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# Job requirements for control room jobs in nuclear power plants

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Abstract

Together with other variables, human factors play a central role in the safety of highly complex technical systems such as nuclear power plants. However, despite the unquestionable importance of human factors, little information is available about relevant ability requirements for control room jobs in nuclear power plants. The purpose of this study was to close this gap, to provide specific information about ability requirements for such jobs, and to evaluate how several hypothesized factors (ability domain, type of jobs, and operating conditions) contribute to ability requirements. We found that high levels of cognitive as well as social/interpersonal abilities are needed for control room jobs, and that ability requirements increase with the hierarchical job level for these two domains but decrease for psychomotor/physical abilities and for sensory/perceptual abilities. Furthermore, specifically concerning jobs with a leadership function, we found some differences between incidents and normal operations regarding requirements for social/interpersonal abilities, indicating that the former require a different leadership style than the latter.

Keywords: nuclear power plants; job analysis; ability requirements; control room jobs; nuclear safety

Job analysis of control room jobs in nuclear power plants

## 1. Introduction

Safety is a key issue in the field of nuclear energy. However, prior to the accident at Three Mile Island, human factors had received little attention in nuclear safety research. Following the Three Mile Island accident, all nuclear accidents were reviewed, and it was found that human error contributes to nuclear accidents (Carvalho et al., 2006).

According to Carvalho et al. (2006), as a result of this finding, human error and human behavior have come to be treated with the same attention as technical (hardware) systems. Thus, it has now been acknowledged that human error constitutes an important factor in the malfunctioning of complex technical systems such as nuclear power plants and in accidents associated with their operation, meaning that human error is a significant contributor to plant risk. In line with this, estimates have been made in the literature that between 20 and 70% of all system failures at nuclear power plants are due to human error (cf. Fleishman and Buffardi, 1999). Similarly, events reported in the International Atomic Energy Agency (IAEA)/Nuclear Energy Agency (NEA) incident reporting system (IRS), a worldwide data collection system that tracks unusual events in nuclear power plants (NEA, 2004), show that inadequate human action is responsible for 48% of all reported events. Only a small number of IRS events were found to be due to purely technical causes or to new phenomena causing non-expected plant behavior. These figures stress the importance of the human factors in the field of nuclear safety. Therefore, minimizing human error is a fundamental aim in the nuclear industry, and one which becomes even more apparent when considering the literature, in which it is assumed that even relatively small improvements in human error probabilities can result in substantial improvements in many accident sequences (Samanta et al., 1988).

To describe nuclear accident sequences, a system perspective including both human errors and technical system components as well as the organizational context seems to be most appropriate (e.g., Hofmann et al., 1995). From such a perspective, various factors are important to avoid accidents. On the technical side, defenses-in-depth systems exist to avoid potentially dangerous events (i.e., systems in which multiple layers of protection are used so that each layer guards against a possible breakdown of the other layers). These systems are influenced by organizational factors such as management decisions, organizational processes, corporate culture, and others. At the workplace, error-producing and violation-producing work conditions may exist. Job incumbents can also contribute to accidents through unconscious errors and/or conscious violations. These technical and human conditions contribute to the probability of accident sequences (Reason, 1997, 2008). In this respect, Reason used a metaphor to describe the conditions for accidents to occur. He entitled this concept "the Swiss cheese model", to reflect that defensive layers are like slices of Swiss cheese, which contain holes, but where the presence of a defensive hole in any one slice does not normally lead to an accident. Instead, accidents can occur only when holes in successive layers overlap, meaning that there is a trajectory of accident opportunity that brings hazards into damaging contact with victims. Thus, according to this model, in order for an accident to occur, many unlikely factors have to operate concurrently, which also means that several different components of defenses-in-depth systems must fail simultaneously.

There are various sources among the factors mentioned that can influence the occurrence of human errors (cf. Buffardi et al., 2000). Some of these sources concern aspects of the work environment or of the job, such as the plant type (pressurized water reactor vs. boiling water reactor), organizational safety climate, the type of job within a plant, or the operating conditions of a plant, while others concern the characteristics of the employees who perform the jobs in a plant. An important source of human error is said to be a poor match between employees' abilities and relevant job requirements (Buffardi et al., 2000). Human abilities are important in several different ways. First, employees are less likely to make errors if they are able to cope with the requirements of their job. Clearly, a match between employees' abilities and job requirements is important in every job, but it is especially crucial for employees in high-reliability organizations like nuclear power plants. Second, abilities can also be used to actively prevent incidents and accidents (e.g., Reason, 2008). Therefore, an important goal is to determine which abilities are relevant for jobs in nuclear power plants.

There are a number of different ways in which to improve the fit between employees' abilities and the different job requirements. Selection, support, and training of employees or the specific adaptation of the workplace are examples of such interventions. The basis for all of these measures is knowledge about the requirements of a job (Ash, 1988). One important way in which to accurately identify relevant job requirements is to carry out systematic job analyses (Landy, 1988).

Despite the obvious importance of job analysis to increase nuclear safety by defining the job requirements, there is limited information available on the different abilities required for jobs in nuclear power plants. Specifically, there is no broad empirical collection of ability requirements concerning jobs in the control room of nuclear power plants. Although the IAEA emphasizes the importance of job analysis (IAEA, 2000), only a small number of technical reports exist, and these are difficult to access.

Perhaps the most publicly accessible and systematically collected database in the field of job requirements for jobs in nuclear power plants can be found in the O*NET (i.e., the Occupational Network), a comprehensive database that represents the primary source of occupational information in the United States. O*NET is organized around a theoretical content model comprising six major areas: worker characteristics, worker requirements, experience requirements, occupation requirements, occupational characteristics, and occupation-specific information (O*NET, 2010a). Specific requirements for a vast number of different jobs can be found in the database (M. D. Mumford and Peterson, 1999; Peterson et al., 2001). However, even in this database, information concerning ability requirements for jobs in nuclear power plants is rather undifferentiated, with only one job profile for several job positions (cf. O*NET, 2010b). Thus, different job positions are integrated into one job profile even though they differ, for example, with regard to whether or not they include leadership responsibilities. Furthermore, the data provided are limited to cognitive, psychomotor/physical, and sensory/perceptual abilities, while social/interpersonal abilities are largely omitted. Finally, the profiles and requirements do not distinguish between normal operations and incidents, even though these two operating states might place very different demands on employees concerning the abilities required.

One of the few available studies concerning the relevance of ability requirements for safety in nuclear power plants was conducted by Buffardi et al. (2000). This study confirmed that the abilities required for tasks in nuclear power plants are related to human error probabilities, such that error probabilities were found to increase when a larger number of abilities or a higher ability level were required for a task. Again, this provides clear evidence for the role of job requirements. However, the number of abilities considered in this study was very restricted; no social and interpersonal abilities were considered, and no information was provided about the results of the actual job analysis.

Given the limited information concerning the ability requirements in nuclear power plants, the first goal of the present study was to close this gap. Specifically, we aimed to identify the abilities that are required for different control room jobs, addressing cognitive, psychomotor/physical, sensory/perceptual, and social/interpersonal abilities. In the first of two studies, our goal was to determine which ability categories are more important for different control room jobs. In the second study, we evaluated whether the ability level required is influenced by the operating condition (normal operations vs. incidents).

## 2. Factors that Might Influence Ability Requirements

In the following sections, we briefly review the relevant literature and develop hypotheses for several factors that might influence the abilities and the ability levels required for the three control room jobs examined. The factors considered in the present research are different ability domains, different control room jobs, and different operating conditions.

