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Operational Decisionmaking and Action Selection Under Psychological Stress in Nuclear Power Plants

David I. Gertman
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OPERATIONAL DECISIONMAKING AND ACTION SELECTION UNDER PSYCHOLOGICAL STRESS IN NUCLEAR POWER PLANTS

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ABSTRACT

An extensive review of literature on individual and group performance and decisionmaking under psychological stress was conducted and summarized. Specific stress-related variables relevant to reactor operation were pinpointed and incorporated in an experiment to assess the performance of reactor operators under psychological stress. The decisionmaking performance of 24 reactor operators under differing levels of workload, conflicting information, and detail of available written procedures was assessed in terms of selecting immediate, subsequent, and nonapplicable actions in response to 12 emergency scenarios resulting from a severe seismic event at a pressurized water reactor. Specific personality characteristics of the operators suggested by the literature to be related to performance under stress were assessed and correlated to decisionmaking under stress.

The experimental results were statistically analyzed, and findings indicated that operator decisionmaking under stress was more accurate under lower levels of workload, with the availability of detailed procedures, and in the presence of high conflicting information. Conflicting information interacted with procedures and with workload. Unlike the other variables, conflicting information did not affect decisionmaking in the direction hypothesized. This result is discussed in terms of possible confounding factors. Specific personality characteristics were found to be related to decisionmaking under stress. Internal locus of control and experience with many past stressful situations were related to enhanced decisionmaking under stress. Evidence is also presented that operator response to stress may be affected by general level of anxiety, degree of emotional exhaustion, feelings of depersonalization, and feelings about personal accomplishment. Based on the findings of the literature review and the experiment, a number of recommendations for decreasing the adverse effects of stress on decisionmaking in nuclear power plants are offered.

FIN No. A6391—NPP Operating Personnel Performance During High Stress Events

EXECUTIVE SUMMARY

The purpose of this research project is to determine if psychological stress induced by emergency plant conditions in a nuclear power plant has a significant adverse effect on operator performance of typical tasks required during plant emergencies. To this end, two technical tasks were undertaken: (a) technical findings from prior studies of human performance under stress were reviewed and evaluated, and (b) an experiment was performed with 24 trained reactor operators placed under varying conditions of psychological stress to measure the effectiveness of their decisionmaking and responses for different reactor operation requirements.

Findings from existing technical literature indicate specific factors important to operator performance under stress. These factors are:

- Perceptual narrowing, which can restrict the operator's understanding of stressful conditions and the subsequent ability to respond appropriately to them;

- Cognitive rigidity, which can restrict the cognitive capacities of the operator to analyze, evaluate, and plan alternative courses of action in response to the stressful conditions;

- Changes in the nominal degree of correctness of decisions arrived at by the individual or by the group;

- Reliance on prior training and the mental set such training provides;

- Enhanced role and importance of centralized authority to the operator in responding to stressful conditions;

- Information distortion by individuals and by the group about the stressful conditions and their effects;

- Response perseveration, or the tendency to repeat ineffective actions or to make responses that are not appropriate to the stressful conditions.

The experiment involved three stress-related variables to assess their effects on operator decisionmaking under stress. Workload (i.e., amount of time to perform), conflicting information (i.e., background noise and voices), and the level of detail in available written procedures were manipulated as three stressors. Decisionmaking performance was evaluated by the correct selection of actions to mitigate 12 emergency scenarios that could result from a seismic event at a pressurized water reactor. Operators responded to each scenario by selecting from a response list specific actions to be taken immediately, or subsequently, or that were nonapplicable. Also, certain personality variables of the operators, related to decisionmaking performance under stress, were assessed and correlated.

Results from the experiment with reactor operators revealed:

- Operators under stress perform better under lower levels of workload;

- Availability of detailed procedures may enhance operator performance and decisionmaking so that negative effects of psychological stress are reduced;

- Operators selected significantly more actions correctly in the presence of high conflicting information, relative to low conflicting information;

- The interactions of conflicting information with procedures, and conflicting information with workload, suggest a complex relationship between stress variables and decisionmaking performance;

- Specific operator personality characteristics were found to be related to enhanced decisionmaking under stress;

- Operators who perceive reward as contingent on their behavior perform better under stress than those who perceive reward as independent of their behavior;

- Operators who have coped successfully with many past stressful experiences perform better under stress than those who have coped with fewer past stressful situations;

- Operators' response to stress may be affected by their general level of anxiety, their degree of emotional exhaustion, feelings of depersonalization, and feelings about personal accomplishments.

Analysis of these findings from the literature and from the operator experiments identified general measures for decreasing the effects of stress. These are (a) training programs geared to develop operator knowledge, characteristics, and coping mechanisms which will enhance operator performance under stressful conditions; (b) training programs and procedures that are compatible with the response characteristics of operators experiencing stress; and (c) awareness by supervisors, management, and operating personnel of operator characteristics that are related to decisionmaking performance under stress. Specific measures to be considered are:

- Providing training and drills that establish mental set (i.e., an expectant attitude within the operator) toward the mitigation of an emergency and the reduction of high stress;

- Establishing procedures that optimize individual workload during emergencies while maintaining individual responsibility;

- Presenting effective displays of critical information in the control room, which are designed for a narrowed range of cue utilization by operators during emergencies;

- Ensuring that procedures are compatible with operator reliance on established authority and centralization of authority during emergencies;

- Providing procedures compatible with restrictive cognitive and problem-solving processes;

- Providing formal training of operator strategies in broadened problem-solving techniques, novel problem solving, and decision reassessment;

- Providing training in information management, and procedures geared to reduce information distortion and to improve the flow and communication of critical information;

- Holding frequent drills to help operators overlearn effective procedures and to allow practice in novel problem-solving and decision reassessment. This includes opportunities to exhibit effective coping with such problems as part of the drills (especially if the drills are somewhat stressful) to help operators cope with future stressful events;

- Training personnel to view plant conditions and problem solving from a standpoint of internal locus of control (i.e., so that the operator performs because his/her performance is perceived as effectual and rewarding) in conjunction with the plant management's administrative policies;

- Training shift supervisors and plant managers to be aware of personality factors in their crews that could negatively affect decisionmaking and performance under high stress. Supervisors could use this information to structure the control room personnel into the most effective decision unit possible by deployment of individual responsibility, work assignment, and tailor-made training programs and drills;

- Incorporating findings relating operator personality characteristics to performance under stress in a career selection guide for prospective operators.

CONTENTS

OPERATIONAL DECISIONMAKING AND ACTION SELECTION UNDER PSYCHOLOGICAL STRESS IN NUCLEAR POWER PLANTS

INTRODUCTION

Human performance plays an important role in ensuring that reactor operations are safely conducted. Much attention has been paid to reviewing the factors that produce reliable and efficient performance from operating crews. There has been an acknowledgment that equipment design, training, procedures, and operating policies can serve to either enhance or degrade performance.

The Nuclear Regulatory Commission (NRC) specifies requirements to ensure that nuclear power plant (NPP) structures, systems, and components important to safety be designed to withstand the effects of earthquakes without loss of capability to perform their function (NRC General Design Criteria 2 for NPPs in Appendix A to CFR Part 50). No attempt has been undertaken to regulate the capability of personnel at NPPs to make important decisions and take appropriate actions under stress of such a similar significant event. The difficulty lies in predicting crew response and decisionmaking under psychological as opposed to physical stress. It can be argued that job performance requirements associated with response to abnormal or emergency events produce moderate or high stress in NPP personnel. Data gathered from a variety of industries, working environments, and situations suggest that stress is a moderator of human performance and it often causes delays in response, reduced accuracy, narrowing of attention, and reduced capability to respond to nonroutine events. Poor job performance may be associated with no stress or with high levels of stress, and improved job performance with a moderate amount of stress.

This present research examines the effects of moderate and high stress on the decisionmaking ability of operating crew personnel. A two-fold technical approach was undertaken for this research. First, a literature review was completed on the general topic of psychological stresses including performance in severe environmental conditions. Second, these results were used to design an experiment to evaluate the effects of stress on the performance of operators. Variables relative to a nuclear power plant control room that could impact the ability of a crew to respond in a safe and efficient manner during high stress events include adequacy of procedures as well as the amount of contradictory or confirmatory information present. The amount of workload encountered and the individual personalities of control room crews may also serve to either limit or enhance overall response to high stress events. To the extent possible, these variables and their impact were assessed. This study is limited by two factors: the general nature of laboratory research, and the ethical and moral considerations relative to inducing stress or measuring the effects of stress in human subjects. The present literature review provides insight into group performance under stress; however, the current experiment is designed to assess individual and not crew response. Further research efforts should focus upon total crew response. What follows is a brief definition of stress and a review of stress-related research applicable to nuclear power plant training, design, and operation.

Background to Stress and Its Effects

Stress can be viewed as a physical or psychological stimulus as well as the resulting physiological and psychological response. The focus of this work is on psychological stress. Psychological stress, as distinguished from physiological stress, is a concept concerned with events that are stressors because they involve emotional response. The context of the event is the perceived challenge or threat to the person. In other words, the person in the stress situation brings an attitude plus his own individual personality into the dynamics of the event. The study of stress in the work place has shown that it is a complex response. At times, stress may result in increased performance up to a certain level, at which point it becomes a disorganizing effector of behavior. That is, a moderate amount of arousal can improve performance (Hebb, 1955; Lindsley, 1952), but greater amounts lead to a state of performance degradation. For this study, stress is defined as the perceived imbalance between demand and capability to respond under conditions when failure to meet the demand has important consequences.

The first two topics considered in this literature review provide data related to stress management and related occupations. These discussions are intended to provide information related to the subsequent major topics of interest.

Stress Management Techniques

There is an important difference between acute (transitional) and chronic stress. Many techniques have been developed and used as methods of coping with and reducing chronic stress. Stress reduction techniques have been applied to almost all forms of chronic stress, including muscle relaxation training (LaCivita, 1982; Charlesworth and Dempsey, 1982; Ganster et al., 1982; Sarason et al., 1979), deep breathing (LaCivita, 1983), and systematic desensitization (Charlesworth and Dempsey, 1982). Further examples of widely used stress management procedures are positive imagery (Charlesworth and Dempsey, 1982), stress-inoculation training (Schuler et al., 1982), and covert self-management (Ganster et al., 1982; Sarason et al., 1979). Also, the use of physical fitness programs to help mitigate stress has been suggested for similar populations (Rader, 1981; Adams, 1981; Sharit and Slvendy, 1982). Other methods proposed to help manage organizational stress are planning (Smart and Vertinsky, 1977), prioritizating tasks, decreasing high workload (Bateman, 1981), providing organization (Rader, 1981), and reducing ambiguity and conflict (Abdel-Halim, 1982).

For public health and hospital employees, Jackson (1983) used participation in decisionmaking, and Richardson and West (1982) suggested motivational management as stress reduction methods. Reducing uncertainty and risk (Johannsen and Pfendler, 1983), making available a performance-linked coping strategy (Wachtel, 1968), and increasing low workload (Miller, 1960) have been shown experimentally to reduce the adverse effects of stress on cognitive and motor performance. Sarason (1979) demonstrated that the development of adaptive self statements can help police officers cope with stress. In a U.S. national workforce survey, Karasek, Triantis, and Chaudhay (1982) found social support to be a stress-reducing variable. Although many stress management techniques are reported, the literature is seriously lacking in direct comparison studies which would shed light on differential effectiveness. Industries other than nuclear have helped devise and attempted to employ such techniques to reduce the stress experienced by workers at all organizational levels.

