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# STRESS AND DURESS MONITORING AT NRC-LICENSED FACILITIES

ANTHONY FAINBERG

September 11, 1979



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## Abstract

Various current and near-future methods of detecting stress in humans are evaluated as to effectiveness and cost with a view to application as a screening mechanism at portals at NRC-licensed facilities. Also, similar and related techniques of stress detection and covert switches are evaluated for use by guards at NRC-licensed facilities as methods of informing the Central Alarm Station that the guard is under duress.

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## Other Reports in this Series

O'Brien, J.N., "Stress and Duress Detection for NRC Facilities: A Constitutional and Regulatory Analysis", July 1979, NUREG/CR-1032.

## Acknowledgements

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I apologize to those whom I have inadvertently omitted.

## I. STRESS MONITORING AT NRC-LICENSED FACILITIES

### A. Introduction

The purpose of this study is to investigate the reliability of current or near-future stress-detecting methods, and to assess their possible application to access portals at NRC-licensed facilities. What is envisioned, is some means by which entering personnel may be rapidly screened, on a preliminary level, for undue levels of stress. The rationale is that insiders with malevolent intentions with respect to the facility may be under stress when they are attempting illegally to bring contraband onto the site. Stress is defined here as physical and chemical changes induced in a human as a result of external pressures which could be of either a physical or mental nature. A system which is able to detect this stress, within a few seconds, as the subject passes a portal, could be of use in, at least, indicating which particular subjects should receive closer scrutiny, such as a "pat-down" search, before being permitted entry.

There are several parameters which define criteria of interest in evaluating such possible systems. One is the detection capability. Given a stressed individual, one would like to know the likelihood of detection by a given system. This is difficult to define since it is difficult, if not impossible, to give a precise quantitative estimate of the degree of stress on a person, and since different individuals respond to stress to different degrees. Some method of normalizing a given subject's normal stress level may therefore be necessary. Also necessary is some idea of how drugs, such as alcohol or tranquilizers, can affect the system's ability to recognize stress. Further, some notion should be had of how feasible it would be for a motivated individual to circumvent the detector by dint of self-control and will-power.

Thus, a second criterion of effectiveness is the resistance of the system to being fooled.

A third criterion is the false alarm rate. Clearly, a system which alarms on a large fraction of the entrants to a facility would be useless, even if the detection rate were 100% and the system were impossible to fool. A false alarm rate of not more than 5-10% is essential; less than 1% would be preferable. A difficulty is that stress may arise from other factors than evil intentions or fear of exposure. There are, in the first place, physical causes of stress or stress-related symptoms (physical exercise, disease) and, in the second place, emotional causes which may have to do with personal problems totally unrelated to work at the facility. There may be hopes of separating physical from mental stress symptoms by various means. However, separating non-malevolent emotional causes of stress from the intent to sabotage may be very difficult, indeed. One could hope, perhaps, for a setable threshold which could lower false alarm rates to a manageable level without cutting out the signal (namely, the real evil-doers). Such possibilities will be discussed.

A number of stress-detecting systems will be investigated in detail. First, various methods of voice stress analysis will be covered. These techniques attempt to detect the suppression of voice micro-tremors (controlled by involuntary muscles), which occurs under stress. Attempts have been made to use such techniques to detect deception. Results are controversial.

Another possibility is the detection of secretions on the skin when stress occurs. Epinephrine, nor-epinephrine, glucose and catecholamine concentrations in sweat may vary as a function of stress. Attempts have been made to use dogs and gerbils to accomplish a real-time detection of stressed individuals. Chemical analysis has been used as well, but, as far as the author can determine, hardware detection of such secretions in real-time, and applicable to portal situations, has not been investigated.

Finally, there is the possibility of measuring biophysical parameters which could reflect stress. The most likely parameters, which could conceivably be used in portals, are heart rate and skin resistance. There is, in fact, some hope that heart rate, change in heart rate, and skin resistance could provide enough information for an algorithm which could not only detect stress, but could also detect the difference between physical and emotional stress. This would provide a highly useful handle in the problem of portal stress detection.

B. Voice Stress Analysis

The theoretical basis for voice stress analysis lies in a frequency modulated 8-14 Hz tremor normally present in the human voice. Under stress, this tremor is supposed to decrease in amplitude, thus providing a signal. This tremor is further thought to be controlled by involuntary muscles, making it difficult for the subject to mask. If used to detect deception, the hope is that a deceptive statement would be accompanied by stress in the subject, which would then be revealed through the voice.

