ELECTRIC POWER RESEARCH INSTITUTE

EFFECTS OF RESPIRATOR USE ON WORKER PERFORMANCE

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ABSTRACT

In 1993, EPRI funded Yankee Atomic Electric Company to examine the effects of respirator use on worker efficiency. Phase I of Yankee's effort was to develop a study design to determine respirator effects. Given success in Phase I, a larger population will be tested to determine if a statistically significant respirator effect on performance can be measured. This paper summarizes the 1993 EPRI/Yankee Respirator Effects Pilot Study, and describes the study design for the 1994 EPRI/Yankee Respirator Study to be conducted at the Oyster Creek Nuclear Power Plant. Also described is a summary of respirator effect studies that have been conducted during the last ten (10) years.

INTRODUCTION

As of January 1, 1994, the NRC, through implementation of the new 10 CFR Part 20, is requiring licensees to keep internal plus external doses ALARA. With implementation of this regulation, the NRC is requiring licensees to make decisions based on respirator effects on worker efficiency.

As an example, if a worker is in a radiation area where he will accrue an effective dose equivalent of 100 mrem in an hour from inhalation of airborne activity, and accrue an effective dose equivalent of 200 mrem in an hour from an external radiation source, and respirator use reduces worker efficiency by 50%, then the one hour job shall be performed without a respirator to comply with good ALARA principles. The total effective dose equivalent (TEDE) differences for performance of this one hour job, with and without the respirator, are as follows. With a respirator the 1 hour job will take 2 hours to complete because of the 50% reduction in worker efficiency. The TEDE for this job will be 400 mrem (0 internal + 400 external). Without a respirator the job will take 1 hour, and the TEDE is 300 mrem (100 internal + 200 external).

In summary, Subpart H of the new Part 20 requires licensees to decide when to use respirators to achieve the new Part 20 goal of keeping the TEDE ALARA.

OBJECTIVE

The objectives of the current Yankee/EPRI study are to determine if respirator use affects worker performance during a standard nuclear power plant task, and if possible, to quantify this effect. This study has been subdivided into two phases.

Phase I consisted of developing a study design to measure the respirator effect, and then determining if this study design was capable of quantifying the respirator effect by testing a population of 6 workers. This report presents the results of Phase I.

Based on the results of Phase I, Phase II will consist of testing a population of about 50 workers, to quantify the respirator effect with statistical significance.

LITERATURE SEARCH

Three independent literature searches on the topic "Respirator Effects on Worker Efficiency" have been performed. The first search was conducted in 1985, by the Georgetown University Library staff. This literature search was part of a respirator efficiency study conducted at TMI[1]. The second literature search was conducted by Encore Technical Resources, Inc. in 1992, and a third search was conducted at Virginia Polytechnic Institute in April of 1993. Both of these literature searches were conducted as part of the Yankee/EPRI study. The results of these searches identified only one applicable study that quantified respirator effects on worker efficiency.

Most of the studies measured the body's response (i.e., heart rate, temp., etc.) to different work levels while wearing respiratory protection, or stay time limits to avoid heat stress related health effects while using respiratory protection.

In May of 1982, the U.S. ARMY conducted studies which involved the discharge of firearms while wearing gas masks, but these results are difficult to apply to nuclear power plant worker efficiency. A study conducted in 1984, at Ontario Hydro[2], consisted of quantifying worker efficiencies while wearing protective apparel; however, the respiratory protection equipment used in this study (Air-Supplied Suit) is significantly different than the respiratory protection equipment commonly used in the U.S. (Face Mask). Also, a 1992 University of Maryland/Army study predicted worker efficiencies while wearing protective apparatus, but most of this data is based on models rather than actual human experiments.

In 1985, a study was conducted at TMI, in which 48 male nuclear power plant workers performed a 20 minute task with and without a respirator[1]. The objective of this study was to demonstrate the respirator effect on worker efficiency. Each worker performed the test twice. Half the workers wore the respirator for the first trial, and the other half wore the respirator for the second trial. Statistical analysis of the test data showed that all workers performed the task faster the second time, regardless of whether they were wearing a respirator. The workers had not performed the task before the actual testing, and did it faster the 2nd time as a result of "learning" the task. However, because the order of performing the first test with a respirator was staggered, worker efficiency analysis was examined independent of the learning effect. This analysis determined that there was no respirator effect for this 20-minute task.