Occupations

There is no direct information in the literature about performance of nuclear power plant personnel under stress. However, stress levels and reaction to stress are different across occupations. These differences vary greatly depending on the specific stress variable in question. Stress-related conditions such as hypertensive heart disease, arteriosclerosis, hypertension, ulcers, liver cirrhosis, suicide, and homicide show a unique pattern across occupations of management and staff (Zaleznik, Kets de Varies, and Howard, 1977), public utilities, mining, and construction (Karcher and Linden, 1982), and public health and educators (Richardson and West, 1982). It is suggested that occupation selection is related to personality and that personality is a large factor in stress-related responses (Sharit and Salvendy, 1982).

Problem Solving, Decisionmaking, and Judgment

Of particular interest is the extent to which high stress might limit the ability of operations personnel to correctly and quickly mitigate problems that might occur during emergency plant conditions. Increased stress adversely affects the quality and quantity of individual and group decisionmaking. Smart and Vertinsky (1977) reviewed relevant literature and outlined many possible disorganizing effects on decisionmaking that may result from high stress. These include narrowing of the cognitive process characterized by more errors and less alternative generation, problem solving rigidity, information limitation, and inordinate attention to short-range issues at the expense of long-range concerns. They also report information distortion under stress, characterized by information overload, delayed reports, preference for agreeable information, and stereotyping of the adversary or threat situation. People under severe stress may show repeated ineffectual responses and resistance to change of standardized procedures plus a lack of decision readiness characterized by surprise leading to increased stress. These studies indicate that decisionmaking behavior by nuclear power plant operators could be impaired so that ineffective or inefficient responses to severe stress may occur. Staw, Sandelands, and Dutton (1980) in a multilevel analysis of organizational behavior found similar stress effects on individual decision behavior. Wallach, Kogan, and Bem (1964) present evidence that diffusion of responsibility leads to greater risk taking by the group. Application of decision models to decision processes during the Israeli raid at Entebbe concluded that well-defined procedures, e.g., standard operating procedures, enhance decisionmaking. This indicates a need for highly structured procedures, overlearning of the procedures, and a formal centralized authority.

High stress adversely affects judgment by inducing cognitive rigidity and reducing perception. High stress reduces the range of cue utilization for decisionmaking. Bacon (1974) demonstrated that under increased stress, perceptual focus centers on cues that initially attract attention even though they may be less important to resolution of the stress situation than other cues. He also reported that reduced perceptual sensitivity under stress may be linked to a reduction in short-term memory capacity. Wachtel (1968) discovered that sensitivity to cues located near the perceptual periphery could be significantly reduced by the threat of electrical shock. He found that this reduced sensitivity could be attenuated when subjects were given a method of coping with the stressful situation.

Ivancevich and Donnelly (1974) as well as Gavin and Axelrod (1977) found uncertainty to be a contributing factor to physical and psychological stress. The tendency for uncertainty to adversely affect human decisionmaking and judgment in fault diagnosis and correction is demonstrated by Johannsen and Pfendler (1983). Common sources of uncertainty are role ambiguity and information deficit (Holbrook and Ryan, 1982; Smart and Vertinsky, 1977). Smart and Vertinsky (1977) also outlined a number of stress-induced disorganizing effects on group decisionmaking. Under high stress, group members develop an illusion of invulnerability resulting in excessive optimism and increased risk taking, rationalize the status quo, and ignore warnings and negative feedback, all of which may hinder decision reassessment. Stress results in group underestimation of the importance of a crisis or threat. Members of a group under stress may exert pressure on any one member who shows doubt or dissent concerning group decisions and thus force conformity. Unconsciously, they may develop self-appointed members who shield the group from information that contradicts group beliefs.

Blumenthal (1977) provides a concept on the problem of decisionmaking, problem structuring, and risk-taking behavior. He says that solutions to problems can be stated as a sequence of orderly steps. It is far more likely that the person in a problem-solving situation arrives at solutions and decisions through a series of tentative stops and starts. The person imagines conclusions or makes associations or creates multiple hypotheses. At nuclear facilities, it is quite conceivable that operators will make hypotheses about plant conditions, the integrity of safety grade systems, and the type of transient occurring. It is possible that hypothesis generation will impact the selection and performance of immediate and subsequent operator actions. There appear to be limiting factors which have to be understood if this sequential process is examined. These are information processing or time sharing identifiable in chunking of knowledge in memory, and focusing and scanning whereby a subject chooses one or another strategy in a problem-solving situation. For example, a focusing strategy involves concentration on a positive indicator of a hypothesis and a comparison of samples in the field that represent the hypothesis. A scanning strategy is used when a subject varies two or more stimulus attributes at a single time as in the development of a trial hypothesis when partial data are fitted to a selected stimulus.

Blumenthal concludes that, while various degrees of focusing and scanning behavior may determine efficiency of problem solving, the crucial point is the degree to which information is gained by the way attention is deployed. He sums his discussion this way: "A key mechanism in the control of these processes is the central emotional reaction. The central process of attention is aroused, directed, or inhibited by the emotional experience it engenders." The scanning strategy is an explicit risk-taking strategy of problem resolution. Finally, decisionmakers seem to base their choice on the sources of information: factual from data sources, experimental resources, and historical data; judgmental from extrapolations, perceptions, and uncertain assumptions. Training in decisionmaking allows the problem solver to cast his images, conclusions, and actions in a series of efficient steps which form sequences leading to an acceptable solution. Heuser (1978) investigated problem-solving behavior under stress. Poor performance was interpreted as being caused by a shift in the subject's attention. Stress seemed to transfer part of the attention process from task solution to the possible danger of damaging the self-image if failure occurred. The element of risk interacted with decisionmaking.

Research by Mandler (1979) suggests that stress may impact performance by its influence upon hypothesis generation. He has postulated that, when highly stressed, subjects form hypotheses and then try to select responses that support these first hypotheses. Information is then filtered or ignored after the first hypothesis has been generated. These findings confirmed those of Smock (1955), who determined that subjects under stress were unable to revise earlier perceptions of the task.

The indications that stress creates cognitive rigidity and perceptual narrowing which hinder problem solving and judgment are important in terms of operator effectiveness during an emergency. Couple these effects with other findings that distortion of information is a common result of stress and the problem becomes more complex. A probable result of the combination of these factors is a high degree of conflicting information present in the control room during an emergency. The degree to which conflicting information may hinder the decisionmaking abilities and control action responses of operators during a crisis is one focus of the present research.

Findings that suggest that people experiencing a sudden high intensity stressor or encountering an acutely stressful situation tend to rely heavily on previously established procedures and authority and resist change of standardized procedures are also important in terms of proper operator response to severe emergencies. Effective procedures compatible with the response characteristics of operators under stress would assist correct operator action better than equally valid procedures which because of their form or method of implementation are not consistent with behavior under stress. One important consideration concerning the usefulness of procedures under stress may be the level of detail present in those emergency procedures. There may be an optimal level of detail for a procedure designed for use under conditions of psychological stress. This optimal procedure may be one which would not contain so much detail as to be difficult for an operator under severe stress to follow but still provide a sufficient level of information to assist effective control actions. Such an optimal procedure may also be easier to standardize and establish cognitively, both important considerations relating to human response under stress, than a greatly detailed and complex procedure. Determining the relationship between the level of detail in available emergency procedures and operator action and decisionmaking under stress is another focus of the present research.

Workload and the Inverted U Function

Workload is a function of the time allowed to successfully complete a task as well as the number of tasks specified. As such, it is defined as a combination of speed (the time allowed) and load (the number of tasks to be performed). Workload may be increased by reducing the time allowed to perform primary and/or secondary tasks as well as by adding additional or ancillary tasks. A number of studies have shown extremely high or extremely low workload to be positively related to stress (Bateman, 1981; Gavin and Axelrod, 1977). Specifically, performance under workload approximates an inverted U-shaped function (Miller, 1960; Holbrook and Ryan, 1982). That is, as workload increases from very low to very high levels, performance initially improves, then peaks before declining. Likewise, performance of tasks under low to high levels of stress also approximates an inverted U-shaped function (Freeman, 1940; Berkun, 1964; Broadbent, 1971; and Anderson, 1976). These findings have particular implications for the nuclear industry where workload flow varies during the normal shift cycle, and plant cycle, i.e., a fuel loading, may be very high (e.g., high stress) due to physical and mental demands.

Another area of research related to performance decrements associated with workload is time stress. Time stress is a phrase coined by Siegel and Wolf (1969) to assist in understanding human performance. Time stress is defined as a ratio of time to perform remaining tasks divided by the time available. Siegel and Wolf (1969) also demonstrated the characteristic inverted U-shape function between time stress units and the level of performance. Research cited in Hutchinson (1981) has demonstrated that human performance breaks down as a time stress ratio of 2 is exceeded.

At the onset of a severe emergency at a nuclear power plant, the consequent sudden increase in operator workload may be a significant factor in the inducement of higher levels of psychological stress. Another focus of the present research is to determine if increasing workload will result in higher subjective levels of stress reported by operators and decrements in the quality of operator decisions and control actions.

Part of the inverted U-shaped function in performance which occurs under stress may be explained by what we know about arousal. Low arousal may result in inattention and hence poor performance. During high arousal states, there is also some evidence that performance is poor and this may relate to the filtering of input (Broadbent, 1971). Novel stimuli (new information) are filtered out, and steady-state (status quo) information is allowed to pass through. As a result, stress leads to response perseveration. Naatanen (1973) has also postulated that high stress effects occur because individuals reorient from the primary task to a secondary task of dealing with stress itself.

Coping behaviors have been found to act as moderators in assisting individuals under stress to maintain performance. Anderson (1976) has confirmed the existence of a U-shaped function for decision-making across stress. He noted that "problem-solving coping mechanisms are related to high performance, . . . while emotional-defensive coping mechanisms are associated with lower levels of performance under high stress, possibly through the suppression of problem solving attempts."

Stress and Personality

Personality variables have been shown to be related to the ability to handle stress or stressful situations. Inabilities to handle stress often may result in performance decrements and/or cardiovascular, psychosomatic, allergic, and emotional disturbance (Karcher and Linden, 1982; Zaleynik, Kets de Varies, and Howard, 1977; and Sharit and Salvendy, 1982).

One of the personality variables that has been the subject of much research is Type A versus Type B. In particular, this research began with the examination of coronary-prone individuals in Friedman and Rosenman (1969) and in Rosenman (1978). Type B personality is characterized by a relaxed, unhurried, satisfied approach to life and work in which strivings for achievement tend to flow with the stream of life rather than against it. Type A behaviors are a characteristic action-emotion complex related to strivings for achievement, preoccupation with time and success even if against the flow of the environment, plus restlessness, and feelings of being pressured. The Type A individual is extreme in terms of these factors, and this may be related to commitment to profession to the exclusion of all other aspects of one's personal life (Jenkins, 1971, 1975, 1976). Orpen (1982) discovered a strong positive relationship between stress and psychological strain in Type A personalities.

A related and significant personality variable is that of locus of control, which is defined to be either internal or external to the individual. Internals believe reward is contingent on their own actions, while externals believe reward is not entirely contingent on their actions and is under control of outside forces. Individuals with an internally based locus of control as defined by Rotter's (1966) test tend to be less adversely affected by stress than do individuals with an external locus of control (Anderson, 1977). This may be a factor of internals having a built-in coping mechanism (e.g., they believe their actions can affect events around them), while externals believe they are at the mercy of external events (Rotter, 1966).