Reliance upon the ability of the questioner to provoke a stressful response on the part of the subject is rather strong. There is also an uncertainty as to whether stress, even provoked stress, is due to deception or other causes. (Note below the reference to "guilt complex reactions".) The questioner/examiner must be able, in addition, to account for differences in individuals' normal unstressed voice patterns. That is, different people will produce different voice spectra, even if in an unstressed state. One person's "normal" spectrum could have stress characteristics similar to another's

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"stressed" spectrum. It is up to the examiner or the system to subtract out individual effects in determining stress levels. One cannot overemphasize the importance of technique, insight, and preparation on the part of the examiner.

There are a number of detectors now commercially available which use the above-described principle. One is the Psychological Stress Evaluator (PSE), manufactured by Dektor Counter-Intelligence and Security, Inc. of Springfield, Virginia. Another analyzer is the Mark IX-P voice stress analyzer system, produced by Communication Control Systems, Ltd. of Washington, D.C. Other systems are the Hagoth HS/2 voice analyzer produced by Hagoth Corporation of Bellevue, Washington, and the Mark 2 analyzer of LEA, Belleville, New Jersey. All of them work basically on the same principle, looking for a reduced frequency-modulation in the human voice at 8-14 Hz. In addition, Dektor's method looks for patterns in the amplitude modulation of the voice which are also supposed to be signs of stress. The Dektor output is a chart recorder which requires some expertise to analyze in polygraph fashion. The Mark IX-P system provides a digital output. Each subject is asked "neutral" questions to give a measure of an individual's normal background stress level. A significant change in the digital readout when an important question is put, indicates deception. The Hagoth machine doesn't bother with this sort of normalization and gives as output a series of 8 red and 8 green lights. The more red lights which are illuminated, the more stress is present. Green lights indicate absence of stress. All three rely on the 8-14 Hz FM component for input.

Discussion of the efficacy of this system has become quite acrimonious and polemic, pitting the vendors' experts against academic scientists. As may be imagined, the vendors make strong claims for their product, whereas outsiders are more skeptical. This is not to say that some outsiders have not found favorable results.

An early study by Kradz (Kradz, 1972) tested Dektor's PSE in a field situation. Kradz was, at the time, a detective with the Howard County Police Department in Maryland. He has since joined Dektor as an employee.

Kradz compared the polygraph with the PSE on forty-three suspects in criminal investigations. For each subject, a polygraph chart recording and a voice tape recording of the polygraph interrogation was made. An examiner evaluated the data from the voice recording, as analyzed and put on a chart by the PSE. This examiner did not know whose chart he was evaluating, and thus functioned as a blind evaluator, allowing comparison between the PSE results and those of the polygraph.

The PSE and polygraph agreed in all but one case. A second examiner independently interpreted the PSE data and agreed with the first in all cases. Whether both PSE and polygraph were accurate is a different question from the finding that they agree. In the 16 cases where the PSE determined deception, there were thirteen admissions and three cases, where according to Kradz the deception was corroborated by investigation. Of 27 cases indicating that the subjects told the truth, 21 cases where "corroborated by investigation" and in 6 cases no contrary evidence was adduced. In conclusion, one cannot absolutely prove the accuracy of an "innocent" determination by the PSE as well as one could prove (by confession) a "guilty" verdict. However, the agreement between the PSE and polygraph is striking. In fact, Kradz was impressed enough to join the vendor firm.

Later, in 1973, Kubis investigated the PSE for the U.S. Army Land Warfare Laboratory (Kubis, 1973). Kubis set up a simulated theft experiment, wherein subjects acted out a theft, as either thief or lookout, and were later questioned using the PSE. This experiment has the advantage of absolute knowledge of guilt on the part of the experimenter, but the severe disadvantage of not stressing the subject as much as a real-life situation would. This latter drawback has been the origin of attacks on the validity of this experiment as has the poor quality of some of the tapes.

Kubis found that the polygraph examiners had a 76% accuracy in determining whether the subject was thief, lookout, or innocent. PSE evaluation had a 38% accuracy, which is consistent with chance. A VSA (Voice Stress Analyzer manufactured by Decision Control, Inc.) scored 36%, also consistent with chance. The impression is, that for this low-stress situation, polygraphs can detect deception, but voice stress analyzers cannot. Incidentally, observers making "global observations" on the behavior of the subjects scored 75%.