### 2.1 Ability Domains

It is clear that not all abilities or ability domains are equally important for each job. Given that the most important abilities for control room jobs described in the O*NET (2010b) mainly include cognitive abilities (i.e., eight of the ten most important abilities were from the cognitive domain), we assume that for control room jobs, the ability levels required are higher in the domain of cognitive abilities than in the domains of psychomotor/physical or sensory/perceptual abilities. Research in fields where human error is an important safety issue, such as the field of aviation psychology, shows a quite similar picture for airline pilots and air traffic controllers (Goeters et al., 2004). Additionally, these aviation studies also found that social and interpersonal abilities play an important role alongside cognitive and perceptual-motor abilities. Specifically, evidence from high-profile accidents in the airline industry, in which a lack of effective teamwork was found, stresses the importance of social and interpersonal abilities (e.g. Cannon-Bowers and Salas, 1998; Weick, 1990). As control room employees in nuclear power plants have to work in shift teams for many hours of the day and have shared responsibilities, we expect that they also need high levels of social and interpersonal abilities.

Therefore, we make the following prediction:

Hypothesis 1: Control room employees need a higher level of cognitive abilities and social/interpersonal abilities than of psychomotor/physical abilities or sensory/perceptual abilities.

## 2.2 Differences between Control Room Jobs

Different jobs and differences in tasks and responsibilities related to these jobs are another relevant factor for the abilities required. The three jobs covered in the present study (reactor operator, shift supervisor, and safety engineer) are hierarchically structured. With increasing hierarchical level, employees' responsibility and decision-making power also increase (see below). The job of reactor operator reflects the lowest level of the hierarchy. After a few years, reactor operators can be promoted to shift supervisors, and then after several additional years to safety engineers if they have the necessary level of education (an engineering degree) in addition to the required abilities and experience.

Reactor operators are responsible for the operation of nuclear installations and supervise the operational events and processes. Shift supervisors supervise a shift group and are responsible for the operation of the plant. They are responsible for control room operation and safety and have the authority to decide to switch off the plant. Shift supervisors also serve as the main communication channel from the control room to the other parts of the plant, and even outside the plant (Carvalho et al., 2006). Finally, safety engineers are not in the control room the whole time, but stand in during emergency alerts to support the shift supervisor. They also take the lead in high-risk emergency alerts. In addition to their duties in the control room, they have various additional responsibilities outside the control room (e.g., they often serve as trainers, or have specific tasks relating to radiation protection or research). However, these individual duties are not relevant for their tasks in the control room.

Leadership models and research suggests that the cognitive demands for leaders increase with their level in the leadership hierarchy (T. V. Mumford et al., 2007). Accordingly, individuals with leadership roles in high reliability organizations face higher demands concerning appropriate situation assessment or the quality of decision making (Crichton et al., 2005). Thus, given that control room jobs are hierarchically structured, and that the cognitive complexity of the tasks increases with increasing levels of seniority, we assume that the required levels of cognitive abilities reflect this hierarchy. Thus, we make the following prediction:

Hypothesis 2: Required levels of cognitive abilities increase with the level of seniority of the job.

Previous research has shown that the extent of social skills required of different control room employees also depends on their function. In a study by O'Connor et al. (2008), who used the critical incident technique (Flanagan, 1954) to investigate the team skills required by nuclear power plant operations personnel, statements about team workload management (prioritizing and coordinating tasks and resources) and leadership (directing and coordinating activities, motivating others, assessing team performance, and establishing a positive atmosphere) were most often related to supervisory roles, such as shift supervisors and safety engineers. Many of these behaviors are related to social and interpersonal abilities like behavioral flexibility, coordination, negotiation skills, resistance to making premature judgments, or social sensitivity.

Furthermore, research in the leadership domain suggests that the importance of social and interpersonal skills also increases with an increase in the hierarchical position of a leader (cf. the leadership skills strataplex model by T. V. Mumford et al., 2007).

In addition to this, it has been argued that the quality of the relationship between supervisors and their subordinates (i.e., leader-member exchange, LMX) is important for safety because this quality is an important factor that influences the degree to which supervisors and subordinates communicate openly about safety issues (Hofmann and Morgeson, 1999; Reason, 1997). Thus, supervisors' social and interpersonal abilities, such as social sensitivity or coaching, are relevant for ensuring good relationships and trust between them and their subordinates.

Finally, it has been found that certain command skills are important for people with leadership roles in high reliability organizations because such skills are relevant for managing teams and workload, coordinating important activities, providing direction, or taking charge when the situation requires it (Crichton et al., 2005). Social and interpersonal abilities that are relevant in this regard include achievement striving, assertiveness, social confidence, self-control, resilience, perseverance, and coordination.

Based on the research reviewed, we also assume that individuals with leadership roles in the control room (i.e., shift supervisors and safety engineers) need a higher level of social and interpersonal abilities than individuals without leadership roles (i.e., reactor operators).

Hypothesis 3: Shift supervisors and safety engineers need a higher level of social/interpersonal abilities than reactor operators.

## 2.3 Differences between Operating Conditions

Two operating conditions can be distinguished for nuclear power plants: normal operations and incidents. During normal operating conditions, operators only need to maintain the general operating procedures for normal operation of the nuclear power plant. By contrast, during incidents, a large number of auditory and visual warning signals appear on the wide display panel and operators have to immediately and simultaneously deal with these signals and respond to them appropriately (cf. Lin et al., 2009).

According to Carvalho et al. (2008), the operation of nuclear plants is characterized by a large amount of boredom, due to the surveillance requirements and the long-term control strategies needed during continuous normal operation, and a small amount of high stimulation, due to the need to quickly and effectively handle alarm situations. Both boredom (low mental workload) and stimulation (high mental workload) can affect mental performance and have a negative effect on system safety and operation (Hwang et al., 2008). This finding stresses the important role of human factors in both operating conditions. However, Crichton et al. (2005) found that incidents make specific requirements with regard to the quality of assessing the situation correctly and making appropriate decisions. Thus, it seems likely that requirements for cognitive abilities are higher for incidents than for normal operations, but the size of the differences between the ability requirements across the two working conditions remains an open question. Moreover, this question is especially important because large differences in the required abilities would make it more difficult to find suitable control room personnel and would also make it more difficult for control room crews to demonstrate optimal performance in both work conditions. Nevertheless, given the differences in the tasks related to the two conditions, it can be assumed that a higher level both of cognitive abilities and of sensory/perceptual abilities is needed in the incident condition than under normal operating conditions.

Hypothesis 4: A higher level of cognitive abilities and of sensory/perceptual abilities is required in the incident condition than in the normal operating condition.

As mentioned above, shift supervisors hold leadership roles in the control room. As team leaders, they have an important influence on the team's performance (Crichton and Flin, 2004). Especially in relation to complex incidents, effective leadership can help to minimize negative consequences (cf. Crichton et al., 2005; Kapucu and Van Wart, 2008). However, what constitutes effective leadership is also strongly influenced by the specific situation that a leader faces. In line with this, contingency models of leadership emphasize that different kinds of leadership behavior are effective in different situations (cf. Yukl, 2006). Specifically, in certain situations, a more directive style of leadership may be necessary. For example, during periods of high workload and pressure, such as during incidents, a directive style might be more appropriate, whereas a more participative leadership style seems more appropriate in slower paced situations such as under normal operating conditions (Crichton et al., 2005). This would also be in line with the Vroom-Yetton model of leadership (Vroom and Jago, 1978; Vroom and Yetton, 1973) as well as with research suggesting that effective leaders should be able to show both a task-oriented and a people-oriented style of management (e.g., Judge et al., 2004) in order to effectively co-ordinate the efforts of the team members and to handle the demands of the different situations they face.

With regard to incidents, this means that individuals with leadership roles need certain social/interpersonal abilities that are related to a more directive leadership style (e.g., assertiveness, behavioral flexibility, perseverance, resilience, self-control, or social confidence) to a stronger degree than in normal operating conditions. By contrast, they require social/interpersonal abilities that are related to a more participative leadership style (e.g., agreeableness, coaching, negotiation, sociability, or social sensitivity) to a weaker degree. Accordingly, we make the following prediction:

> Hypothesis 5: Compared to the normal operating condition, in the incident condition, shift supervisors need a higher level of social/interpersonal abilities that are related to a directive leadership style, but a lower degree of social/interpersonal abilities that are related to a participative leadership style.