Another significant personality variable is that of impulsivity, that is, the degree to which persons have sudden inclinations to take actions and/or make decisions. Research indicates impulsivity may moderate the U-shaped performance function. Low-impulse control subjects show high deterioration under stress, while high-impulse control subjects can maintain high levels of performance.

Psychological set may be a temporary condition that has some effect on performance. English and English (1958) have defined set as an "often recurrent condition of the person which (a) orients him toward certain events rather than others, selectively sensitizing him for apprehending them, (b) facilitates certain activities or responses rather than others." We believe that the past training and experience of power plant operators combined with the instructional set established by training to criteria will ready them in a positive sense to accomplish the behavioral action sequences necessary to mitigate transients after the occurrence of an emergency such as a severe seismic event.

Swain and Guttman (1980) identified many variables in nuclear power plants they called performance shaping factors, including characteristics within the domains of attitude, individual differences, and personality. Machreiner (1970) had shown that motivational factors had an impact on vigilance, an activity which frequently is required in a control room. Grandjean et al. (1977) found that when subjects were stressed (in this case, fatigued), there was an accelerated decrement in performance. Lazarus and Lanier (1967, 1977, 1978) emphasize the effects of the life circumstances and societal environments. However, they do not address the small group processes. They focus on the occasions during a lifetime that are sources of stress, such as births, deaths, marriage, divorce, health, family or job-related problems. In their structure of stress, the personality of the individual plays an important part in coping with life stressors. They do include the effects due to individual differences. The first generalization is that severe stress is only one of a number of stress situations experienced by people, and people respond to life stressors by choosing coping behaviors. Personality characteristics or traits, such as Type A and Type B traits, also may be important in effective decisionmaking. A second generalization is that effects of prior stressful situations can be useful in coping with new stressful stimuli (Berkun, 1964; Abe, 1978).

In general, differences in personality, intelligence, and past history in terms of dealing with stressful events all result in differences in the way one responds to stressful events. Frequently, these differences have been treated as error, but it has become apparent that they may be important predictors of performance in high stress situations [Poulton (1975), Mackie (1977), O'Hanlon and Kelley (1977)]. Thus, individual personalities of the operators may be a significant factor in the way they respond to stressful events such as severe earthquakes or other critical plant emergencies. Therefore, another concern of the present research is to assess certain relevant personality characteristics in a group of operators and determine if relationships exist between these characteristics and the quality of the operators' decisions and control actions under stress.

Rationale

The literature review has provided four major areas of interest for this study. These areas were chosen because of their likely role during a high stress (accident) event in the control room.

The first major supposition is that conflicting information present in the control room during a high stress event would add to that stress the operator(s) was experiencing. The conflicting information may influence the decisionmaking processes and the control action responses of the operator during the event.

The second supposition concerns the relationship between the level of detail in a procedure and the resultant operator action and decisionmaking during a high stress event. As reported, persons under high stress tend to rely on established procedures and resist change of standardized procedures. This study looks at the level of detail required for the optimal procedure.

The third supposition is based upon the relationship of workload and stress. It has been clearly demonstrated that performance under workload and stress approximates an inverted U-shaped function. This study intends to determine if increasing workload will result in decrements of operator decision quality and reported levels of stress.

The fourth supposition is centered upon the relationship between personality characteristics and decision quality under stress. This study will identify certain personality characteristics and investigate the ability to predict performance from these variables.

From these suppositions, three specific independent variables related to stress, associated with the tasks and working environment of nuclear power plant operation in the context of a severe seismic event or other serious emergency, were chosen as a focus of the present study. These variables are workload, conflicting information, and the level of detail in available emergency procedures. Also, certain personality variables which the literature suggests are related to human performance under stress were selected for examination. The purpose of this study is to determine the relationships between these stress variables and operator decisionmaking performance and to define specific associations between operator personality characteristics and decision performance under stress. The following hypotheses are evaluated to assess whether decisionmaking performance is affected:

1. Each stressor (high conflicting information, limited procedures, and high work load) will serve individually to limit decisionmaking performance.

2. The greatest decrement in performance will occur in the presence of a combination of high conflicting information, limited procedures, and high work load.

3. Operators with Type B personality characteristics will perform better in stressful situations than operators with Type A personality characteristics.

4. Externals, as defined by Rotter's Locus of Control measure, will perform better than internals in the presence of detailed procedures.

5. Operators who have successfully mastered previous stressful events during their lives, as measured by the Life Stress Index, will perform better under stressful conditions.

METHOD SECTION

Subjects

Twenty-four operators currently or previously certified at the Loss-of-Fluid Test Reactor served as subjects in the present experiment. Their mean experience level in reactor operations was nine years. All had vision correctable to 20/20 and hearing within normal limits as determined by company physical examination.

Design

Three independent variables—workload, procedures, and conflicting information—are incorporated in the experimental design. The workload and conflicting information variables each contain two levels, high and low. Limited and detailed procedures are the two levels of the procedures variable. The conflicting information variable is blocked so that half of the subjects received high conflicting information and half received low conflicting information. The procedures and workload variables are completely crossed so that each subject received four conditions representing the possible combinations of the two levels of each of these two variables. These four conditions are high workload with limited procedures, high workload with detailed procedures, low workload with limited procedures, and low workload with detailed procedures. The dependent measures in the present study consist of seven response action scores for each subject. These, in turn, related to immediate, subsequent, and nonapplicable actions indicated by the subjects for the mitigation of 12 off-normal events. Each subject received three different postseismic event scenarios or trials in each of four conditions for a total of 12 different scenarios. The design is blocked out below.

	Procedure[a]			
	Low Work Load		High Work Load	
Type of Information	Limited	Detailed	Limited	Detailed
Low conflicting	ss 1 - 12	ss 1 - 12	ss 1 - 12	ss 1 - 12
High conflicting	ss 13 - 24	ss 13 - 24	ss 13 - 24	ss 13 - 24

a. Each subject received three different scenarios in each of the four workload-procedure combinations.

Materials

Five sets of materials were developed for this experiment. The first set of stimulus materials consisted of 12 scenarios developed to depict off-normal conditions that might occur after a seismic event has occurred at a pressurized water reactor (PWR). These scenarios were developed by Nuclear Regulatory Commission (NRC) operator licensing examiners with experience in PWR operation and are listed in Appendix A. The next set of materials was an action-response list based upon actual plant procedures for responding to off-normal events at a commercial PWR. This list contained 20 items, which fall into one of three categories: immediate response, subsequent response, and not applicable response. Immediate responses were defined as steps (actions) performed by an operator prior to referring to a procedure, subsequent responses required the use of a procedure, and not applicable responses were normally subsequent responses that did not apply to the scenario being evaluated. The response action list is shown in Appendix B. This categorization scheme for operator action responses allowed the authors to examine the differential sensitivity of response types to experimentally manipulated psychological stressors. This is important because stress in nuclear power plant control rooms may only affect certain types of decisionmaking, i.e., whether to consult procedures or whether to act. A secondary task of the operators was to listen to conflicting information being played on a tape recorder. This information consisted of pieces of procedures that would interfere with normal attempts at problem solving. To ensure that subjects actually attended to this conflicting information, each subject was required to indicate how many times he heard certain phrases repeated on the tape. Two lists of phrases were developed to correspond to the two types of conflicting information, high and low. The low conflicting information referred to one voice discussing plant conditions and required that the subjects keep track of two phrases. The high conflicting information condition required subjects to listen to two voices on the tape and to keep track of four phrases. The tracking sheets for this secondary task are presented in Appendix C.

Next, detailed and limited emergency procedures to be made available to the operators during the course of the experiment were developed. These procedures were constructed by experts from actual emergency procedures for a commercial PWR. The limited procedure was a single page list of nine top-level steps to be taken in case of an emergency. The detailed procedure, which was eight pages long, described which valves were to be open/closed, made reference to other procedures, and specified other detailed action sequences required to place the plant back into a safe state. The final set of materials used in the present experiment was a set of personality inventories related to the variable of stress. Prior to evaluating the scenarios, each subject received a personality test packet, which included the Jenkins' activity survey, the trait form of the State-Trait Anxiety Inventory, the Life Experience Questionnaire, Rotter's Locus of Control, and the Maslach Burnout Inventory. These tests were selected because research findings to date suggest them to be good measures of personality characteristics that might be sensitive to psychological stress. Each of these personality measures is described briefly below.

Jenkins' Activity Survey. This instrument was designed to measure Type A (coronary prone) behavior, the overt manifestations of which are competitiveness, striving for achievement, aggressiveness, restlessness, and the pressure of time (Jenkins, Zyzanski, and Rosenman, 1979). Those who exhibit a relaxed, more satisfied interest in achievement and life are considered Type B. In addition to the Type A-Type B scale, three component dimensions have been empirically established: Factor S (speed and impatience), Factor J (job involvement), and Factor H (hard driving and competitive). The self-report multiple-choice format consists of 52 items that measure the Type A-Type B behavior pattern. Reliability coefficients were calculated for the scale in two ways: Kendall's tank one-year test-retest coefficient (Kendall, 1948), and the squared multiple correlation coefficient (Nunnally, 1967, p. 354). These were found to be 0.83 and 0.85, respectively. The four scales demonstrate that uniform reliability and test-retest reliability at a 4-yr interval ranged from 0.65 to 0.82. The scale has been found to correlate with structural interviews and production of coronary heart disease, risk of reinfarction, and arteriosclerosis. Populations include a wide range of cultural and occupational groups. The present study is the first we know of where the relationship between Type A personality factors and the decisionmaking of power plant personnel has been tested.

State-Trait Anxiety Inventory. This test developed by Spielberger, Gorsuch, Lushene, Vagg, and Jackobs (1983) measures the concepts of state and trait anxiety elucidated by Cattell (1963). State refers to the emotional state existing at a particular moment in time and trait to a more enduring cross-section of a person's life. Trait anxiety refers then to differences in anxiety proneness, while state anxiety refers to the intensity of an anxiety reaction. The instrument is composed of self-report scales, based on how people feel "right now" and how they feel "in general." The test has been used for clinical, research, and screening purposes (for anxiety problems). The most recent versions of the scales were produced in 1979 and were used in the present study. Four point scales are used and norms are available for different occupational groups. The most recent version (the one used in the present research project) was based on an N of 5,000. F-scale reliability ranges from 0.73 to 0.86, and S-scale reliability is normally 0.90 and above for a large variety of populations. The current study uses this inventory to assess the relationship between trait anxiety and the quality of power plant operator decisionmaking under stress.

Life Experience Questionnaire. The Holms' Life Experience Scale (also called the Social Readjustment Rating Scale) is a self-report instrument consisting of short descriptions of 43 potentially stressful life events. Holms ranked and weighted these events in terms of stressfulness. The most stressful event is ranked one, and the weightings range from 100 for the most stressful to 11 for the least stressful event. For example, death of a spouse is ranked one and weighted 100; divorce is ranked second and weighted 73; marriage is ranked seventh and weighted 50; business readjustment is ranked 15th and weighted 39; change in sleeping habits is ranked 38th and weighted 16; and minor violation of the law is ranked 43rd and weighted 11. Respondents are asked to place a check mark by each event they have experienced and to indicate how many times each experienced event occurred to them. A score reflecting the general stressfulness of the type of stressful life events experienced by the respondent is obtained by summing the weightings of each event checked by the respondent. A score reflecting stressfulness of both the type and the amount of stressful life events experienced is obtained by multiplying the weightings for each event by the number of times that event occurred and summing the products. The Life Experience Questionnaire will provide a means for the present research to assess possible relationships between operators' past experience with stressful situations and the quality of their control action decisions under stress.