There have been a number of other tests, with a variety of results. Heisse (Heisse, 1976) coordinated a test of the PSE using real criminal suspects and job applicants, comparing results with reported known solutions. He found an accuracy of over 96%. There is some question about the internal consistency of some of his data, but this, at worst, would reduce the accuracy to 93%. An examiner used "global" impressions as well as PSE results in each of 52 cases, and five different evaluators gave their verdict from PSE charts only. The cited accuracy refers only to the evaluator interpretations. A long series of carefully chosen questions was used to get a general idea of the individual's own normal state as well as to eliminate "guilt-complex" reactions -- the latter involving a subject's "guilty" reactions to a non-existent crime which he/she could not have committed. This is necessary, since many people react guiltily to an accusatory question, even if asked in a neutral voice. <u>Heisse notes that</u>

in 24 cases, if this "background subtraction" had not been made, innocent persons would have been indicated guilty by the voice stress technique. This caveat is, particularly since it comes from an obvious PSE partisan, a serious warning against careless use of the device.

Another PSE test by Barland (Barland, 1973) had less positive results. A low-stress test, in which some subjects were asked to lie on occasion, showed no positive result. An attempt was made to increase stress by wagering the subject a small sum that he could not fool the device, but this did not change things. A second, high-stress test involved recordings of criminal suspects who were being tested with a polygraph at the same time. Each polygraph indicator, skin resistance, cardiovascular response, and respiration was rated in effectiveness against voice analysis. Voice rated behind skin resistance and ahead of cardiovascular and respiration. In fact, cardiovascular was found to be unreliable, in disagreement with previous work, and, thus, some doubt is cast on the reliability of the whole study. Also, absolute truth was not known. The only measure was to test the four parameters against each other. A blind evaluator found statistically significant agreement (79%) with the polygraph. The overall conclusion is that high-stress situations may be required to give reliable results. In general, low-stress trials produce poor results while high-stress ones show significant detection capability, in all of these, a careful interrogation technique is essential.

However, there is a likelihood that the system can be fooled even here. One use of the PSE (Borgen, 1976) is to detect lower levels of stress after administration of a tranquilizer. This experiment was undertaken to test the drug's effectiveness. However, a conclusion is that a saboteur could deceive successfully and simply by taking tranquilizers or possibly depressants (such as alcohol) to reduce stress in the voice. Further, there is one report that a subject trained in polygraph countermeasures could fool a voice analyzer (Hagoth); in fact, he fooled it so consistently that he gave the wrong indication 100% of the time (that is, registering deception when there was none, and vice-versa)! Of course, this perfect record allowed the examiner to invert his algorithm to catch the subject out. The point is, that if a subject is aware that his/her voice is being scrutinized, he/she can deceive a voice analysis device by trickery. It is noted that in a facility portal situation, the subject will likely be quite aware of the testing.

## C. Skin Secretions

A totally different technique relies on skin secretions which occur under stress; epinephrine (adrenaline), nor-epinephrine, and other catecholamines are known to be produced in such situations (O'Hanlon, 1973) and may be present in sweat in small amounts (stress can be either physical or mental). If these chemicals can be detected by some remote means in a few seconds, this would give a possible handle to detect stress.

One easy-to-operate system for such chemical detection could be animal olfaction. Dogs commonly detect individuals who are afraid of them, for example. Some preliminary experiments along these lines were performed by Biederman (Biederman, 1974) with positive results. He tried further tests with gerbils in a portal-like situation at an airport (Biederman, 1978) and did pick up some guilty stressed individuals (petty smugglers) and some innocent ones (a sports team). False alarm rates were quite low. However, it is not know how many "guilty" parties were not caught. Such animal techniques seem worthy of pursuit in controlled experiments, including the effects of drugs (cf. above) on the secretion of these stress-revealing [illegible]s.