# 3. Study 1

The first aim of Study 1 was to determine the abilities required for control room jobs in nuclear power plants. The second aim was to investigate to what degree ability requirements differ between the different ability domains and whether the ability requirements are influenced by the type of job.

## 3.1 Method

### 3.1.1 Participants

In total, 187 control room employees served as participants for the present study. Of these, 87 were reactor operators, 60 were shift supervisors, and 40 were safety engineers. The mean age was 43.98 (*SD* = 8.69) for reactor operators, 51.07 (*SD* = 6.53) for shift supervisors, and 49.03 (*SD* = 7.28) for safety engineers. Their mean amount of work experience was 10.68 years (*SD* = 9.60) for reactor operators, 13.88 years (*SD* = 8.59) for shift supervisors, and 11.24 years (*SD* = 8.61) for safety engineers. The employees came from four different nuclear power plants (Plants A to D). The output of the different plants increased from Plant A to Plant D.

Plants A and D were boiling water reactors and were both built by the same producer, while Plants B and C were pressurized water reactors that were built by two different producers. Plants A and B began operations around 1970, Plant C during the late 1970s and Plant D during the mid-1980s.

3.1.2 Job Analysis Instrument

To determine the ability requirements for different control room jobs, the German version of the Fleishman Job Analysis Survey (F-JAS, Kleinmann et al., 2010) was used. The F-JAS was developed from a long-standing program of research involving the identification of ability requirements in human task performance (Fleishman and Mumford, 1991; Fleishman and Quaintance, 1984; Fleishman and Railly, 1995; Kleinmann et al., 2010). The ability taxonomy underlying this instrument is also used in O*NET (Fleishman et al., 1999). The domains and abilities covered by the F-JAS taxonomy include: (a) 21 cognitive abilities; (b) 10 psychomotor abilities; (c) 9 physical abilities; (d) 12 sensory/perceptual abilities, and (e) 21 social/interpersonal abilities (Fleishman, 1995, 1996).

For each ability, a behaviorally anchored 7-point rating scale is provided, on which higher values reflect higher requirement levels. The scales include construct definitions, distinctions from similar abilities, definitions of high and low levels of each ability requirement, and task anchors to provide raters with examples of everyday tasks that reflect high, moderate, and low levels of each ability (cf. Figure 1 or Buffardi et al., 2000, for an example of such a scale; or Fleishman et al., 1999, for additional examples). The scale values of these task anchors were determined empirically and were selected due to their high reliability (Fleishman and Mumford, 1991; Fleishman and Railly, 1995).

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Insert Figure 1 about here

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The F-JAS has several advantages that make it especially suitable for the present purpose. First, the instrument is easy to use even when the respondents are job incumbents and not specifically trained job analysts (Landy, 1988). Second, it is the most rigorously developed instrument to determine ability requirements (Wilson, 2007) and, as mentioned above, it considers quite a broad field of abilities including cognitive, psychomotor/physical, sensory/perceptual, and social/interpersonal abilities. And third, previous empirical work has confirmed that the F-JAS and the scales included in it are suitable to describe jobs and tasks in a wide range of industrial, governmental, and military settings that also encompass safety-relevant jobs (Fleishman and Mumford, 1991). Interrater reliabilities for single abilities in past studies tended to be in the .80s and .90s when 15 or more raters were available (cf. the research reviewed by Buffardi et al., 2000, or by Fleishman and Mumford, 1991). In addition, the scales show substantial evidence of construct and predictive validity (Fleishman and Mumford, 1991; Kleinmann et al., 2010).

3.1.3 Procedure

In a first step, a workshop was conducted prior to the actual data collection phase in order to reduce the number of abilities considered in the present study and to select potentially relevant abilities for control room employees. During this workshop, a group with five subject matter experts, including one representative of each nuclear power plant and one representative of the government agency for nuclear safety, identified 51 abilities out of the original 73 included in the F-JAS, which were considered to be potentially job-relevant and were subsequently used for the main data collection. Thus, 22 abilities were omitted, primarily in the area of psychomotor and physical abilities.

The main survey included only the 51 abilities selected during the subject matter expert workshop. Data were collected in 21 group sessions during working hours in the training classrooms of the four nuclear power plants. Each group consisted of between 4 and 14 control room employees. These control room employees first received a 15-minute introduction to the design and usage of the F-JAS. After the researcher had clarified participants' questions, participants were asked to complete the survey and to describe the ability requirements of their own job. At the end, participants were asked to fill in several demographic questions. Altogether, participants needed approximately 60 minutes to complete the survey.

3.1.4 Reliability of Participants' Ratings

We calculated interclass correlations for participants' ratings of the required ability levels in order to determine the reliability of these ratings (ICC 2,1, Shrout and Fleiss, 1979). The mean reliability was .98 across 87 reactor operators, .98 across 60 shift supervisors and .98 across 40 safety engineers. These values compare favorably to estimates from previous research with the F-JAS (Buffardi et al., 2000; Fleishman and Mumford, 1991).

3.2 Results

Tables 1 to 4 show the mean required ability levels (and standard deviations) for the three different control room jobs and for the different ability domains. According to Fleishman and Railly (1995), abilities with mean ratings of 4 and above should be considered relevant for a job. Thus, the vast majority of the cognitive abilities were relevant for all three jobs, and all but one of the social/interpersonal abilities were relevant for all three jobs. Concerning the domain of sensory/perceptual abilities, about half of the abilities were relevant for the different control room jobs. Finally, Control Precision was the only ability from the psychomotor/physical domain that was relevant for two of the three jobs (reactor operators and shift supervisors). As an indicator of the general level of ability that is required in each of the four domains, we also determined mean values across all abilities for each domain. These mean values are shown in the bottom line of each table.

3.2.1 Comparison of Ability Requirements across Ability Domains

To evaluate Hypothesis 1, which predicted that control room employees need higher levels of cognitive abilities and of social/interpersonal abilities than of psychomotor/physical, or sensory/perceptual abilities, we conducted a 3 × 4 analysis of variance (ANOVA), in which we used the mean ability level from each domain as the dependent variable. This ANOVA included type of control room job (reactor operator, shift supervisor, or safety engineer) as a between-subjects factor and ability domain (cognitive, social/interpersonal, psychomotor/physical, and sensory/perceptual) as a within-subjects factor. Degrees of freedom for the within-subjects factor in this and all subsequent ANOVAs were corrected according the Huynh-Feldt procedure when necessary (as indicated by a significant Mauchly test of sphericity).

In line with Hypothesis 1, across all three jobs, the mean requirement level for cognitive and social/interpersonal abilities was higher than the mean level for psychomotor/physical and sensory/perceptual abilities (cf. Tables 1-4). Accordingly, the ANOVA revealed a main effect for ability domain, $F(2.30, 422.32) = 780.58$, $p < .01$, partial $\eta^2 = .81$. Subsequent Bonferroni-corrected pairwise comparisons between all four ability domains confirmed that the mean requirement levels for social/interpersonal abilities and cognitive abilities were significantly higher than the mean requirement levels in the other two domains. Furthermore, the mean requirement level for social/interpersonal abilities was even higher than the mean requirement level for cognitive abilities. And finally, the mean requirement level for sensory/perceptual abilities required was also higher than the mean requirement level for psychomotor/physical abilities.