Rotter's Locus of Control. This instrument, established in 1966 (Rotter, 1966), measures a person's perception of whether reward is contingent on behavior or independent of it, and whether a person perceives reward as based on skill or chance. This construct is called internality/externality and is a continuous, rather than dichotomous, phenomena. People's belief in internal as opposed to external control has its roots in Social Learning Theory (Rotter, 1966). There has been a wealth of research performed employing this instrument. Moderate findings exist for test-retest reliability and internal consistency. The original test consisted of 29 self-administered choice items and was employed in the present study. This instrument enables a comparison to be made of the performance of operators having internal and those having external locus of control.

Maslach Burnout Inventory. The inventory (Maslach and Jackson, 1981) is keyed to an individual's burnout, a syndrome of emotional exhaustion. There are three subscales to the syndrome: emotional exhaustion, depersonalization, and lack of personal accomplishment. Each subscale has two dimensions, frequency and intensity. Scores for each subscale are considered individually. Present scales were based on an N of 1,025 and derived through principal factor analysis with iteration and orthogonal rotation; eigenvalues for the scales all were above unity. No factor structure was identical for both frequency and intensity. Internal consistencies were observed to range from 0.71 to 0.90. Highest consistencies were determined for emotional exhaustion, depersonalization, and lack of personal accomplishment, respectively. External validations have been demonstrated for mental health worker, police officer, physician, and social security administration populations. Discriminant validity data distinguishes the scales from job satisfaction measures. In addition, there is no significant correlation between this inventory and social desirability scale ratings as determined by the Crowne-Marlowe (SD) scale. Operators' level of emotional exhaustion, feelings of depersonalization, and feelings about personal accomplishment will be correlated to the quality of their control actions under stress in the current study.

Procedures

Subjects were ushered into the testing room, and roughly 5 to 10 min were taken to establish rapport between subjects and experimenter. Subjects were then given $\sim$20 min of training, which consisted of discussing what actions an operator would perform in terms of the response action list for a simple training transient (see Appendix A). The subjects were administered training in a group in the presence of detailed and limited procedures and high and low conflicting information. All participants were encouraged to ask any questions they might have during the training session. Following the training session, subjects were then given a further orientation to the tasks by being told that they would respond to 12 scenarios in the same manner that they did during the training sessions. Testing sessions averaged 2-1/2 h and included completion of the personality inventory as well as the action response sheet for each of the 12 scenarios. The order of the scenarios was individually randomized for each subject as was the ordering of the actions on the response action list. The order of the five stress-related measures composing the personality inventory was also completely randomized for each subject. Three consecutive scenarios were administered under each of the four conditions representing the combinations of the workload and procedure variables, and each subject responded individually to each scenario by marking the actions on a corresponding action response list as immediate, subsequent, and nonapplicable. Prior to administration of each scenario, the subjects were made aware of the available written procedures and the time allotted to them for the completion of the action response list for that scenario. Following the administration of the three scenarios in each procedure-workload condition, as a check on the experimental manipulations, each subject completed a four-question, five-point Likert scale regarding the degree to which he felt pressured during his evaluation of the scenarios. This manipulation check inventory appears in Appendix D. One-half of the subjects were exposed to the high conflicting information condition and one-half to the low conflicting information condition. Conflicting information tapes were recorded on a Panasonic tape recorder Model RQ-2309A. The same tape machine was used to run the tapes during all testing phases, with the volume control set at level four. Testing was conducted in a well-lighted room located in the Technical Support Building at the Idaho National Engineering Laboratory. All subjects evaluated each of the 12 scenarios in terms of the immediate, subsequent, and nonapplicable actions contained on the response action sheets by placing either an I, S, or NA next to each action response. All subjects were guaranteed anonymity by use of a numerical coding scheme. Because of the sensitive nature of the personality scores, all test information was coded with the other data and stored securely for analysis.

Method of Analysis

Subjects' scores were compiled and analysis of variance and multiple regression models applied for seven measures. These measures fell into two categories, percent correct and error analysis. Percent correct analysis made use of standardized scoring keys that had been developed by subject matter experts for each of the 12 scenarios. These keys were used to score each action response list on percent of immediate, percent of subsequent, percent of nonapplicable, and percent of total actions marked correctly. Error analysis was based upon the contribution of each of the three response categories to the total error score derived per scenario. This resulted in the three error scores: percent of errors marked immediate, percent of errors marked subsequent, and percent of errors marked nonapplicable. Summation of the percent of errors marked immediate, subsequent, and nonapplicable always equaled 100.

RESULTS

To demonstrate the effectiveness of the experimental manipulation, scores on the four-question, five-point Likert scale administered following each experimental condition were analyzed using a 2 (high and low conflicting information) by 2 (high and low workload) by 2 (detailed and limited procedures) analysis of variance (ANOVA) model with repeated measures on procedures and workload. The subjects reported significantly more time-related stress under high workload (mean = 3.81) than under low workload (mean = 2.65), $F(1,22) = 54.01$; $p < 0.05$. Subjects reported the procedures to be significantly more inadequate while under high workload (mean = 4.21) than while under low workload (mean = 3.88), $F(1,22) = 5.77$; $p < 0.05$. The subjects reported feeling significantly more pressured under high workload (mean = 2.31, lower score = more pressured) than under low workload (mean = 2.83), $F(1,22) = 11.71$; $p < 0.01$. There was no significant difference between high and low workload in terms of subject reports of performance due to background noise and voices (i.e., conflicting information). None of the four manipulation check questions revealed a significant difference between high and low conflicting information or limited and detailed procedures. The results of these subjective reports in the experimental manipulation check indicate that the workload manipulation was effective in producing a stress recognizable to the subjects. These results further indicate that the manipulation of conflicting information produced no differences in operators' subjective reports of performance hindrance or stress level, and that the manipulation of procedures generated no difference in the self-report measures except as they relate to workload.

Operators were also scored for the percent of the key phrases they were able to pick out of the conflicting information present in the taped background voices. The group receiving high conflicting information and the group receiving low conflicting information, as defined by the study, did not differ significantly in the percent of conflicting information attended to.

A separate 2 (high and low conflicting information) by 2 (high and low workload) by 2 (detailed and limited procedures) ANOVA with repeated measures on workload and procedures was run for each of seven dependent measures. The dependent measures were four percentage scores for actions identified correctly, and three scores based on the type of errors committed, for each subject's action response lists. The percent correct scores are (a) percent immediate actions correctly identified, (b) percent subsequent actions correctly identified, (c) percent of nonapplicable actions correctly identified, and (d) percent total actions correctly identified. The error scores are (a) percent of errors incorrectly identified as immediate actions, (b) percent of errors incorrectly identified as subsequent actions, and (c) the percent of errors incorrectly identified as nonapplicable actions. The ANOVAs for percent immediate actions correct and for percent total actions correct indicate certain significant main effects and interactions among the independent variables. The ANOVAs for the remaining five dependent measures yielded no significant effects or interactions. The means and standard deviations for percent immediate actions correct and for percent total actions correct for the scenarios in each experimental condition appear in Tables 1 and 2.

Table 1. Means and standard deviations for percent immediate actions correct

	Low Workload				High Workload			
	Detailed Procedures		Limited Procedures		Detailed Procedures		Limited Procedures	
Type of Information	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Low conflicting	75.97	18.04	58.58	24.69	58.89	23.85	54.67	19.18
High conflicting	72.56	13.56	69.00	18.06	72.31	20.16	71.25	20.47

Table 2. Means and standard deviations for percent of total actions correct

	Low Workload				High Workload			
	Detailed Procedures		Limited Procedures		Detailed Procedures		Limited Procedures	
Type of Information	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Low conflicting	54.44	16.33	46.53	18.62	46.11	19.35	43.47	17.19
High conflicting	55.25	15.94	54.03	13.67	54.03	15.76	56.81	15.59

The results of the ANOVAs for percent immediate actions correct and for percent total actions correct are presented in Tables 3 and 4. For percent immediate actions correct, there is a significant main effect for the workload variable, $F(1,22) = 5.45$ at the 0.05 confidence level, and also a significant main effect for the procedures variable, $F(1,22) = 10.91$ at the 0.01 confidence level. The mean percent immediate actions correct for high workload is 64.28 and for the low workload is 69.03. Under low workload, subjects picked significantly more immediate actions correctly than under high workload. The mean percent immediate actions correct for limited procedures is 63.38 and for detailed procedures is 69.93. When subjects had detailed emergency procedures available for reference, they marked significantly more immediate actions correctly than when they had only limited emergency procedures available. However, it should be noted here that the experimenters observed the subjects to refer to the procedures infrequently during the experimental session. When questioned about this following the sessions, most subjects explained that their task load was too high to allow extensive reference to the written procedures and that they had most of the emergency procedures memorized.

The ANOVA for the dependent variable percent total actions correct indicate a significant main effect for the conflicting information variable, $FC(1,22) = 4.36$, at the $P < 0.05$ confidence level. The mean percent total actions correct for high conflicting information is 55.03 and for low conflicting information is 47.64. As suggested in hypothesis one, these experimental results indicate that decrements in operator decisionmaking performance occur individually under high workload relative to low workload and in the presence of limited procedures relative to detailed procedures. Contrary to hypothesis one, however, experimental results indicate more correct decisionmaking by operators exposed to high conflicting information relative to operators exposed to low conflicting information. This result suggests a number of interpretations.

First, performance as a function of arousal, as with stress, has been demonstrated to be an inverted U function. Thus, the current manipulation of conflicting information from low to high may simply be reflecting two points on the ascending portion of the inverted U arousal function. That is, the high conflicting information condition may have generated increased arousal relative to the low conflicting information condition in the current subjects, with both arousal levels falling below the arousal level reflecting the optimal arousal-performance relationship occurring at the peak of the inverted U.

Second, results of the experimental manipulations check (Likert scaling) show that subjects perceived no difference in performance or induced stress between the low and high conflicting information conditions. This, coupled with the result that subjects experiencing low conflicting information and subjects experiencing high conflicting information were able to attend to roughly equal percentages of imbedded key information, suggests that the current manipulation of conflicting information may have been less than effective. If this is the case, the observed main effect of conflicting information could be a spurious result of a type one statistical error or the result of uncontrolled confounding variables such as arousal. However, it should be

Table 3. ANOVA for the dependent measure percent immediate actions correct

Variable	df	Hypothesis SS	Error SS	Hypothesis MS	Error MS	F	Significance of F
Conflicting information	1,22	6160.5	36055.1	6160.5	1638.9	3.76	NS(<0.07)
Workload	1,22	1624.5	6554.3	1624.5	297.9	5.45	<0.05
Procedures	1,22	3094.2	6236.9	3094.2	283.5	10.91	<0.01
Conflicting information by workload	1,22	2380.5	6554.3	2380.5	297.9	7.99	<0.01
Conflicting information by procedures	1,22	1300.5	6236.9	1300.5	283.5	4.59	<0.05
Workload by procedures	1,22	1104.5	9070.8	1104.5	412.3	2.68	NS
Workload by procedures by conflicting information	1,22	512.0	9070.8	512.0	412.3	1.24	NS

KEY:

df - degrees of freedom
SS - sum of squares
MS - mean square
F - significance test
NS - not significant

noted that subjects' failure to perceive differential effects of the conflicting information manipulations does not preclude those manipulations from having an effect on their performance. Indeed, a statistically significant effect of conflicting information was observed in terms of the percent of total actions correctly identified by operators in the present research.