Another possibility, which to the author's knowledge has not yet been tried, is the application of hard[illegible] techniques to the detection of such chemicals. A portal-like situation, similar to explosives detectors now in use at facilities, could be used to sample air around the subject. Mass spectrometric or, more likely, ion-mobility techniques could be tried for detection of epinephrine and the other secretions. Success would depend on reaction rates for ionizing such molecules and on the effects of possible backgrounds such as from epinephrine in antiasthma sprays. Many mass spectrometers and ion-mobility spectrometers are in existence and a small amount of investment could provide some potentially valuable information. There is an inherent advantage in stress detection through secretions over explosive detectors in current use, namely explosives can be wrapped and sealed, whereas, in practice, an observed subject passing the portal cannot seal his skin from the detector.

D. Biophysical Monitoring

After research involving various parameters including EEG, EKG, muscle tone, blood pressures and others, an analysis of skin conductivity, heart rate, and change in heart rate (over at least 10 seconds) seems to provide the best hope for successful stress detection. In a portal situation, the subject's hand would probably have to be placed, for a few seconds, in a detector which could monitor the two parameters. Work at the Lovelace Foundation (Tuttle, 1978) has indicated a correlation between various forms of stress and these variables.

The first part of the Lovelace effort involved a laboratory experiment in which stress was induced in three ways in a number of subjects. One test was a simple physiological stress experiment wherein the subject pedaled a bicycle against some resistance for several minutes. Another test involved immersing the subject's right foot in ice water for two periods of one minute each. These were physical stressing runs. There was also a mental stress test which required the subject to count backwards from 300 by three's in time with a metronome while being subjected to his own voice, delayed by 0.15 seconds. Further, subjects were told (falsely) that at the end of the test, they would receive a shock proportional in intensity to the number of errors committed. This presumably increased mental stress. In addition, errors were indicated to the subject by a loud beeper alarm.

After study of the data thus obtained, it was found that some criteria could be defined as indicators of stress for the following field tests. A simple criterion for a given individual was to require the exceeding of the maximum heart rate provoked in the laboratory tests (about 30-40% above the normal rate). There was also some apparent difference between the mental and physical stress, not in the mean heart rate, but in the heart rate variability; that is, the heart beat seemed more irregular for mental stress than for physical stress. Some more work is needed to provide better statistics to confirm this important result.

The next stage of the experiment was a field test over a five-month period, with 22 members of the Albuquerque Police Force as subjects. All had taken the laboratory tests to provide their individual baseline heart rate data. Each officer was provided with heart rate and skin conductance measuring electrodes attached to a battery-powered cassette recorder for 12 eight-hours working shifts. The hope was to apply the laboratory criteria to stress situations arising in the line of duty. Skin resistance measurements turned out to be impractical in the field test.

The results are not perfectly clear, but do provide some grounds for optimism. First, only four serious life-threatening situations arose during field testing, and in all four cases, the assigned threshold criterion heart rate was exceeded.

However, out of 213 events listed logged by the officers in a broad category of "police calls increasing strain", only 144 were detected by the heart rate criterion. This may be due to the insufficient description of such events, many of which probably did not actually threaten the officer's well-being. The experimenters wished to reduce their impact on the police, and thus only asked for sketchy written information at the end of each shift. It is hoped that future experimental procedures will be able to clear up the question of just how many events are missed. The false positives (false alarms) seem to have been reasonably low.

Besides basic detection feasibility, there is also an effort to apply heart rate measurements as a stress detector at entry portal situations. There are a number of ways, adaptable to a portal, wherein a subject can have his/her heart rate monitored without undue difficulty (Davis, 1979). The most promising seems to be a plethysmograph, a device which illuminates a portion of the body (say, a fingertip) and measures the transmitted light. Light is partially absorbed by the blood in skin capillaries, and the pulsations in this absorption can be measured. The hope is that, instead of the 20 second sampling time, 10 seconds or less would suffice, because a portal is a more controlled situation than the field tests used with the Albuquerque police.

The problems with using heart rate in a portal situation appear to me to be relatively serious, however. Countermeasures, using drugs or self-control to

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reduce heart rate are feasible and are difficult if not impossible to overcome without requiring the entrant to perform some physical exercise, which in turn would cause a prohibitive time requirement in most portal situations. Further, to use such a system, it would be imperative to have a baseline heart rate measurement in a computer memory bank for each entrant, since individual differences are not insignificant. These would have to be updated on a (probably) weekly basis to account for possible pathological variations with time. A heart rate file for each entrant is not a terribly difficult problem, but it is one which has to be considered from the points of view of both cost and privacy. The first problem, that of countermeasures, appears to be serious enough to warrant skepticism regarding feasibility for the foreseeable future.