3.2.2 Impact of Control Room Jobs on Ability Requirements

With regard to the impact of the different jobs on the ability levels required, the 3 × 4 (Job × Ability Domain) ANOVA with the mean ability requirements in each domain as the dependent variable revealed a main effect of job, $F(2, 184) = 7.39$, $p < .01$, partial $\eta^2 = .07$, as well as an interaction between job and ability domain, $F(4.59, 422.32) = 18.26$, $p < .01$, partial $\eta^2 = .18$. In partial support of Hypothesis 2, which predicted an increase in the required level of cognitive abilities with increasing level of seniority of the job, Bonferroni-corrected pairwise comparisons confirmed that shift supervisors and safety engineers both needed significantly higher levels of cognitive abilities than reactor operators. However, the cognitive ability requirements did not differ meaningfully between the two jobs. As an indicator of the effect size for differences between two means, we calculated Cohen's *d*. Values for Cohen's *d* are also given in Tables 1 to 4. For the comparisons between reactor operators vs. shift supervisors and reactor operators vs. safety engineers, the effect sizes were -0.74 and -0.63, respectively. According to conventional standards, these values reflect intermediate to large effects (Cohen, 1992). Furthermore, comparable pairwise comparisons confirmed Hypothesis 3, which predicted that shift supervisors and safety engineers both need a significantly higher level of social/interpersonal abilities than reactor operators (Cohen's $d = -.82$ and $-.76$). The size of these differences was large according to conventional standards.

In the next step, we analyzed the impact of the different control room jobs on the specific ability requirements in more detail. Specifically, we conducted a one-factorial multivariate analysis of variance (MANOVA) for each ability domain, for which we compared the three different jobs and considered the separate abilities as the dependent variables. With regard to cognitive abilities, the MANOVA confirmed the impact of the three different job positions on the abilities required as indicated by a main effect of job, Wilks' $\Lambda = .61$, $F(32, 338) = 2.94$, $p < .01$. For each ability, Table 1 also shows the results of Bonferroni-corrected pairwise comparisons between the different control room jobs and the effect sizes obtained. As can be seen, about 63% of the considered abilities showed significant differences in requirement levels between the three jobs. In half of these cases, shift supervisors and safety engineers both needed significantly higher ability levels than reactor operators. In the remaining half, only the difference between shift supervisors and reactor operators was significant, with the former needing higher levels of the respective abilities. Effect sizes were of intermediate size in most of these cases. Finally, we did not find significant differences between shift supervisors and safety engineers for any of the cognitive abilities. These findings corroborate the finding from the previous analyses that Hypothesis 2 is only partially supported. Specifically, the results showed that the required levels of cognitive abilities increased from reactor operators to shift supervisors, but that shift supervisors and safety engineers did not differ significantly from each other.

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Insert Table 1 about here

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With regard to specific social and interpersonal abilities, the MANOVA also revealed a significant difference between the three job positions, Wilks' $\Lambda = 0.41$, $F(38, 332) = 4.84$ , $p < .01$. In line with Hypothesis 3, ability levels were higher for shift supervisors and safety engineers than for reactor operators for nearly all of the abilities considered, with significant differences concerning many of the specific abilities, and effect sizes of these differences in the intermediate and large range (cf. Table 2). Furthermore, as illustrated by the results from Bonferroni-corrected *t*-tests, shift supervisors and safety engineers usually did not differ significantly, which is also in accordance with Hypothesis 3. The only exception from this pattern is Coaching, where we found a significantly higher level of this ability for shift supervisors than for safety engineers.

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Insert Table 2 about here

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Even though we had no specific hypotheses concerning differences between the three control room jobs for psychomotor and physical abilities or for sensory and perceptual abilities, we also conducted MANOVAs for these domains so as to explore potential differences. With regard to psychomotor and physical abilities, we found a significant multivariate difference between the three job positions, Wilks' $\Lambda = .72$, $F(12, 358) = 5.38$ , $p < .01$. As can be seen in Table 3, safety engineers showed the lowest required levels for all abilities. In two cases (Control Precision and Finger Dexterity), these levels were significantly lower than for both reactor operators and shift supervisors, and in one case (Gross Body Equilibrium), there was a significant difference between safety engineers and shift supervisors. For abilities for which significant differences were found, effect sizes were large. The requirement levels between shift supervisors and reactor operators did not differ significantly in any of the cases.

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Insert Table 3 about here

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Finally, with regard to sensory and perceptual abilities, the MANOVA also showed a significant main effect of job, Wilks' $\Lambda = .80$, $F(20, 350) = 2.01$, $p < .01$. Similar to the domain of psychomotor and physical abilities, safety engineers needed these abilities to a lower degree than the other two jobs, meaning that several significant differences of intermediate size were found between safety engineers and reactor operators or shift supervisors. Furthermore, no significant differences were found between shift supervisors and reactor operators.

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Insert Table 4 about here

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## 3.3 Discussion

Our results showed that both factors evaluated in this study influenced the ability requirements of nuclear control room jobs. As expected, we found differences between different ability domains and between different control room jobs. In line with Hypothesis 1, control room employees in particular need cognitive as well as social/interpersonal abilities to a higher degree than psychomotor/physical or sensory/perceptual abilities. In partial support of Hypothesis 2, the jobs of shift supervisors and safety engineers require higher levels of cognitive abilities than reactor operators. However, in contrast to our hypothesis, the former two jobs did not differ meaningfully. This means that the main difference concerning the cognitive ability requirements for control room jobs is between reactor operators and the other two jobs. Furthermore, the assumptions made in Hypothesis 3 were confirmed, meaning that shift supervisors and safety engineers need a higher level of social and interpersonal abilities than reactor operators. Thus, in accordance with research by O'Connor et al. (2008), social and interpersonal abilities are more important for employees who hold leadership positions.

In addition to these specific hypotheses, several significant differences were found with regard to sensory and perceptual abilities, where the job of safety engineer has lower ability requirements than the other two jobs. Given that safety engineers do not have to monitor displays, read measured values, or identify auditory signals themselves in the control room, these differences seem obvious in retrospect. Finally, we found several significant differences between ability requirements for the domain of psychomotor/physical abilities. Even though some of these differences reached large effect sizes (reflecting lower required levels for safety engineers), it should be noted that hardly any of the means in this domain lay above 4. Thus, according to Fleishman and Railly (1995), the corresponding abilities cannot be considered relevant for the different control room jobs, indicating that the psychomotor and physical ability requirements for these jobs are generally relatively low.

## 4. Study 2

A limitation of Study 1 was that it did not address the potential impact of differences between operating conditions on ability requirements. Thus, the aim of Study 2 was to close this gap and to compare requirements for control room jobs under different working conditions.

### 4.1 Method

#### 4.1.1 Participants

One hundred control room employees served as participants for Study 2. Of these, 64 were reactor operators and 36 were shift supervisors. Safety engineers were not considered as participants in Study 2 because they are not usually present in the control room during normal operations but only come to the control room during an emergency alert; therefore, it was not possible to compare the two operating conditions for safety engineers. The mean age was 42.47

for reactor operators (*SD* = 8.32) and 49.80 (*SD* = 7.06) for shift supervisors. On average, reactor operators had 9.52 years (*SD* = 9.37) of job experience and shift supervisors had 11.53 years (*SD* = 9.03) of job experience. These employees came from three of the four power plants considered in Study 1 (Plants B, C, and D).

### 4.1.2 Job Analysis Instrument

As in Study 1, the German version of the Fleishman Job Analysis Survey (F-JAS, Kleinmann et al., 2010) was used to determine the ability requirements for both operating conditions and both control room jobs. Furthermore, the same 51 abilities as in the first study were included in the present survey.

### 4.1.3 Procedure

The procedure was the same as in Study 1, with the following exceptions: The data collection was conducted in 14 group sessions during working hours in the training classrooms of the nuclear power plants. Between 4 and 11 employees participated in each session. Employees only rated the ability requirements for either normal operating conditions or for incidents (half of the reactor operators and half of the shift supervisors were assigned to each operating condition).

### 4.1.4 Reliability of Participants' Ratings

As in Study 1, we calculated interclass correlations for participants' ratings of the required ability levels in order to determine the reliability of these ratings. The mean reliability (ICC 2,1) for the normal operating condition was .95 across 32 reactor operators, and .96 across 18 shift supervisors; for the incident condition, it was .96 across 32 reactor operators, and .96 across 18 shift supervisors. Thus, the obtained values were quite similar to those in the first study.