Third, it is possible that certain types of decisionmaking (for example, whether to act immediately or refer to written procedures) may be especially sensitive to disruption by either high or low conflicting information. Additional dependent measures (e.g., number of actions selected as immediate), additional data analysis, and possibly further experimentation would be required to determine such relationships. In general, the main effects discussed thus far suggest that the relationships between psychological stress and the decisionmaking requirements of nuclear power plant operation are complex.

Four significant interactions were formed as a result of conflicting information affecting performance in an opposite direction than procedures and workload. The interactions are conflicting information by workload, $F(1,22) = 7.99$; $p < 0.01$ for percent immediate actions correct and $F(1,22) = 4.81$; $p < 0.05$ for percent total actions correct, and conflicting information by procedures, $F(1,22) = 4.59$; $p < 0.05$ for percent immediate actions correct and $F(1,22) = 6.53$; $p < 0.05$ for percent total action correct.

Table 4. ANOVA for the dependent measure percent of total actions correct

Variable	df	Hypothesis SS	Error SS	Hypothesis MS	Error MS	F	Significance of F
Conflicting information	1,22	3930.9	19845.1	3930.9	902.1	4.36	<0.05
Workload	1,22	435.1	3447.2	435.1	156.7	2.78	NS
Procedures	1,22	364.5	2225.1	364.5	101.1	3.60	NS(<0.07)
Conflicting information by workload	1,22	754.0	3447.2	754.0	156.7	4.81	<0.05
Conflicting information by procedures	1,22	660.1	2225.1	660.1	101.1	6.53	<0.05
Workload by procedures	1,22	387.3	8376.6	387.3	380.8	1.02	NS
Workload by procedures by conflicting information	1,22	7.3	8376.6	7.3	380.8	0.02	NS

KEY:

df - degrees of freedom
SS - sum of squares
MS - mean square
F - significance test
NS - not significant

For the interaction of conflicting information and workload, the poorest quality decisionmaking in terms of percent immediate and percent total actions correct occurred for the combination of high workload and low conflicting information. Figures 1 and 2 show the interactions between conflicting information and workload for percent immediate and percent total actions correct, respectively. For the interaction of conflicting information by procedures, the poorest quality decisionmaking in terms of percent immediate and percent total actions correct occurred for the combinations of limited procedures and low conflicting information. Figures 3 and 4 present the interactions for percent immediate and percent total actions correct, respectively. The specific cell means reflecting these interactions may be determined from Tables 1 and 2, if desired.

An SPSS forward stepwise inclusion, regression model was used to regress each of the 14 personality factors representing the scales and subscales of the five tests included in the personality battery on the seven dependent measures. The three independent variables—conflicting information, procedures, and workload—were dummy coded to indicate the level of each variable across all subjects and were also included in the regression analysis. Thus, each of the 17 factors representing the personality and independent variables were regressed on the seven dependent measures. Tables 5 through 11 summarize the results of this analysis. Each table represents the regression of the 17 included variables on one of the dependent measures. The order of inclusion of the variables in these tables is determined by the respective contribution of each variable in explaining the variance of the dependent

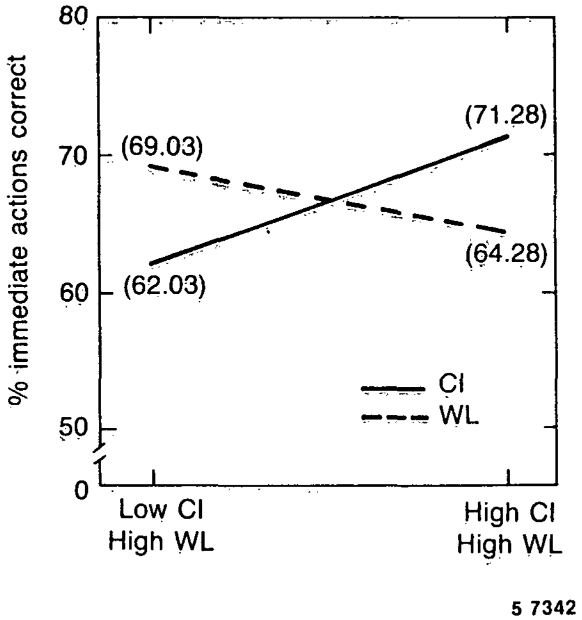

Figure 1. Interaction of conflicting information (CI) by workload (WL) for percent of immediate actions correctly identified.

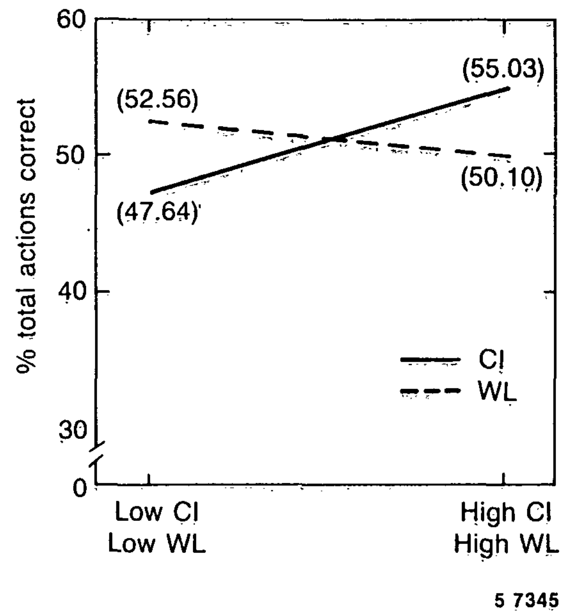

Figure 2. Interaction of conflicting information (CI) by workload (WL) for percent of total actions correctly identified.

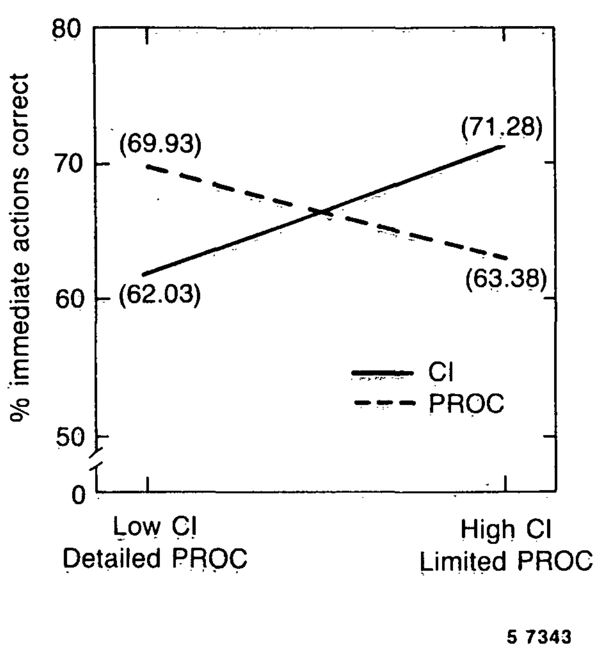

Figure 3. Interaction of conflicting information (CI) by procedures (PROC) for percent of immediate actions correctly identified.

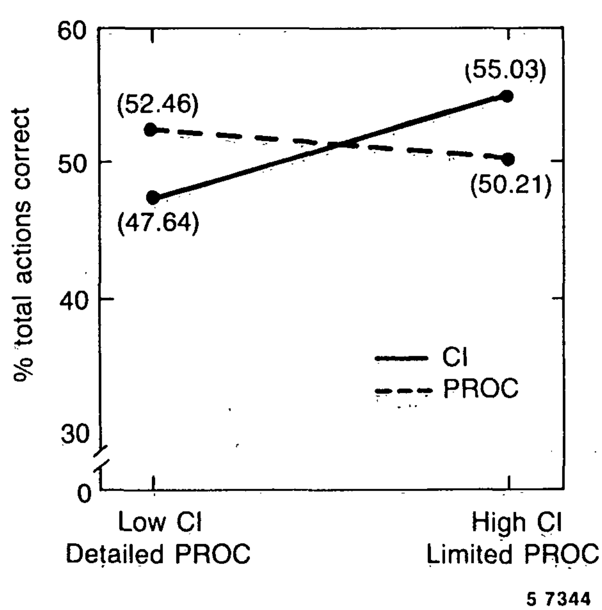

Figure 4. Interaction of conflicting information (CI) by procedures (PROC) for percent of total actions correctly identified.

Table 5. Stepwise multiple regression for percent immediate actions correct

Variable	Multiple R	R Square	Overall F	Significance
Rotters	0.2472	0.0611	18.6102	0.01
EE:F	0.3369	0.1135	18.2409	0.01
PA:F	0.3844	0.1478	16.4154	0.01
Procedures	0.4139	0.1713	14.6233	0.01
JAS:A	0.4406	0.1941	13.5861	0.01
Workload	0.4542	0.2063	12.1720	0.01
Life	0.4671	0.2181	11.1597	0.01
JAS:H	0.4735	0.2242	10.0766	0.01
STAI-T	0.4825	0.2328	9.3753	0.01
Conflicting information	0.4919	0.2420	8.8419	0.01
PA:I	0.4976	0.2476	8.2549	0.01
JAS:I	0.5088	0.2589	8.0056	0.01
DP:I	0.5205	0.2710	7.8337	0.01
EE:I	0.5274	0.2781	7.5131	0.01
Life 2	0.5339	0.2850	7.2286	0.01
DP:F	0.5436	0.2955	7.1035	0.01
JAS:S	0.5468	0.2990	6.7732	0.01

Table 6. Stepwise multiple regression for percent subsequent actions correct

Variable	Multiple R	R Square	Overall F	Significance
EE:F	0.2062	0.0425	12.7046	0.01
JAS:J	0.2764	0.0764	11.7820	0.01
JAS:H	0.3590	0.1289	14.0061	0.01
Life	0.3693	0.1364	11.1746	0.01
Life 2	0.3933	0.1547	10.3204	0.01
STAI:T	0.4105	0.1685	9.4893	0.01
DP:F	0.4167	0.1737	8.4054	0.01
DP:I	0.4212	0.1774	7.5196	0.01
JAS:A	0.4233	0.1792	6.7418	0.01
JAS:S	0.4295	0.1845	6.2667	0.01
Conflicting information	0.4347	0.1889	5.8450	0.01
Rotters	0.4393	0.1930	5.4793	0.01
EE:I	0.4435	0.1967	5.1620	0.01
PA:I	0.4506	0.2030	4.9676	0.01
Procedures	0.4518	0.2041	4.6499	0.01
PA:F	0.4525	0.2048	4.3618	0.01
Workload	0.4533	0.2055	4.1070	0.01