E. Summary and Conclusions

The voice analysis method of investigating stress seems inapplicable. There is some controversy as to the efficacy of this technique, but even discounting this, voice stress advocates would generally admit that a skilled questioner is essential. In a portal situation, this is impractical. Further, repetition of a limited number of questions day after day would reduce their effectiveness. Also, it is undesirable to allow more than 10 seconds for each person passing. This limits the number of questions which may be asked of the subject, which in turn limits the abilities of the method. Finally, it is highly likely that countermeasures, using either drugs or internal mental control, would be able to circumvent the method in either case, unless subjects were not aware that they were being tested. In conclusion, there is little likelihood that voice stress analysis would be useful in protecting licensee facilities in a portal situation.

Regarding detection of epinephrine and other secretions, more research is necessary to determine first, the capability of rapid (10 second) detection, second, the false alarm rate, and third, the resistance of the system to tampering with drugs. Some more research with animals is indicated, as well as, perhaps, work with hardware vapor detectors which already exist for detecting pollutants or explosives. At least one to two years of fairly intense work would be needed to demonstrate feasibility.

Finally, biophysical monitoring also needs more work to show feasibility for portal use. It seems clear that biophysical parameters can indicate stress. However, their reliability needs further demonstration. There is considerable doubt that rapid portal feed-through would be feasible since long (~ 20 sec.) heart-rate sampling times may be necessary. Circumvention possibilities would also have to be dealt with more definitively.

It must be borne in mind in all cases that a false alarm rate of up to 10% could be tolerated, since the ultimate application of stress methods will likely be as a screening device for hands-on pat-down searches, perhaps as a replacement for random selection. Civil liberties implications of stress detection are discussed in an accompanying paper (O'Brien, 1979).

Table 1 shows a summary of techniques and capabilities.

Table 1

STRESS DETECTING TECHNIQUES

| Technique | Availability | Capability of Detecting Stress | Portal Time Required | Susceptibility to Counter-Measures | False Alarms |
|---|---|---|---|---|---|
| Voice | Current | Good, but with qualified examiner | Probably much greater than 20 seconds | Controversial, seems high | Dependent on examination technique |
| Secretions | Could be within 1 or 2 years | Needs positive demonstration | A few seconds | Unknown | Unknown, indications of a few percent |
| Biophysical | Could be within 1 or 2 years | Needs positive demonstration | Probably much greater than 10 seconds | High | Probably low, needs more work |

## II. DURESS MONITORING AT NRC-LICENSED FACILITIES

### A. Introduction

In this section, the current status of duress indicators is examined, with a view to possible use by roving guards at NRC-licensed facilities. Of interest are devices which can indicate t( the central alarm station (CAS) that the guard is under duress and may not be able to communicate directly that this is the case, due to adversary actions. Duress is defined here as constraint on a guard by an adversary, compelling the guard to act in a manner contrary to his own volition or incapacitating him. Possible means to detecting stress could be voice stress analyzers, biophysical monitors (both discussed in Section I), and covert switches. All methods require some means of telemetry to send information to the CAS. Below will be discussed these techniques and assessments of their feasibility. Also, their costs and possible impacts on the facility will be touched upon.

Since voice and biophysical techniques and research have been described in some detail in the above-cited report, comments on them here will concern only their possible applicability to duress monitoring. Covert switches and telemetry will be treated in more detail.

### B. Voice Stress

The main objections to use of voice stress in portal situations concerned a) the need to question a possible deceiver rather carefully, and b) the possibility of using counter measures (e.g., drugs, voice control) to fool the system. In the case of guards under duress, these problems do not apply. A guard, forced by an adversary to communicate with the CAS, will not be interested in controlling his/her voice to hide stress. We assume he/she will



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not have taken drugs before going on duty to unstress his/her voice. If a guard does show up to work drugged and is discovered, this should be a disciplinary matter and, one would hope, such a situation is an anomaly.

Note that in such a case, one is only interested in finding stress in the guard's voice. Questioning is not necessary to provoke stress due to deception, as it is in the portal situation. One should, if possible, be able to compare a particular guard's voice under non-stressed conditions with a communication which is suspect. If a voice analyzer is on-line constantly at the CAS, it should be no problem to obtain and store (either manually or by communication with a computer) background readings for each guard. A sudden increase for a given guard should then be an alarm, to be reacted to by using CCTV, sending other guards to the guard who is "alarming", etc. Needless to say, it may not be a good idea to cross-examine the "alarmed guard" directly in such a case.