4.2 Results

4.2.1 Impact of Operating Condition on Ability Requirements for Reactor Operators

To determine the impact of the operating condition, we first conducted a 2 × 4 ANOVA for the reactor operator sample with the between-subject factors operating condition (normal operating condition vs. incident) and the within-subjects factor ability domain (cognitive, social/interpersonal, psychomotor/physical, or sensory/perceptual). This ANOVA, which used the mean ability level from each domain as the dependent variable, revealed a main effect of ability domain, $F(2.58, 159.83) = 196.61$, $p < .01$, partial $\eta^2$ =76. This mirrors the differences in ability requirements that were found in Study 1. More importantly, however, there was no significant main effect for the operating condition and no interaction between operating condition and ability domain, both *F*s < 1.08, both *p*s < .31.

In addition to this overall ANOVA, we also conducted separate one-factorial MANOVAs for each ability domain, in which we evaluated the impact of the operating condition in more detail. These MANOVAs revealed significant effects of the operating condition for social and interpersonal abilities, Wilks' $\Lambda = 51$, $F(19, 44) = 2.23$, $p < .05$, and for sensory and perceptual abilities, Wilks' $\Lambda = .70$, $F(10, 53) = 2.26$, $p < .05$. These main effects indicate that somewhat higher levels of these abilities are required in the incident condition than in the normal operating condition. However, the operating condition did not significantly influence ability requirements in the domains of cognitive abilities or of psychomotor and physical abilities, both Wilks' Λs > .76, both *F*s < 1. Furthermore, average effect sizes were not large for any of these domains (all *d*s < .24).

Finally, we also compared the required ability levels for each ability. Table 5 gives an overview of all abilities that differed significantly between the two conditions. As can be seen, the absolute number of abilities for which significant differences were found was rather small (only 6 out of 51). In line with the results from the multivariate analyses, of the abilities which required higher levels in the incident condition, three were from the social/interpersonal domain (Behavior Flexibility, Self Control, and Oral Defense), and two were from the sensory/perceptual domain (Speech Recognition and Auditory Attention). Finally, one ability from the cognitive domain (Time Sharing) was needed to a larger degree in the incident condition. Thus, these results provide only partial support for Hypothesis 4, which predicted that higher levels of cognitive and of sensory/perceptual abilities are needed in the incident condition. However, it should be noted that the effect sizes were in the medium to large range for all of the abilities in which the two operating conditions differed significantly.

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Insert Table 5 about here

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4.2.2 Impact of Operating Condition on Ability Requirements for Shift Supervisors

Concerning mean ability levels from each domain, the differences between the two conditions were larger for shift supervisors than for reactor operators. Accordingly, the 2 × 4 ANOVA for the shift supervisors with the between-subjects factors operating condition (normal operating condition vs. incident) and the within-subjects factor ability domain (cognitive, psychomotor/physical, sensory/perceptual, or social/interpersonal) revealed a significant interaction between operating condition and ability domain, $F(3, 102) = 3.26$, $p < .05$, partial $\eta^2 = .09$, in addition to the significant main effect of the ability domains, $F(3, 102) = 229.73$, $p < .01$, partial $\eta^2 = 87$.

The reason for the significant interaction was that the effects of the operating conditions were larger on some domains than on others. Specifically, separate one-factorial MANOVAs for each ability domain revealed significant effects of the operating condition for cognitive abilities, Wilks' $\Lambda = 29$, $F(16, 19) = 2.94$, $p < .05$, as well as for social and interpersonal abilities, Wilks' $\Lambda = .19$, $F(19, 16) = 3.62$, $p < .01$. In line with Hypothesis 4, ability requirements for cognitive abilities were generally (somewhat) higher in the incident condition (average effect size across all cognitive abilities $d = -.22$), and with regard to Hypothesis 5, ability requirements for social and interpersonal abilities were generally higher in the normal operating condition (average *d* across all social and interpersonal abilities = .39). Concerning the domains of psychomotor and physical abilities and of sensory and perceptual abilities, the MANOVAs did not reveal significant differences between the two operating conditions, both Wilks' $\Lambda$s > .69, both *F*s < 1.92, both *p*s > .11.

Finally, Table 6 shows the specific abilities for which we found significant differences between the two operating conditions. In line with the multivariate analyses and also in accordance with Hypothesis 5, several social and interpersonal abilities that are related to a participative leadership style (Agreeableness, Social Sensitivity, Negotiation, Sociability, Openness to Experience, and Coaching) were needed to a higher degree in the normal operating condition than in the incident condition. In addition, the only social and interpersonal ability related to a directive leadership style that is needed to higher degree in the incident condition was Perseverance. Furthermore, for two specific cognitive abilities (Problem Sensitivity and Written Expression), and for one psychomotor and physical ability (Explosive Strength), significant differences were found between the two conditions. The ability requirements for Written Expression and Explosive Strength were both lower in the incident condition than in the normal operating condition, whereas the opposite was the case for Problem Sensitivity. Thus, Written

Expression represents an exception to the generally higher ability requirements in the incident condition that were found in the multivariate analyses. Finally, it should be noted that effect sizes for the abilities for which the two operating conditions differed were substantial – often, they were even larger than what would usually be considered a large effect (.80, cf. Cohen, 1992). This means that ability requirements differed considerably between the two operating conditions in the case of a few very specific abilities.

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Insert Table 6 about here

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4.3 Discussion

Study 2 addressed the question of whether ability requirements for control room jobs differ in relation to the operating condition. Our results confirmed the existence of such differences between normal operating vs. incident conditions, although these differences were generally limited to a small number of abilities. Importantly, however, for the specific abilities for which significant differences were found, effects sizes were substantial.

Specifically, the effects of operating condition on cognitive and on sensory and perceptual abilities predicted by Hypothesis 4 were only partially confirmed. As expected, reactor operators need sensory and perceptual abilities to a higher degree in the incident condition than in the normal operating condition. However, no such effect was found for shift supervisors. In contrast, with regard to cognitive abilities, no effect of operating condition was found for reactor operators (with the exception of Time Sharing), but an effect was found for shift supervisors. A notable exception here was Written Expression, which is required to a substantially lower degree in the incident condition than under normal operations.

Concerning the impact of the operating condition on social and interpersonal abilities, there was some support for Hypothesis 5, meaning that there were differences between the ability requirements for shift supervisors. These differences particularly reflected the need for a more participative leadership style in the normal operating condition as compared to the incident condition. Or in other words: The incident condition requires a more directive leadership style.

## 5. General Discussion

From a system perspective (Hofmann et al., 1995; Hollnagel, 2004; Reason, 2008), both technical and human factors contribute to the safety of complex systems. Human factors are important on different levels. The organization of safety requires good management decisions, embedded organizational processes and a safety culture. Favorable workplace conditions and suitable job incumbents also improve the safety of complex systems. Therefore, the errors associated with human factors are an essential source of nuclear power plant accidents and incidents (O'Hara et al., 2004).

Accordingly, Buffardi et al. (2000) found a systematic relationship between ability requirements for tasks in nuclear power plants and human error probabilities. However, specific knowledge about the ability requirements for control room staff in nuclear power plants has so far been lacking. Thus, the present research makes several important contributions in this regard.

First, the present study is the first investigation to include a systematic analysis of ability requirements for different control room jobs and different operating conditions. As such, an important aspect of this research is that it provides a reference for information concerning the required abilities for these control room jobs. This information can be used for the selection of control room personnel to ensure that none of the important abilities are overlooked.

Additionally, it can also be used for training purposes and the development of training programs (IAEA, 2000) or for job redesign.