Table 7. Stepwise multiple regression for percent nonapplicable actions correct

Variable	Multiple R	R Square	Overall F	Significance
DP:I	0.3775	0.1425	47.5296	0.01
JAS:S	0.4181	0.1748	30.1891	0.01
PA:I	0.4570	0.2088	24.9871	0.01
JAS:A	0.4796	0.2300	21.1295	0.01
Rotters	0.4929	0.2429	18.0971	0.01
EE:F	0.5073	0.2574	16.2301	0.01
DP:F	0.5379	0.2893	16.2836	0.01
STAI:T	0.5412	0.2929	14.4431	0.01
JAS:J	0.5442	0.2962	12.9976	0.01
PA:F	0.5485	0.3008	11.9186	0.01
Life	0.5572	0.3104	11.2953	0.01
JAS:H	0.5584	0.3118	10.3847	0.01
Workload	0.5596	0.3131	9.6087	0.01
EE:I	0.5605	0.3141	8.9300	0.01
Conflicting information	0.5617	0.3155	8.3561	0.01
Life 2	0.5625	0.3164	7.8384	0.01
Procedures	0.5626	0.3166	7.3561	0.01

Table 8. Stepwise multiple regression for percent of total responses correct

Variable	Multiple R	R Square	Overall F	Significance
Conflicting information	0.2162	0.0467	14.0236	0.01
JAS:H	0.2719	0.0739	11.3720	0.01
PA:F	0.3010	0.0906	9.4328	0.01
Life	0.3491	0.1219	9.8176	0.01
PA:I	0.3740	0.1399	9.1738	0.01
DP:I	0.4057	0.1646	9.2265	0.01
Rotters	0.4146	0.1719	8.3027	0.01
Workload	0.4207	0.1770	7.4980	0.01
JAS:S	0.4264	0.1819	6.8656	0.01
Procedures	0.4314	0.1861	6.3320	0.01
DP:F	0.4357	0.1899	5.8805	0.01
EE:I	0.4375	0.1914	5.4233	0.01
Life 2	0.4380	0.1918	5.0021	0.01
JAS:A	0.4383	0.1921	4.6366	0.01
EE:F	0.4389	0.1927	4.3272	0.01
JAS:J	0.4390	0.1927	4.0430	0.01

Table 9. Stepwise multiple regression for percent of action response errors marked immediate

Variable	Multiple R	R Square	Overall F	Significance
PA:I	0.2461	0.0606	18.4404	0.01
Rotters	0.3043	0.0926	14.5403	0.01
JAS:S	0.3391	0.1150	12.3026	0.01
JAS:J	0.3483	0.1213	9.7679	0.01
DP:I	0.3517	0.1237	7.9596	0.01
EE:I	0.3666	0.1344	7.2700	0.01
JAS:A	0.3769	0.1420	6.6219	0.01
Life	0.3798	0.1442	5.8781	0.01
PA:F	0.3830	0.1467	5.3091	0.01
EE:F	0.4093	0.1676	5.5752	0.01
DP:F	0.4178	0.1746	5.3062	0.01
Life 2	0.4337	0.1881	5.3086	0.01
JAS:H	0.4381	0.1919	5.0065	0.01
Workload	0.4410	0.1945	4.7071	0.01
Conflicting information	0.4434	0.1966	4.4370	0.01
Procedures	0.4440	0.1971	4.1577	0.01
STAI-T	0.4444	0.1975	3.9087	0.01

Table 10. Stepwise multiple regression for percent of action response errors marked subsequent

Variable	Multiple R	R Square	Overall F	Significance
JAS:J	0.2472	0.0611	18.6098	0.01
EE:I	0.2980	0.0888	13.8910	0.01
Life	0.3098	0.0960	10.0500	0.01
Life 2	0.3229	0.1043	8.2342	0.01
Conflicting information	0.3342	0.1117	7.0912	0.01
STAI-T	0.3470	0.1204	6.4105	0.01
DP:I	0.3526	0.1243	5.6786	0.01
DP:F	0.3615	0.1307	5.2420	0.01
JAS:S	0.3667	0.1344	4.7973	0.01
JAS:A	0.3707	0.1374	4.4129	0.01
Rotters	0.3761	0.1415	4.1345	0.01
JAS:H	0.3854	0.1485	3.9973	0.01
EE:F	0.3888	0.1512	3.7543	0.01
PA:I	0.3930	0.1545	3.5619	0.01
PA:F	0.3964	0.1571	3.3796	0.01
Procedures	0.3988	0.1591	3.2036	0.01
Workload	0.4006	0.1604	3.0352	0.01

Table 11. Stepwise multiple regression for percent of action response errors marked not applicable

Variable	Multiple R	R Square	Overall F	Significance
DP:I	0.3095	0.0985	30.2975	0.01
PA:I	0.3538	0.1251	20.3826	0.01
JAS:J	0.3945	0.1556	17.4496	0.01
Life	0.4105	0.1685	14.3351	0.01
EE:I	0.4208	0.1771	12.1370	0.01
PA:F	0.4392	0.1929	11.1955	0.01
JAS:S	0.4707	0.2216	11.3883	0.01
JAS:A	0.4930	0.2430	11.1947	0.01
DP:F	0.5020	0.2520	10.4070	0.01
Conflicting information	0.5126	0.2627	9.8710	0.01
STAI-T	0.5284	0.2792	9.7181	0.01
Rotters	0.5336	0.2848	9.1238	0.01
EE:F	0.5384	0.2898	8.6016	0.01
Life 2	0.5419	0.2936	8.1049	0.01
Procedures	0.5428	0.2946	7.5723	0.01
JAS:H	0.5434	0.2953	7.0974	0.01

measure. The variables are arranged in decreasing order of the amount of variability accounted for in the dependent measure. The inclusion of each variable appearing in Tables 5 through 11 to the variables already entered in the regression for a particular dependent variable resulted in significant contributions at the 0.01 confidence level by that set of variables in accounting for the variance of that dependent measure. The overall F as well as multiple R and R^2 values obtained at each stepwise inclusion are reported in these tables. Cumulative R values for the seven dependent measures range from 0.40 to 0.56, suggesting somewhat moderate relationships. The abbreviations used here for the personality variables are explained in Appendix E.

All the variables in Tables 5 through 11, when included with the variables entered before them, resulted in sets of variables which accounted for a significant amount of dependent measure variability. Table 12 reports those variables for each dependent measure which, when included, accounted for a significant increase in the amount of dependent variability accounted for by that set of variables. The F values reflecting significant additional dependent measure variability accounted for, the amount of change in R^2, and the significance level of the reported F are listed for each variable. The simple correlations indicating the direction of the relationship between the variable and the dependent measures are also reported in Table 12.

Locus of control was the strongest predictor of correct immediate actions, emotional exhaustion frequency was the best predictor of correct subsequent actions, and depersonalization intensity was the best predictor of correct nonapplicable actions. The experimentally manipulated variable conflicting information was the best predictor of total response accuracy.

Regression on error analysis data suggests that personal accomplishment intensity is the strongest predictor of immediate action errors. The job involvement factor of the Jenkins' Activity Survey Type A-Type B scale was the best predictor of subsequent action errors. Depersonalization intensity best predicted errors in which subjects mislabeled steps as nonapplicable.

To aid in the evaluation of hypothesis three, four, and five stating relationships between operator personality factors and decisionmaking performance, two-tailed, independent sample T tests were employed in specific comparisons. As an indication of the Ns used in the T-tests, Table 13 presents the distribution of subjects whose scores appear in the various levels of each scale and subscale of the personality battery.

Table 12. Variables that significantly increase the amount of dependent measure variability accounted for

Dependent Measures	Variable	R^2 Change	F	Significance	Simple R
% immediate actions correct	Rotters	0.0611	18.6102	0.01	-0.25
	EEF:F	0.0524	16.8409	0.01	-0.23
	PA:F	0.0343	11.4294	0.01	-0.14
	Procedures	0.0235	8.0282	0.01	-0.16
	JAS:A	0.0228	7.9920	0.01	0.04
	Workload	0.0122	4.3054	0.05	-0.11
	Life	0.0119	4.2431	0.05	0.04
	JAS:J	0.0113	4.2078	0.05	0.18
	DP:I	0.0121	4.5360	0.05	-0.21
	DP:F	0.0105	4.0231	0.05	-0.24
% subsequent actions correct	EE:F	0.0425	12.7046	0.01	-0.21
	JAS:J	0.0338	10.4401	0.01	-0.16
	JAS:H	0.0525	17.1212	0.01	0.14
	Life 2	0.0183	6.0983	0.05	-0.09
	STAI-T	0.0138	4.6633	0.05	-0.11
% nonapplicable actions correct	DP:I	0.1425	47.5296	0.01	0.38
	JAS:S	0.0323	11.1602	0.01	-0.26
	PA:I	0.0340	12.2085	0.01	0.23
	JAS:A	0.0211	7.7700	0.01	-0.04
	Rotters	0.0130	4.8250	0.05	-0.10
	EE:F	0.0144	5.4630	0.05	0.23
	DP:F	0.0320	12.5885	0.01	0.28
	Life	0.0096	3.8401	0.05	0.02
% total action responses	Conflicting information	0.0467	14.0236	0.01	0.22
	JAS:H	0.0272	8.3594	0.01	0.17
	PA:F	0.0167	5.2178	0.05	-0.06
	Life	0.0312	10.0685	0.01	0.13
	PA:I	0.0181	5.9164	0.05	-0.01
	DP:I	0.0247	8.3024	0.01	-0.14
% errors marked immediate	PA:I	0.0606	18.4404	0.01	-0.25
	Rotters	0.0320	10.0563	0.01	-0.19
	JAS:S	0.0224	7.1951	0.01	0.03
	EE:F	0.0209	6.9482	0.01	-0.07
	Life 2	0.0135	4.5781	0.05	-0.08
% errors marked subsequent	JAS:J	0.0611	18.6098	0.01	-0.25
	EE:I	0.0277	8.6730	0.01	-0.10
% errors marked not applicable	DP:I	0.0958	30.2975	0.01	0.30
	PA:I	0.0294	9.5609	0.01	0.29
	JAS:J	0.0305	10.2593	0.01	0.08
	Life	0.0128	4.3701	0.05	-0.01
	PA:F	0.0158	5.5163	0.05	0.11
	JAS:S	0.0287	10.3175	0.01	-0.03
	JAS:A	0.0214	7.8808	0.01	0.16
	Conflicting information	0.0107	4.0267	0.05	-0.03
	STAI-T	0.0165	6.3010	0.01	0.09

Table 13. Distribution of subjects for the various personality scale levels

Test	Variable	Level	Subject Frequency
STA1	Trait anxiety	Low (<50)	22
		High (≥50)	2
Rotters	Locus of control	Internal (<9)	13
		External (≥9)	11
	EE:F	Low (0-17)	4
		Medium (18-29)	9
		High (>30)	11
	EE:I	Low (0-25)	3
		Medium (26-39)	12
		High (>40)	9
	DP:F	Low (0-5)	4
		Medium (6-11)	12
		High (>12)	18
	DP:I	Low (0-6)	3
		Medium (7-14)	1
		High (>15)	20
MBI	PA:F	Low (>40)	2
		Medium (34-39)	0
		High (0-33)	22
	PA:I	Low (>44)	4
		Medium (37-43)	5
		High (0-36)	15
	Life	>Mean (>561)	12
		<Mean (<561)	12
Life Experience Scale	Life2	>Mean (>4117)	4
		<Mean (<4117)	20
	JAS:A	TypeA (≥50)	7
		TypeB (<50)	17
JAS	JAS:S	TypeA (≥50)	12
		TypeB (<50)	12
	JAS:J	TypeA (≥50)	8
		TypeB (<50)	16
	JAS:H	TypeA (≥50)	3
		TypeB (<50)	21

As determined by the Type A-Type B (JAS:A) scale of the Jenkins' Activity Survey, a separate comparison was made of all subjects with Type A characteristics and all subjects with Type B characteristics for each of the seven dependent measures. The only significant difference between the performance of Type A subjects and Type B subjects appears for the dependent measure percent of errors marked nonapplicable. Type A operators made a significantly greater percent of their errors by marking nonapplicable (mean = 26.02) than Type B operators (mean = 17.75), $T(286) = -2.16$; $p < 0.05$.