There is a problem with some artifacts produced when communications are initated and terminated on a radio: some false alarms are given by the radio noise at these times. A device using voice stress analysis will have to gate out these portions electronically and, perhaps, gate on analysis only when a voice carrier (of $\sim$ 700 Hz) is present. Some analyzers may be less sensitive in this mode, as they may depend to an extent on lengths of utterance, and some experimentation is necessary in this regard.

## C. Biophysical Techniques

The Lovelace Center Group (Tuttle, 1979) has developed a relatively unobtrusive hardware system which has been used by officers performing their normal duties in the field. Electrodes, which pick up heart beat information, lead to a pocket-sized lightweight cassette recorder which stored the data on tape.

The recorder was worn at the belt and was generally forgotten by the officer after a short while.

Instead of a recorder, one would envision a similar sized transmitter which, when a heart rate change exceeded a defined criterion threshold, would transmit an alarm signal to the CAS. Continuous transmission would be possible, but would be a waste of power and might also be considered an invasion of privacy by the guard, resulting in morale problems.

Provided that more data being taken by the Lovelace Group show a good reliabilty for detecting stress, using some algorithm involving the heart rate, this method could be useful and feasible for the applications considered. Again, we assume that no heart-slowing drugs are being taken by the officer. Further, there may be the possibility of using heart rate information to discern whether the officer is unconscious or has been drugged. This could be rather an important piece of information.

## D. Covert Switches and Telemetry

In 1975, MERADCOM (MERADCOM, 1975) studied various possibilities for systems which could be covertly activated by guards under duress. Included were toe switches, holster switches, chest and waist compression switches, and body orientation switches. In addition, there was some discussion of the communication system requirements for sending alarms to the Central Alarm Station. Some problems were involved with the proposed toe switches, in that false alarm rates were rather high. Similar problems were likely with the chest and waist compression switches, wherein the subject was to exert pressure on a belt for several seconds to activate the alarm.

More recent work at Sandia (Draper, 1979) has refined these concepts to a considerable degree. Refinements have greatly reduced the false alarm rate. Also, an effective holster switch has been made, which will be field-tested, along with the toe switch, in the near future.

There are a number of alarm-voice communications systems on the market which are summarized in a report by Draper (Draper, 1979). Body-orientation switches are often incorporated in the alarm transmitter worn by the guard.

1. Toe Switches

The toe switch idea, originally developed for MERADCOM, had, as a goal, providing the guard with a surreptitious means of signaling the CAS that he is in trouble, without informing an adversary who may be watching him closely. Mounted inside a shoe, the hope was that a small toe movement would be undetectable (at least, as a hostile act) by the adversary. Two electrodes, one above the other, were brought into contact by raising the toe nail. Leads ran from the electrodes to a sensing device (eventually, to be built into the transmitter) which detected the closing of the switch. Unfortunately, in the normal course of a tour of duty, the guard may climb stairs, jump from one level to another, stub his toe, etc. As a result, false alarms can result, perhaps at a relatively high rate.

Sandia is developing another type of toe alarm, and the false alarm rate appears very low so far, but definitive results must be awaited.

2. Holster Switches

It is presumed that, unless he/she has a very good reason not to, an adversary will try to deprive a guard of his/her gun, if only for selfpreservation. The idea of a holster switch is to provide an alarm to the CAS when this occurs, whether or not the guard is conscious.

MERADCOM and Sandia are both working on simple devices to be placed at the bottom of a holster which give a signal when the gun is removed, by closing two electrodes. As can be imagined, there are no serious problems here in putting together a device which is simple, reliable, and has a negligible false alarm rate.

3. Chest or Stomach Switches

MERADCOM is also considering pressure switches which can be activated by expanding either the chest or the stomach. The electrodes would have to be mounted either in a belt or in a harness and would short upon contact which would be caused by pressure from the chest or stomach. The guard would try to distend his torso unobtrusively while under duress and hostile observation. Since many false alarms could be expected here, too, one would have to try to eliminate them by requiring the electrodes to be in contact for, say, several seconds. Work is continuing on the feasibility of such devices, but at this point, toe switches seem to provide a better system, because of both false alarms and problems with covert operation.