In 1990, a respirator efficiency study was conducted at Commonwealth Edison by a graduate student at Northwestern University[3]. This study consisted of performing four (4) different tasks with and without a respirator. The tasks were valve repacking, insulation replacement, pipe replacement, and gate valve inspection. The tests were conducted at room temperature, and varied in length from 20 to 47 minutes. Eighteen maintenance workers participated. The valve repacking task was completed, on the average, 29% more efficiently in a respirator. The overall efficiency of the remaining three tasks was 18% more efficient while working without a respirator.

STUDY DESIGN - PHASE I

The objective of Phase I, as stated above, was to develop a study design that measures the respirator effect on worker efficiency, and then test the study design to determine if it is capable of measuring this effect. Six workers were to be used to test the study design, and if possible, quantify the respirator effect. It was during this phase that the study design was to be adjusted, as the preliminary testing was being conducted, in order to meet the quantification objective during Phase II.

A number of meetings were held to develop each aspect of this study design. After careful review of a number of different plant maintenance procedures, the swing check valve inspection was chosen because we anticipated that it would take about an hour to complete, and that it would be a very strenuous task. However, parts of the procedure, such as the inspection steps, were removed because they were qualitative in nature instead of quantitative. Including the inspection steps would have made it possible for the workers to rush if they were uncomfortable, and wanted to complete the task sooner to remove the respirator. (As a result of removing these steps, the average task completion time for the six workers was about 35 minutes.)

The amount and type of training to be given to the workers before they actually performed the test, were also given careful consideration. This was done to avoid testing while the workers were still on the steep part of the learning curve. This learning factor in the TMI study was larger than the respirator factor, and as a result, any small variance brought about by the respirator may have been masked. It was decided that the workers would be trained until their task completion times, without the respirator, no longer showed large differences from one trial to the next.

Consideration was also given to training the workers on a mock-up valve as opposed to the actual in-plant valve. The options were as follows: (1) train the workers on the mock-up and then have them perform the test on the in-plant valve, to be representative of how this task might be performed in the nuclear industry, or (2) train and test the workers on the actual plant valve to obtain a more accurate measurement of just the respirator effect on worker efficiency (rather than introduce more variables by having the surroundings of the valve change between training and testing). When it was observed in training that the first worker performed the task at the mock-up very differently than he did at the in-plant valve, due to surrounding space limitations, it was decided that all workers would be trained and tested at the in-plant valve. The reason for this was to ensure that the respirator effect would not be hidden by the new learning factor associated with the adjustment of performing the task at the in-plant valve.

Humidity and heat directly affect worker efficiency through heat stress limitations. The literature[4] demonstrates that heat stress limits are more restrictive when workers are wearing respirators. Temperature could be controlled with a six foot space heater, and both temperature and humidity were continually recorded.

The type of respirator to be used in the study was the full face negative pressure (FFNP) respirator. Although many different types of respirators are used in the U.S. nuclear industry, the FFNP type was chosen because it is believed to be the most frequently used respirator in the industry. Nose cups were used in the respirators of two of the workers to see if mask fogging was reduced.

Phase I was conducted with 6 experienced nuclear power plant workers who had already been medically approved for respirator use. Three of these workers were from Yankee's maintenance staff, and the other three were Yankee staff electricians. All workers participating in the study, filled out a questionnaire regarding their age, height, weight, work experience, smoking status, eyesight, exercise, and medical status. This questionnaire also asked the worker for their views on internal v.s. external dose, and job performance with a respirator. The results of this survey are given in the Lessons Learned section of this report.

Two workers were to report to the plant for two consecutive days. During the morning of the 1st day the workers attended a classroom training session, where they were trained on each step of the task that was to be performed. After the formal classroom training was concluded, each worker performed the task alone. While worker # 1 was performing the task, worker # 2 was resting. Workers 1 through 4 practiced the task twice before being tested. Two of these 4 workers had differences between their 1st and 2nd training completion times of greater than 10%. To further reduce the learning factor, workers 5 and 6 practiced the task three times before being tested. For workers 5 and 6, completion times for practice performances 2 and 3 differed by less than 6.5%.