Type A subjects scoring higher than one standard deviation above the mean were compared to Type B subjects scoring lower than one standard deviation below the mean for each dependent variable. As in the comparisons of all Type A and Type B subjects, the only significant performance difference occurred in the percent of errors marked nonapplicable. Here again, Type A operators (for this comparison high on the Type A scale) made a significantly greater percent of their errors by incorrectly designating an action as nonapplicable (mean = 30.50) than did Type B (for this comparison low on the Type A-Type B scale) operators (mean = 17.55), $T(118) = -2.47$; $p < 0.05$. It is possible that Type A operators incorrectly select more actions as nonapplicable than Type B operators as a function of decision reassessment. That is, Type As (hard driving, competitive, exhibiting speed and impatience) may spend less time and energy reassessing decisions than the more patient Type Bs.

Internals and externals were also compared across all experimental conditions. The performance of internals was significantly better than the performance of externals again for the two dependent measures percent immediate actions correct (means = 72.42 and 59.83, respectively), $T(296) = 5.18$; $p < 0.01$ and percent total actions correct (means = 54.99 and 47.01, respectively), $T(286) = 4.04$; $p < 0.01$. Internals made a significantly greater percent of their errors (mean = 39.35) by incorrectly indicating an action to be immediate than did externals (mean = 27.43), $T(286) = 3.86$; $p < 0.01$. Externals made a significantly greater percent of their errors (mean = 50.49) by incorrectly indicating an action to be subsequent than did internals (mean = 41.91), $T(286) = 2.42$; $p < 0.05$. This suggests that internals tend to select actions as immediate due to the belief that their actions affect events around them.

To test hypothesis 3, another comparison was made between the performance of internals and externals (Rotter's Locus of Control Scale) in the presence of detailed procedures for each dependent measure. In the presence of detailed procedures, internals picked significantly more immediate actions correctly (mean = 74.46) than externals (mean = 64.58), $T(142) = 2.93$; $p < 0.05$. Also, for the percent of total actions picked correctly in the presence of detailed procedures, the performance of internals (mean = 65.88) was significantly better than the performance of externals (mean = 48.41), $T(142) = 2.67$; $p < 0.05$. Apparently, the greater ability of the internals to select actions correctly under stress overshadowed the hypothesized benefit the externals derived from the detailed procedures.

Subjects scoring above the mean on the Life Experience Scale were compared with subjects scoring below the mean. No significant difference in performance was indicated by this comparison for any of the dependent measures. However, when subjects with scores higher than one standard deviation above the mean on the Life Experience Scale were compared with subjects having scores lower than one standard deviation below the mean on that scale, significant differences in performance appear for percent immediate actions correct and for percent of total actions correct. Subjects high on the Life Experience Scale picked significantly more immediate actions correctly (mean = 78.42) than subjects low on the Life Experience Scale (mean = 57.44), $T(70) = -3.74$; $p < 0.01$. Also, subjects high on this scale picked significantly more of the total actions correctly (mean = 57.71) than subjects low on the scale (mean = 41.35), $T(70) = -3.58$; $p < 0.01$.

In the current study, reactor operators were affected by psychological stress in the laboratory environment. Operators would be expected to be affected to the same or increased level on the job. This may be especially true since the levels of stress we were able to induce in the laboratory, due to procedural and ethical constraints, are probably moderate when compared to the stress that would be experienced by an operator during and after an actual emergency at a functioning plant.

Some results did not support conclusions drawn from others' reports in the literature that were reflected in the present hypotheses. Specifically, results failed to support the hypotheses that high conflicting information would tend to adversely affect decisionmaking ability, and that externals would perform better than internals in the presence of detailed procedures. These findings suggest that the experimental tasks in this study are not similar to those studied in the past, and may be more complex than we believed. Stress differentially affected the kinds of decisions relative to reactor operation reflected in the current research. These decisions include choosing to act immediately or not, choosing to refer to written procedures or not, and possibly even choosing whether to reassess a decision or move on. Indeed, the mixed results concerning the way decision performance relates to personality and the interactions of conflicting information with workload and procedures suggest the complex nature of the reactor operator's job and the way stress affects his performance. Implications of the experimental findings relative to the stated hypotheses are further discussed in the next section.

DISCUSSION

Variables hypothesized to be related to psychological stress including the level of workload, the detail of available procedures, conflicting information, and personality characteristics, as defined by this study, were found to have a significant effect on operator performance. Hypothesis one states that each stressor (high conflicting information, limited procedures, and high workload) will serve individually to limit decisionmaking performance. Increasing workload significantly decreased the capacity for operators to make correct decisions about immediate actions in the mitigation of the 12 off-normal scenarios. The effective manipulation of workload in this study as evidenced by subjective subject reports enhances the credibility of this finding. This suggests that prior planning and procedures to distribute workload as optimally as possible among the control room personnel within the limits of mandatory individual responsibilities could enhance individual operator performance under the stress of a serious off-normal event. However, the literature review indicates that diffusion of responsibility in group decisionmaking may lead to greater risk taking, and that people under stress tend to rely heavily on preestablished authority figures. This tends to suggest that individuals' workload in the control room during an emergency should be kept as optimum as possible and that individual and centralized responsibility should be maintained.

This study also found that availability of detailed procedures as opposed to only limited procedures enhanced operator performance under stress. It should be recalled, however, that the procedures were referred to by the operator only to a limited extent during the experimental sessions and that subjective subject reports of the increased usefulness of detailed procedures over limited ones were lacking. It is possible that reference to a detailed procedure may confirm or disconfirm an operator's initial hypothesis relatively quickly, thus streamlining the decision process, while reference to a limited procedure may provide an insufficient level of information to support or discredit an initial hypothesis, in turn leading to a decrement in problem resolution and performance. However, due to the limited use and questionable subjective effect of procedures in this study, further experimental evaluations of this specific result are indicated.

The four-question, five-point Likert scale, incorporated as a check on experimental manipulations, revealed no significant difference between high and low conflicting information in terms of subjective subject reports. Also subjects were able to attend to roughly the same percentage of the key information in the high conflicting information task as in the low conflicting information task. However, the manipulation of conflicting information did affect the operators' decisionmaking performance. Operator decisionmaking in terms of total actions selected correctly was better in the presence of high conflicting information than in the presence of low conflicting information. This counter intuitive finding may be the result of high conflicting information increasing arousal in the subjects to a more optimal level relative to performance. The finding that the two levels of conflicting information differentially affected performance but were not differentially perceived by the subjects suggests a variable that has the potential of detrimentally affecting control room performance while going largely undetected. In the present research, conflicting information interacted significantly with the detail of procedures and the level of workload. Greatest performance decrements were observed in the presence of low conflicting information and high workload and in the presence of low conflicting information and limited procedures. Due to the unexpected direction of the effect of conflicting information, hypothesis two, stating that the greatest decrement in performance would occur in the presence of high conflicting information, limited procedures, and high workload, was not supported by the current findings. These results reaffirm the complex nature of operator response to stress. Further experimentation into the nature of the relationships between conflicting information, psychological stress, and decisionmaking performance is indicated.

It was determined that personality variables are associated with operator performance under stress. In this study, personality variables accounted for more of the dependent measure (performance) variability than did the three independent variables of workload, conflicting information, and procedures. In general, operators' response to stress can be affected by their general level of anxiety, their locus of control, their degree of emotional exhaustion, the degree to which they feel depersonalized and estranged from others in the work environment, their feelings about personal accomplishments, and their contribution to overall well being, plus their prior coping behavior. Plant supervisors and managers could be trained to be aware of these individual factors that can negatively affect decisionmaking. When individuals show themselves to be emotionally exhausted or depersonalized, remedial efforts can be introduced.

Hypothesis three states that in stressful situations, operators characterized as having Type A personality characteristics will perform less efficiently than operators with Type B personality characteristics. The only significant comparisons between all Type A and Type B subjects, and also between the subjects scoring higher than one standard deviation above the mean and subjects scoring lower than one standard deviation below the mean of the Type A-Type B scale, were for the dependent measure percentage of errors marked nonapplicable. These comparisons show that Type A operators make a significantly greater percentage of their errors by incorrectly marking an action as nonapplicable than Type B operators. Perhaps Type A operators (tendency to work faster, be hard driving, and more job involved) tend more than Type B operators to accept their first impressions about the applicability of an action and spend less time reassessing any hypothesis about an action being nonapplicable. A program training all operators in some form of decision reassessment may mitigate this difference between Type A and Type B operators. There were no significant differences between Type A and Type B operators in picking actions correctly. Due to this and to the mixed correlational directions relating Type A-Type B behavior to performance under stress, we cannot conclude that there is a major difference in performance under stress between Type A and Type B operator personalities.

The results of this study provide no support for hypothesis four that externals, as defined by Rotter's Locus of Control Scale, will perform better than internals in the presence of detailed procedures. Hypothesis four implies that the decisions of externals would be aided by detailed procedures to a large enough degree to overshadow the inherent capacity of internals to better cope with stress suggested by the literature. Findings show this not to be the case, with internals exhibiting more accurate decisionmaking across all experimental conditions. Comparisons of internal subjects with external subjects in the presence of detailed procedures and across all experimental conditions demonstrate that internals performed better than externals by selecting a significantly greater percentage of immediate actions correctly, and a significantly greater percentage of the total actions correctly. These results demonstrate internal locus of control to be especially valuable as a moderator of stress. It is possible that internals perform better under stress than externals because they have a built-in coping mechanism (i.e., they feel their actions can significantly affect what happens to and around them), while externals may feel their actions are largely ineffective. Thus, internal locus of control tends to mitigate the adverse effects of stress on operator performance. It is suggested that training power plant operators to solve problems from a viewpoint of internal locus of control could improve decisionmaking performance and mitigate operator stress effects during an emergency.

Hypothesis five states that operators who have successfully mastered previous stressful events during their lives, as measured by the Life Experience Scale, will perform better under stressful conditions. The higher one scores on the Life Experience Scale, the more stressful life situations one has experienced. This study demonstrates that operators scoring high on this scale pick significantly more immediate actions correctly and significantly more of the total actions correctly than do operators scoring low on this scale. Past successful coping with stressful situations appears to be a factor in preparing one to perform well under future stress.

The results of this experiment were used to guide the development of a predictive model. This model extends the implications of the current findings by allowing prediction of decision performance under stress as a function of several measurable personality factors.