Although there is only limited research about the trainability of specific F-JAS skills and abilities (Kleinmann et al., 2010), research in the safety domain has generated promising evidence and provides specific recommendations concerning the trainability of safety behavior. In a meta-analysis, Burke et al. (2006), for example, investigated the effectiveness of different training methods on employee safety and health. Specifically, they distinguished between three categories of training interventions: least engaging (e.g., lectures, pamphlets), moderately engaging (e.g., feedback interventions) and most engaging (e.g., behavioral modeling, hands-on training). As training methods became more engaging, trainees demonstrated better acquisition of safety knowledge, better safety-related behavior, and reductions were seen in accidents and injuries. However, all methods of training led to meaningful behavioral performance improvements. Furthermore, additional meta-analytic research in the training domain also confirmed that training can improve skills from all of the ability domains covered by the F-JAS (Arthur et al., 2003; Taylor et al., 2005).Therefore, it seems likely that training can help to develop certain skills and abilities that are covered by the F-JAS.

With regard to job redesign, the information provided by the job analysis also has important implications. Specifically, identifying tasks with requirements for high levels of specific abilities may lead to the use of job aids, the redesign of these tasks, or the reallocation of such tasks to individuals who possess higher levels of these abilities. In this way, a better match between employees' abilities and relevant job requirements can be ensured, which will contribute to lower human error probabilities and thus to better nuclear safety in the long term.

As a second contribution, our findings confirmed that ability requirements are not only high for cognitive abilities but also for social and interpersonal abilities for all three control room jobs considered. This is an important finding, especially given that social and interpersonal abilities are not considered in O*NET (2010b), which is – as noted above – the database providing the most systematically collected information on job requirements for jobs in nuclear power plants. However, our findings are in line with results from other fields with high demands on safety issues such as aviation, where research has even revealed an increase in the importance of social and interpersonal abilities (Goeters et al., 2004; Maschke, 2004). The parallels between these fields are not surprising given that employees in both fields have to handle complex technical systems and often work in teams with shared responsibilities. Furthermore, ability requirements for cognitive and social/interpersonal abilities were higher than for the domains of psychomotor/physical as well as sensory/perceptual abilities. Again, this has important implications for selection and training, in which the domain of social/interpersonal abilities should be given appropriate consideration in addition to the domain of cognitive abilities.

A third contribution of our research lies in its confirmation of the existence of differences between control room jobs. This is important because the limited available information on ability requirements for control room jobs does not distinguish between different jobs (O*NET, 2010b). In particular, we found differences between ability requirements for cognitive as well as for social and interpersonal abilities between the jobs of reactor operator and the two hierarchically higher jobs. As predicted, reactor operators need lower levels of these abilities than the other two jobs. These findings are in line with those of Lin et al. (2009), who found that the job of shift supervisor involves more cognitive tasks than the job of reactor operator. However, contrary to our assumptions, there were no meaningful differences between the job of shift supervisor and the hierarchically higher job of safety engineer in the domain of cognitive abilities. Similarly, in the domain of social/interpersonal abilities, the two jobs only differ with respect to the ability of Coaching, and this ability is needed to a higher degree for the job of shift supervisor. A possible reason for the small size of the differences found between the two jobs could be that we only considered ability requirements needed in relation to control room tasks. However, the job of safety engineers includes a wide range of additional tasks that are independent of control room activities, such as training or research. Finally, ability requirements for safety engineers are lower than for the hierarchically lower jobs of shift supervisor and reactor operator in the domains of psychomotor/physical and sensory/perceptual abilities. This finding is not surprising given that safety engineers do not have to gather information or monitor the various signals themselves when they are in the control room. Instead, their main task is to support the shift supervisor and to take the lead during high-risk emergency alerts. Thus, shift supervisors and reactor operators provide safety engineers with the necessary information, meaning that required levels of psychomotor/physical and sensory/perceptual abilities are higher for the former two jobs than for the latter. Given the limited applicant market for nuclear control room jobs, the somewhat limited differences between different types of control room jobs are beneficial for selection and development purposes. Specifically, with appropriate training, it seems possible to ensure that employees can meet the ability requirements for hierarchically higher jobs after they have worked as reactor operators for some years.

Finally, in line with contingency models of leadership, our results showed that ability requirements differed between normal operating conditions and incident conditions, but that these differences were limited to a small number of abilities, especially for reactor operators. For shift supervisors, the main differences concerning ability requirements between the two operating conditions were found in the domain of social/interpersonal abilities. In this domain, however, differences were substantial for the few abilities concerned. This indicates that the two conditions differ in the necessary leadership style, with leadership during an incident having to be more directive than in the normal operating condition. Accordingly, abilities such as Agreeableness, Negotiation, Sociability, Social Sensitivity, and Coaching are needed to a higher degree in the normal operating condition.

## 5.1 Limitations and Lines for Future Research

The present research made several important contributions. Nevertheless, there are also several limitations that need to be addressed. First, we determined ability requirements for different control room jobs, but were unable to link these requirements to specific errors or error probabilities. Although Buffardi et al. (2000) found such links in their study in nuclear power plants, additional research is necessary to confirm these potential relationships for the relevant abilities identified in the present studies, and this seems especially relevant for social and interpersonal abilities, as such abilities were not considered by Buffardi et al. (2000). Furthermore, it might well be the case that additional abilities are relevant to actively prevent safety-related problems.

Second, the present research only focused on the individual level as a level that is relevant for safety in nuclear power plants. However, as noted above, a system perspective including both human errors and technical system components as well as the organizational context seems to be most appropriate (e.g., Hofmann et al., 1995; Hollnagel, 2004; Reason, 2008). Thus, future research is needed to investigate the interplay of these different factors.

Third, the present research focused on ability requirements to perform the specific jobs in the control room. However, in addition to abilities that are necessary to perform a job, additional aspects on the part of the employees might be beneficial to foster safety-related behaviors and to implement a safety culture. Thus, as noted above, the relationship between leaders and their subordinates is an important factor for safety communication (Hofmann and Morgeson, 1999; Reason, 1997). In addition, Hofmann and Morgeson (1999) also found that perceived organizational support constitutes another social exchange variable in addition to leader-member exchange (LMX), which is more indicative of the organizational context but which also impacts safety communication.

Finally, we have argued that evidence concerning the effectiveness of training shows promise, leading us to expect likely positive effects of training with regard to specific abilities identified in the present research. Nevertheless, as also noted above, evidence concerning the trainability of specific F-JAS skills and abilities is limited. Thus, future research is necessary to investigate and hopefully confirm our positive expectations.

## 5.2 Conclusions

Important factors for the safety of nuclear power plants include defenses-in-depth systems, organizational and workplace factors, individual skills, and the abilities of job incumbents. None of these factors should be neglected. Knowledge of these required abilities can help to improve safety through adequate personnel selection, training methods, and job redesign in nuclear power plants. The present research attempted to contribute to the safety of nuclear power plants by providing empirical data concerning requirements across a wide range of abilities and by considering the impact of different control room jobs and different working conditions on these requirements.

