by Priority - The CANDU Owners Group (COG) has sponsored research in annunciation for the last 5 years. This work is now complete and available to all members of COG. A careful selection of the alarms to be voiced is required. The priority 1 alarms might all be voiced, whereas priority 2 alarms may be voiced as: "Priority 2 Alarm; Priority 2 Alarm". Correspondingly, priority 3 alarms would be voiced as "Priority 3 Alarm; Priority 3 Alarm. This application must be carefully studied to determine the suitability of all alarms designated priority 1 and can only be done if all alarms are setup as per the priority methodology.

4. Voice Complex Messages - This suggestion involves full voicing of negative and positive complex alarms. This improvement would be in addition to some of the above voiced suggestions. For instance, a program could be written that does alarm checks or deviation checks on many of the critical operating parameters of the station and simply reports to the operator that: "All Critical Operating Parameters Are Within Normal Limits." The operator would still do his/her routine system monitoring of the processes and attend to all alarms that occur.

During an upset or a trip, the annunciation system could be made to say "SDS1 Trip Successful; SDS1 Trip Successful", or "Station Service Transfer Successful", or "Loss of Class IV; Loss of Class IV". A successful SDS1 trip means that 26 or more Shutoff Rods dropped and Reactor power is below and certain level and trending down. All of these types of messages are more complex than the simple bit level information delivered by a tank level high or low alarm. For instance, a low Heat Transport Storage Tank level meeting its alarm curve might cause a voiced message "Heat Transport System OPP Violation"; meaning that an Operating Policies and Principles limit has been hit and attention is required immediately. These alarms add to and enhance the operator's interaction with his/her machine.

Again, these alarms must be chosen on a solid basis of importance, quality of signal and information content.

All of the changes suggested can be adequately configured on the full scope simulators and operators can be involved to tailor the alarm sounds to their specific liking.

CONCLUSION

This paper has presented the audible side of annunciation. The treatment has by no means been exhaustive;, but there are enough ideas presented here for the reader to first examine the ideas presented and then experiment with changes that might best fit your operating crew. Enough examples are presented in the paper to show that other engineering disciplines are well ahead of the nuclear engineering field in practice. Ample examples of annunciation problems and needs in the nuclear plant are also presented to alert operators of all types of industrial plants to the problems with klaxon technology. Most important are the psychological aspects that are explored. Many of the improvements suggested are simple enough to implement. Other changes need concerted engineering work. We predict that there will be less and less use of the klaxon technology and more and more use of direct voiced alarms.

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