The eight variables in the regression analysis found to be most effective in accounting for dependent measure variability were selected for the model. The eight variables chosen were the personality variables, frequency of emotional exhaustion, frequency and intensity of feelings about personal accomplishment, intensity of depersonalization, locus of control, previous stressful life experiences, Type A-Type B traits, and job involvement. These eight variables were regressed on the seven dependent measures using a SPSS forward stepwise multiple regression across 22 of the

24 subjects. Two subjects were excluded from the analysis to allow for assessment of the model. Subjects 13 and 23 were chosen completely at random, one from the high and one from the low conflicting information condition. Based on this analysis, regression equations for predictions of operator performance on percent immediate and percent total actions correct were determined. The prediction equation for percent immediate (PI) action correct is:

$$
\begin{aligned}
PI' = {} & 66.1259 + (\text{Rotter's}) - (0.4982) \\
& + (EE{:}F)(0.7733) - (PA{:}F)(1.49) \\
& + (JAS{:}J)(0.2125) \\
& + (JAS{:}A)(0.0554) \\
& + (DP{:}I) - (0.7729) \\
& + (PA{:}I)(0.8481) \\
& + (\text{Life})(0.0189)\ . \qquad (1)
\end{aligned}
$$

The prediction equation for percent total (PT) actions correct is:

$$
\begin{aligned}
PI' = {} & (EE{:}F)(0.3356) + (PA{:}F) - (0.8692) \\
& + (\text{Rotter's}) - (0.3920) \\
& + (\text{Life})(0.0163) \\
& + (PA{:}I)(0.5194) \\
& + (DP{:}I) - (0.4333) \\
& + (JAS{:}A)(0.0567) \\
& + (JAS{:}J)(0.0293) \\
& + 53.047\ . \qquad (2)
\end{aligned}
$$

These equations were then used to predict the performance of Subjects 13 and 23 on percent immediate and percent total actions correct. These predictions were compared with the actual performance of these two subjects on one experimental scenario chosen at random for each subject. Table 14 summarizes the results of these comparisons, reporting predicted performance, actual performance, and the percent error of the predictions.

Table 14. Comparison of performance predicted from multiple regression model with actual performance on a randomly chosen scenario

Subject	Actions Taken	Predicted Performance (from model)	Actual Performance	% Error of Prediction
13	% immediate	57.61	50	15
	% total	44.14	35	26
23	% immediate	68.41	64	7
	% total	50.01	60	17

The average percent error of prediction is 16%. This indicates a moderate to good predictive capability of the model. It should be noted that this model made use of only personality characteristics, which suggests their overall importance in determining performance during high stress events.

CONCLUSIONS

Findings from the present experiment indicate that operators under stress perform better under lower levels of workload and that the availability of detailed procedures may supplement operator performance and decisionmaking under stress. The experiment also indicates that certain operator personality characteristics are related to enhanced performance under stress. Specifically, operators with internal locus of control perform better under stress than operators with external locus of control, and operators who have successfully coped with many past stressful experiences perform better under stress than those who have coped with few past stressful situations. The experiment further indicates that operator response to stress may be affected by the general level of anxiety, the degree of emotional exhaustion, feelings of depersonalization, and feelings about personal accomplishments.

Findings suggest that one way to attenuate the adverse effects of stress on operator performance of tasks required during an emergency is to optimize individual workload while maintaining individual responsibility during a crisis. This follows from results of the current experiment indicating that operators under stress perform better (make more accurate decisions) under lower levels of workload, and suggestions in the literature that diffusion of responsibility across a group leads to greater risk taking. However, the findings also suggest that even though individual responsibility should be maintained during an emergency, authority should remain somewhat centralized because the literature shows that people under stress rely heavily on previously established authority figures. Thus, training that emphasizes individual and crew team response in terms of assigned responsibility, lines of authority, information flow, and decision structure is important.

Findings further suggest that group decisionmaking and performance by operating personnel under crisis conditions would be enhanced by training and established procedures for information management, communication, and flow during emergencies. This could improve crew performance during an emergency because the literature shows that information distortion and information mismanagement by individuals and groups are frequent and extensive under conditions of high psychological stress. Training to establish cognitive set toward mitigation of an emergency, novel problem solving, and stress reduction may tend to mitigate the effects of stress on operators. The literature suggests that people tend to act from existing cognitive set when subjected to psychological stress. Written emergency procedures with a sufficient level of detail to assist required decisions may supplement adequate performance under stress.

Results of the current experiment suggest that operators made more accurate decisions about plant emergencies with the availability of the detailed, as opposed to the limited, written emergency procedures developed for this experiment. Here, availability is the key word since the written procedures were referred to by the subjects (operators) only to a limited extent during the experimental sessions. Findings suggest training, procedures, and displays of critical information designed to be compatible with the response characteristics of operators under stress could enhance their decisions and performance during emergencies. The literature indicates that unfavorable (in terms of decisionmaking and performance) response characteristics of people under psychological stress include reduced perception and narrowed cognition.

Our research provides support that drills to cognitively establish effective procedures and allow practice in novel problem solving and decision reassessment may improve operators' ability to handle stress. Effective coping with such drills, especially if the drills are somewhat stressful, may help operators cope with future stressful events. The literature indicates that people tend to rely on established procedures when subjected to stress, and results of the current experiment indicate that decisions about emergency plant conditions tend to be more accurate for operators who have successfully coped with many past stressful situations than for operators who have experienced few stressful life experiences.

The research suggests that training personnel to view plant conditions and problem solving from a standpoint of internal locus of control could improve operator decisions and performance under stress. The experimental findings indicate that plant operators having internal locus of control make more accurate decisions about emergency control actions than operators having external locus of control.

Findings suggest that crew performance during a crisis may be enhanced by training plant supervisors to be aware of personality factors in their crews which could negatively affect decisionmaking and performance under high stress. This information could be used to structure the control room personnel into the most effective decision unit possible with the given personalities, by work position assignment, deployment of individual responsibilities, and tailor-made training programs and drills. The literature and the current experiment pinpoint specific personality characteristics that affect operator response to stress. These findings could also be incorporated in a career selection guide for prospective power plant operators.

This research has resulted in information useful for the direction of future work in the area of accident management and stress reduction and provides insight into ways of handling emergencies and mitigating the detrimental effects of psychological stress at nuclear facilities.

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APPENDIX A

SEISMIC SCENARIOS

APPENDIX A

SEISMIC SCENARIOS

You are a reactor operator at a Westinghouse PWR. A seismic event occurs and you have to respond to the following situation:

- Loss of switchyard, condensate storage tank, and refueling water storage tank
- Shock to pipe results in main feed rupture outside of containment
- Rupture on the RCS side of the Number 1 accumulator check valve; nonisolatable
- A safety injection with loss of all ac power; assume diesels are available for emergency buses
- Main turbine trip and steam generator tube rupture; assume automatic SI
- Main coolant pump shaft failure occurs coincident with inability to isolate the coolant leak (seal failure)
- Turbine trip with malfunction of reactor protection system so that the reactor does not trip (ATWS); assume you manually trip reactor, this fails and you have to manually SI it
- LOCA and a crane inside containment falls over and damages fan coolers
- A secondary steam LOCA occurs with simultaneous loss of all ac power; assume emergency diesel and switch gear damage
- Pressurizer safety valve (PORV) fails to open in high pressure condition
- Ice condenser door opens, and containment pressure begins to rise; assume you also lose fan coolers
- Missile damage causes complete and sustained loss of instrument air to the containment building
- TRAINING TRANSIENT—A steam break occurs outside of containment with no reactor trip.

APPENDIX B

ACTION RESPONSE LIST

APPENDIX B

ACTION RESPONSE LIST

I = Immediate
S = Subsequent
N.A. = Not Applicable

________ Verify reactor trip

________ Check if SI is initiated

________ Verify AFW pumps running

________ Verify ac emergency buses

________ Verify AFW pumps running

________ Check RCS hot leg temperature

________ Verify PZR PORVs

________ Check containment temperature

________ Verify adequate shutdown margin

________ Verify secondary pressure boundary

________ Verify CCW pumps running

________ Verify ECCS flow

________ Check containment temperature

________ Verify ECCS pumps running

________ Verify SSW pump breaker indication

________ Verify turbine trip

________ Verify AFW valve alignment

________ Verify containment isolation

________ Verify feedwater isolation

________ Check CST level

APPENDIX C

TRACKING SHEETS FOR CONFLICTING INFORMATION

APPENDIX C

TRACKING SHEETS FOR CONFLICTING INFORMATION

Tracking Sheet for High Conflicting Information

Make a Mark or Check Next to the Apropriate Word(s) in the Following Word List Each Time it is Spoken

STEAM GENERATOR	SECONDARY	PRIMARY	PRESSURIZER

Tracking Sheet for Low Conflicting Information

Make a Mark or Check Next to the Appropriate Word in the Following Word List Each Time it is Spoken

PRESSURIZER	CONTAINMENT

APPENDIX D

EXPERIMENTAL MANIPULATION CHECK

APPENDIX D

EXPERIMENTAL MANIPULATION CHECK

Please indicate the extent to which you agree with the statements presented below by circling the appropriate number below each statement.

1. I had enough time to complete this task to the best of my ability.

1	2	3	4	5
Strongly Agree				Strongly Disagree

2. The procedures available to me were adequate in helping me complete this task.

1	2	3	4	5
Strongly Agree				Strongly Disagree

3. The background noise and voices hindered my performance on this task.

1	2	3	4	5
Strongly Agree				Strongly Disagree

4. I felt pressured during this task.

1	2	3	4	5
Strongly Agree				Strongly Disagree

APPENDIX E

ABBREVIATIONS USED FOR PERSONALITY, INDEPENDENT, AND DEPENDENT VARIABLES

APPENDIX E

ABBREVIATIONS USED FOR PERSONALITY, INDEPENDENT, AND DEPENDENT VARIABLES

Personality Variables

EE:F	Emotional Exhaustion Frequency	
EE:I	Emotional Exhaustion Intensity	
DP:F	Depersonalization Frequency	Maslach Burnout Inventory
DP:I	Depersonalization Intensity	
PA:F	Personal Accomplishment Frequency	
PA:I	Personal Accomplishment Intensity	
Life	Life Experiences Survey	
Life 2	Weighted Life Experiences Survey	
JAS:A	Type A, Type B Factor	
JAS:S	Speed and Impatience Factor	Jenkins' Activity Survey
JAS:J	Job Involvement Factor	
JAS:H	Hard Driving and Competitive Factor	
Rotter's	Rotter's Locus of Control	
STAI-T	State-Trait Anxiety Inventory, Trait Form	

Independent Variables

CI	Conflicting Information (High and Low)
WI	Workload (High and Low)
Proc	Procedures (Limited and Detailed)

Dependent Variables

PI	Percent Action Responses Correct Marked Immediate
PS	Percent Action Responses Correct Marked Subsequent
PNA	Percent Action Responses Correct Marked Not-Applicable
PT	Percent of Action Responses Correct
I	Percent of Action Response Errors Marked Immediate
S	Percent of Action Response Errors Marked Subsequent
NA	Percent of Action Response Errors Marked Not-Applicable

N = 24
12 Ss received High CI
12 Ss received Low CI
All Ss received all levels of WI and Proc. (WI and Proc completely crossed)

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An extensive review of literature on individual and group performance and decisionmaking under psychological stress was conducted and summarized. Specific stress-related variables relevant to reactor operation were pinpointed and incorporated in an experiment to assess the performance of reactor operators under psychological stress. The decisionmaking performance of 24 reactor operators under differing levels of workload, conflicting information, and detail of available written procedures was assessed in terms of selecting immediate, subsequent, and nonapplicable actions in response to 12 emergency scenarios resulting from a severe seismic event at a pressurized water reactor. Specific personality characteristics of the operators suggested by the literature to be related to performance under stress were assessed and correlated to decisionmaking under stress.

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