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Figure 1. Example of an ability requirement scale measuring Written Comprehension (translated from the German version of the F-JAS)

**Oral Comprehension**

This is the ability to listen to and understand spoken words and sentences.

| How "*Oral Comprehension*" is different from other abilities | | |
|---|---|---|
| *"Oral Comprehension":* Involves listening to and understanding words and sentences spoken by others. | vs. | *"Written Comprehension":* Involves reading and understanding written words and sentences. |
| | vs. | *"Oral Expression"* and *"Written Expression":* Involves speaking and writing words and sentences that others can understand |

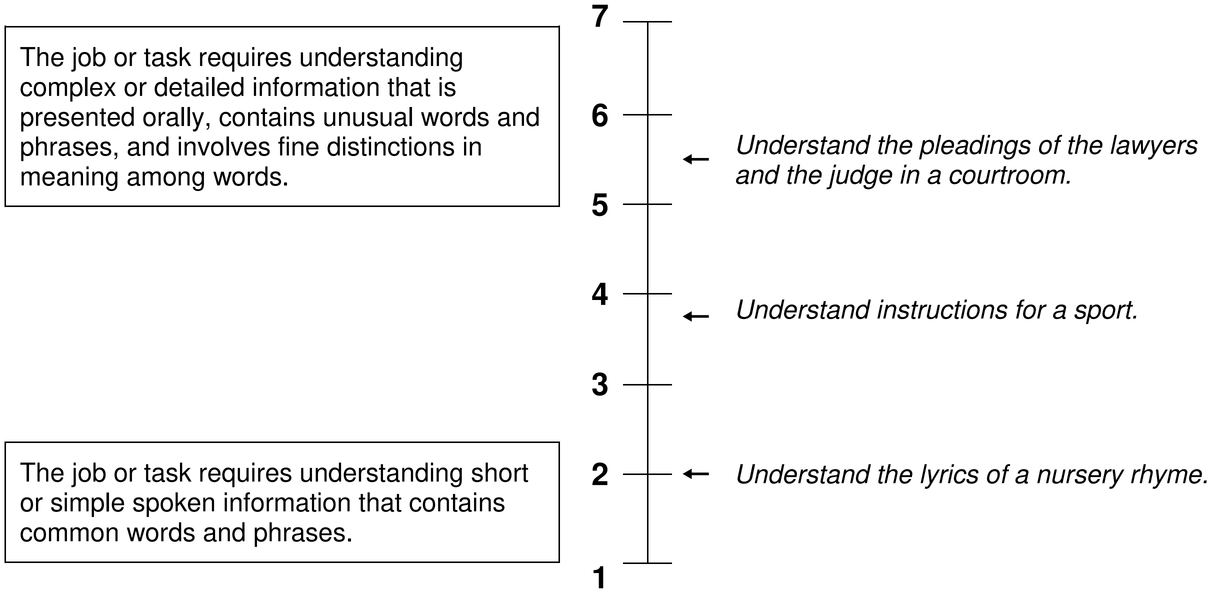

Table 1. Cognitive ability requirements for control room jobs

| Ability | Reactor operator (RO) | | Shift supervisor (SS) | | Safety engineer (SE) | | Differences between jobs[a] | | |
|---|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *M* | *SD* | RO-SS | RO-SE | SS-SE |
| Flexibility of Closure | 4.28 | 1.19 | 4.98 | 0.98 | 4.78 | 1.23 | -0.64** | -0.42 | 0.19 |
| Fluency of Ideas | 3.11 | 1.31 | 3.83 | 1.14 | 4.10 | 1.19 | -0.58** | -0.77** | -0.23 |
| Information Ordering | 4.85 | 0.81 | 5.37 | 0.78 | 5.25 | 0.98 | -0.64** | -0.46* | 0.13 |
| Mathematical Reasoning | 3.52 | 1.09 | 4.17 | 0.85 | 3.83 | 0.81 | -0.65** | -0.30 | 0.41 |
| Memorization | 4.46 | 1.02 | 4.75 | 0.91 | 4.65 | 0.80 | -0.30 | -0.20 | 0.11 |
| Number Facility | 4.02 | 1.08 | 4.53 | 0.89 | 4.63 | 1.05 | -0.51* | -0.56* | -0.10 |
| Oral Comprehension | 5.03 | 0.81 | 5.17 | 0.74 | 5.20 | 0.79 | -0.17 | -0.21 | -0.04 |
| Oral Expression | 5.01 | 0.75 | 5.42 | 0.79 | 5.25 | 0.87 | -0.53* | -0.30 | 0.20 |
| Problem Sensitivity | 5.54 | 0.94 | 5.70 | 0.87 | 5.85 | 0.86 | -0.18 | -0.34 | -0.17 |
| Selective Attention | 5.26 | 0.95 | 5.38 | 0.85 | 5.40 | 1.03 | -0.13 | -0.14 | -0.02 |
| Spatial Orientation | 3.62 | 1.14 | 3.90 | 1.16 | 3.33 | 1.07 | -0.24 | 0.26 | 0.51 |
| Speed of Closure | 4.75 | 0.99 | 4.97 | 1.04 | 4.75 | 1.13 | -0.22 | 0.00 | 0.20 |
| Time Sharing | 5.36 | 0.86 | 5.72 | 0.87 | 5.75 | 0.74 | -0.42* | 0.48** | -0.04 |
| Visualization | 3.83 | 1.27 | 4.37 | 1.07 | 4.48 | 1.13 | -0.45 | -0.53* | -0.10 |
| Written Comprehension | 5.30 | 0.85 | 5.67 | 0.60 | 5.45 | 0.90 | -0.48* | -0.17 | 0.29 |
| Written Expression | 3.91 | 1.14 | 4.65 | 0.88 | 4.58 | 0.78 | -0.71** | -0.64** | 0.09 |
| **Mean across cognitive abilities** | **4.49** | **0.55** | **4.91** | **0.59** | **4.83** | **0.53** | **-0.74**** | **-0.63**** | **0.15** |

*Note*. The scales ranged from 1 to 7 with larger numbers reflecting higher ability requirements. *N* = 87 reactor operators, 60 shift supervisors, and 40 safety engineers. [a] The size of the difference between the means for two jobs is given as Cohen's *d*.
* $p < .05$, ** $p < .01$

Table 2. Social and interpersonal ability requirements for control room jobs

| Ability | Reactor operator (RO) | | Shift supervisor (SS) | | Safety engineer (SE) | | Differences between jobs[a] | | |
|---|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *M* | *SD* | RO-SS | RO-SE | SS-SE |
| Achievement Striving | 4.44 | 0.90 | 4.78 | 0.69 | 4.93 | 0.94 | -0.42 | -0.53** | -0.18 |
| Agreeableness | 4.40 | 1.04 | 4.70 | 1.11 | 4.18 | 0.98 | -0.28 | 0.22 | 0.49 |
| Assertiveness | 4.87 | 0.91 | 5.67 | 0.68 | 5.65 | 0.80 | -0.96** | -0.88** | 0.02 |
| Behavior Flexibility | 4.78 | 0.97 | 5.13 | 0.98 | 5.48 | 0.85 | -0.36 | -0.74** | -0.37 |
| Coaching | 4.03 | 1.17 | 5.15 | 0.86 | 4.43 | 1.22 | -1.06** | -0.33 | 0.71** |
| Coordination | 4.94 | 1.11 | 5.63 | 0.76 | 5.68 | 0.73 | -0.70** | -0.73** | -0.06 |
| Dependability | 6.48 | 0.74 | 6.43 | 0.59 | 6.50 | 0.68 | 0.07 | -0.02 | -0.11 |
| Negotiation | 3.61 | 1.11 | 4.60 | 0.99 | 4.33 | 1.05 | -0.93** | -0.65** | 0.27 |
| Openness to Experience | 4.25 | 1.09 | 4.53 | 1.07 | 4.20 | 1.11 | -0.26 | 0.05 | 0.31 |
| Oral Defense | 4.14 | 1.13 | 4.73 | 0.92 | 5.05 | 1.11 | -0.57** | -0.81** | -0.32 |
| Oral Fact Finding | 5.02 | 1.07 | 5.52 | 0.89 | 5.90 | 0.71 | -0.49* | -0.90** | -0.47 |
| Perseverance | 5.76 | 0.86 | 5.58 | 0.93 | 5.58 | 1.03 | 0.20 | 0.20 | 0.01 |
| Resilience | 4.43 | 1.04 | 4.77 | 0.98 | 5.08 | 1.14 | -0.34 | -0.61** | -0.29 |
| Resistance to Premature Judgment | 5.67 | 0.83 | 5.92 | 0.74 | 6.05 | 0.64 | -0.31 | -0.49* | -0.19 |
| Self-Control | 6.02 | 0.88 | 6.40 | 0.64 | 6.40 | 0.71 | -0.48* | -0.46* | 0.00 |
| Sociability | 4.37 | 1.17 | 4.68 | 1.03 | 4.55 | 1.06 | -0.28 | -0.16 | 0.13 |
| Social Confidence | 4.48 | 1.04 | 5.28 | 0.64 | 5.43 | 0.78 | -0.89** | -0.97** | -0.20 |
| Social Conformity | 5.37 | 1.27 | 5.82 | 1.08 | 5.68 | 1.12 | -0.38 | -0.25 | 0.13 |
| Social Sensitivity | 4.32 | 1.10 | 5.17 | 0.69 | 4.68 | 0.83 | -0.88** | -0.34 | 0.66 |
| **Mean across social and interpersonal abilities** | **5.10** | **0.37** | **5.47** | **0.67** | **5.31** | **0.60** | **-0.82**** | **-0.76**** | **0.08** |