4. Body Orientation Switches

There are a number of mercury switches already on the market, which indicates a change in orientation on the part of the wearer. In general, the alarm consists of 3 switches mounted in different directions such that a tilt of more than 45$^{\circ}$ from the vertical in any direction for more than five seconds activates a distress signal which may be transmitted. This is incorporated in at least one device, produced by AID. The model TX-2113 pocket-sized transmitter contains such a switch under the trade-mark "Deadman Alarm™". The device can be worn on the hip or upper torso, and false alarm rates seem to be quite low (Draper, 1979).

5. Telemetry

Several small transmitters appropriate for guard communication with CAS are available. Some just send alarms (in various formats) and others provide voice communications as well. Detailed lists of these devices, along with their salient features are provided in B. Draper's report (Draper, 1979). Ranges are typically 300 meters. Some of these are now undergoing testing at Sandia.

In addition, there are other telemetry considerations, which go beyond the scope of this report, but which are, nevertheless, important factors. These include jam-resistance capabilities, encoder/decoders for scrambling messages, alarm decoders for use at the CAS to show which guard has given which type of alarm), and direction finding units (to aid CAS in locating the "alarming" guard quickly. Some of these capabilities may be of greater immediate interest in DOE facilities, but some considerations should be given to possible future use in facilities under NRC jurisdiction, if and when they become generally available. Alarm encoders and simple direction finders are now on the market, the former being produced by NAPCO and Plectron, and the latter by AID. Triangulation with the AID "Bird Dog" (each measurement is good to a few degrees) is reasonably accurate. This information is also taken from Draper, 1979.

E. Summary and Conclusions

Both the voice and biophysical stress-sensing systems may be applicable for duress monitoring at NRC facilities. Several covert switches, including toe, holster, and orientation switches are relatively simple and would be easy to integrate into a single alarm transmitter (which could include normal voice communication capabilities, as well). Voice and biophysical techniques need some field testing to demonstrate effectiveness; some covert switches have been tested, and others are being developed: there is no doubt as to their feasibility and value.

It should be noted that some monitors, particularly those using biophysical methods, could be considered an invasion of privacy by the guards themselves. This may give rise to personnel problems, since if a system is strongly resented by guards, attempts will be made to circumvent it, thus rendering it useless. If a licensee decides to use such a system, prior consultation with the guard force members would be useful. During such consultation, emphasis should, of course, be placed on the technique's ability to save a guard's life. Legal aspects are to be found in O'Brien's paper (O'Brien, 1979).

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## APPENDIX A

### Estimated Costs of Stress-Detecting Systems

Voice systems would have a minimum cost impact on a facility if feasible. Each subject would be asked a few questions and then be passed or receive a pat-down search, depending on whether or not an alarm was given. Costs for a unit range from $1500 for Hagoth's small, portable units, to $8350 for Communication Control Systems Mark IX-P (including video training tapes and a 2-day seminar, the model itself is $6250). There is also a cut-rate $250 model produced by Harrison and marketed by JS&A. These costs are comparable to or less than costs for explosive detectors which are now required at facilities.

A biophysical portal monitor, with alarms, would probably cost under $5,000, incuding software and memory storage. It could be combined with currently used key ID systems.

It is too early to estimate a cost for animal stress detection systems, but a similar set-up for explosives may sell for around $20,000 or so.

For voice or biophysical monitoring methods, it may be necessary to store the "normal state" characteristic of each person who passes the portal, to check against the response of the given employee. If no computer is in current use by the physical security system, the additional expense could be in the tens of thousands of dollars. Otherwise, the marginal cost increase, of programming and interfaces is liekly to be on the order of thousands of dollars.

## APPENDIX B

### Estimated Costs of Duress-Detecting Systems

Costs of various systems voice stress systems range in price from $250 to $6000. A biophysical system for roving guards, with telemetry, could cost ~$1000 per mobile unit plus several thousand dollars for a central alarm unit. Toe, holster and orientation switches are simple and should be very cheap when marketed. Aside from voice stress, all these systems could be multiplexed into a single alarm transmitter which could cost, at a rough estimate, from $1000 to $2000 per unit, again with several thousand dollars more needed for the associated CAS equipment, including, perhaps, directional finders.

As noted in Appendix A, the voice or biophysical systems may need computer and software support which could cost on the order of thousands to tens of thousands of dollars.