*Note*. The scales ranged from 1 to 7 with larger numbers reflecting higher ability requirements. *N* = 87 reactor operators, 60 shift supervisors, and 40 safety engineers. [a] The size of the difference between the means for two jobs is given as Cohen's *d*.
* *p* < .05, ** *p* < .01

Table 3: Psychomotor and physical ability requirements for control room jobs

| **Ability** | **Reactor operator (RO)** | | **Shift supervisor (SS)** | | **Safety engineer (SE)** | | **Differences between jobs[a]** | | |
|---|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *M* | *SD* | RO-SS | RO-SE | SS-SE |
| Control Precision | 4.51 | 1.27 | 4.28 | 1.17 | 2.78 | 1.10 | 0.18 | 1.42** | 1.32** |
| Explosive Strength | 2.64 | 1.28 | 2.75 | 1.19 | 2.13 | 0.88 | -0.09 | 0.44 | 0.58 |
| Finger Dexterity | 3.26 | 1.22 | 3.37 | 1.25 | 2.43 | 0.68 | -0.08 | 0.77** | 0.89** |
| Gross Body Coordination | 2.60 | 1.16 | 2.80 | 1.18 | 2.15 | 0.74 | -0.17 | 0.43 | 0.63 |
| Gross Body Equilibrium | 2.60 | 1.14 | 2.85 | 1.15 | 2.15 | 0.80 | -0.22 | 0.43 | 0.68* |
| Stamina | 2.70 | 1.23 | 3.08 | 1.25 | 2.43 | 0.96 | -0.31 | 0.24 | 0.58 |
| **Mean across psychomotor and physical abilities** | **3.05** | **0.94** | **3.19** | **0.92** | **2.34** | **0.61** | **-0.15** | **0.83**** | **1.05**** |

*Note*. The scales ranged from 1 to 7, with larger numbers reflecting higher ability requirements. $N$ = 87 reactor operators, 60 shift supervisors, and 40 safety engineers. [a] The size of the difference between the means for two jobs is given as Cohen's $d$.
* $p < .05$, ** $p < .01$

Table 4: Sensory and perceptual ability requirements for control room jobs

| **Ability** | **Reactor operator (RO)** | | **Shift supervisor (SS)** | | **Safety engineer (SE)** | | **Differences between jobs**[a] | | |
|---|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *M* | *SD* | RO-SS | RO-SE | SS-SE |
| Auditory Attention | 4.89 | 0.87 | 4.93 | 0.92 | 4.50 | 1.06 | -0.05 | 0.41 | 0.44 |
| Depth Perception | 3.08 | 1.30 | 3.15 | 1.18 | 2.35 | 0.80 | -0.06 | 0.62** | 0.77* |
| Far Vision | 4.16 | 0.94 | 4.38 | 0.94 | 3.73 | 0.75 | -0.24 | 0.49 | 0.76* |
| Hearing Sensitivity | 4.02 | 1.07 | 4.13 | 1.14 | 3.50 | 0.96 | -0.10 | 0.51* | 0.59 |
| Near Vision | 4.52 | 0.95 | 4.53 | 0.87 | 4.03 | 0.95 | -0.02 | 0.52* | 0.56 |
| Peripheral Vision | 3.29 | 1.17 | 3.43 | 1.24 | 2.85 | 0.98 | -0.12 | 0.39 | 0.51 |
| Sound Localization | 3.75 | 1.35 | 3.92 | 1.00 | 3.25 | 1.19 | -0.14 | 0.38 | 0.62* |
| Speech Clarity | 4.48 | 0.89 | 4.78 | 0.80 | 4.75 | 0.81 | -0.35 | -0.31 | 0.04 |
| Speech Recognition | 4.48 | 1.10 | 4.85 | 0.92 | 4.48 | 1.15 | -0.36 | 0.01 | 0.37 |
| Visual Color Discrimination | 3.97 | 1.17 | 4.40 | 1.04 | 3.73 | 1.04 | -0.39 | 0.21 | 0.65* |
| **Mean across sensory and perceptual abilities** | **4.28** | **0.64** | **4.46** | **0.75** | **3.60** | **0.68** | **-0.26** | **0.52**** | **0.82**** |

*Note*. The scales ranged from 1 to 7, with larger numbers reflecting higher ability requirements. *N* = 87 reactor operators, 60 shift supervisors, and 40 safety engineers. [a] The size of the difference between the means for two jobs is given as Cohen's *d*.
* $p < .05$, ** $p < .01$

Table 5. Means and standard deviations of the ability requirements that differ significantly between the two work conditions for reactor operators

| **Ability** | **Normal operation** | | **Incident** | | *d* |
|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | |
| Time Sharing (C) | 5.31 | 1.09 | 5.88 | 0.87 | -0.57* |
| Behavior Flexibility (SI) | 4.47 | 1.11 | 5.31 | 0.90 | -0.84** |
| Self-Control (SI) | 5.44 | 1.27 | 6.34 | 0.94 | -0.81** |
| Oral Defense (SI) | 4.06 | 1.34 | 4.88 | 1.16 | -0.65* |
| Auditory Attention (SP) | 4.56 | 1.52 | 5.31 | 0.90 | -0.60* |
| Speech Recognition (SP) | 4.34 | 1.41 | 5.28 | 0.92 | -0.79** |

*Note*. The scales ranged from 1 to 7, with larger numbers reflecting higher ability requirements. $N = 36$. C = cognitive, SI = social and interpersonal, SP = sensory and perceptual. The size of the difference between the means for two jobs is given as Cohen's *d*.
* $p < .05$, ** $p < .01$

Table 6. Means and standard deviations of the ability requirements that differ significantly between the two work conditions for shift supervisors

| **Ability** | **Normal operation** | | **Incident** | | *d* |
|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | |
| Problem Sensitivity (C) | 5.50 | 0.62 | 6.11 | 0.68 | -0.94** |
| Written Expression (C) | 4.67 | 0.84 | 3.83 | 1.04 | 0.88* |
| Agreeableness (SI) | 5.22 | 0.73 | 3.39 | 0.98 | 2.12** |
| Coaching (SI) | 5.06 | 1.00 | 4.11 | 1.45 | 0.76* |
| Negotiation (SI) | 4.67 | 0.97 | 3.28 | 1.23 | 1.26** |
| Openness to Experience (SI) | 4.61 | 0.85 | 3.56 | 1.38 | 0.92** |
| Perseverance (SI) | 5.28 | 0.67 | 6.06 | 0.64 | -1.19** |
| Sociability (SI) | 4.89 | 1.18 | 3.56 | 1.34 | 1.06** |
| Social Sensitivity (SI) | 5.17 | 0.79 | 3.28 | 1.32 | 1.74** |
| Explosive Strength (PP) | 2.33 | 0.91 | 1.78 | 0.65 | 0.71* |

*Note*. The scales ranged from 1 to 7, with larger numbers reflecting higher ability requirements. $N = 64$. C = cognitive, SI = social and interpersonal, SP = sensory and perceptual, PP = psychomotor and physical. The size of the difference between the means for two jobs is given as Cohen's *d*.
* $p < .05$, ** $p < .01$