On the second day, worker #1 would dress up in full PCs, and perform the task once in the morning with a respirator. Worker #1 would then perform the task a second time after a 1.5 hour rest, with full PCs and without a respirator. Worker #2 would perform the task in the morning, while worker #1 was resting. Worker #2 wore full PCs and no respirator for his first performance, and his second performance would be in full PCs and a respirator.

All test performances were videotaped.

A six foot space heater was used during testing, to bring the temperature up to about 78°F. For testing of workers 3, 4, 5, and 6, a temperature of 78°F was reached in the testing area without the use of the space heater, due to high outdoor temperatures. Humidity could not be controlled. The exact temperature and humidity for each worker's test performance was recorded. The Environmental Conditions section below discusses temperature and humidity in more detail.

TASK DESCRIPTION

A standard plant procedure "Inspection Procedure For 10 inch Swing Check Valve" was used for Phase I. As discussed in Section IV, this task was selected due to the physical activity involved and the estimated length of time to complete. The task consisted of the following nine subtasks. (This check valve is illustrated in Diagram 1.)

1. Loosen the twenty 1 13/16" nuts with combination wrench and breaker bar.

2. Remove nuts and bolts by hand and place them in holding bucket.

3. Place two eyebolts in the bonnet cover, and remove bonnet with chain fall.

4. Perform blue test inspection by placing blue ink around the perimeter of the valve disc, and seeing if a blue ring can be seen continuously where the swinging valve disc meets the pipe. Once complete, ensure that the ink is wiped from the valve so that this same test can be conducted by the next worker.

5. Replace bonnet cover, with chain fall, by lining up the bolt holes as the bonnet cover is lowered onto the valve.

6. Install bolts and tighten nuts by hand.

7. Using a torque wrench with a light that indicates when the pre-set ft-lb pressure is reached, tighten the bolts in the sequence illustrated in Diagram 2, to a pressure of 160 ft-lbs.

8. Tighten the bolts in the sequenced referenced above, to a pressure of 330 ft-lbs.

9. Tighten the bolts in the sequenced referenced above, to a pressure of 500 ft-lbs.

ENVIRONMENTAL CONDITIONS

Training and testing were conducted on the ground elevation of the Yankee Nuclear Power Station Turbine Building. The temperature during testing of workers 1 and 2 was 78°F, as maintained with a six foot space heater. The average relative humidity was 63%. For workers 3 through 6, the average temperature was 78°F, and the average relative humidity was 77%, due entirely to external environmental conditions.

A Heat Index, was calculated from a plant heat stress procedure[4], for all testing. The Heat Index for all testing was between 80 and 85. This Index is a measure of the physiological heat stress imposed on the human body, from the additive effect of both temperature and humidity. NIOSH recommended stay times for a Heat Index between 80 and 85, for heavy work (heavy lifting, pushing, or pulling especially when using a negative pressure respirator) are 90 minutes for single PCs, and 25 minutes for Plastic PCs. Workers that were tested in this study, used paper and cotton PCs, which corresponded to NIOSH recommended stay times between 25 and 90 minutes. Therefore, with an average testing performance time of about 35 minutes, there was no immediate concern with heat stress.

LESSONS LEARNED

Mock-Up Facility

A mock-up of the check valve was used to train workers 1 and 2. It was our intention that following mock-up training, these workers would perform the actual test performance in full PCs, with and without a respirator, on the actual in-plant check valve. This mock-up was set up in a section of the Turbine building where there were no obstructions that could interfere with performing the task. However, by mistake, worker 1 conducted his last training performance on the actual in-plant check valve, and his completion time was noted to increase dramatically. This performance time increase was caused by various pipes and other obstacles surrounding the in-plant valve, that forced the worker to perform the task at angles that were different from his task performance at the mock-up. Noting this difference between the mock-up and the in-plant check valve performance, all subsequent training was conducted at the in-plant check valve. Our primary objective in this study was to quantify the effect of the respirator, only, on worker efficiency. Therefore, to minimize the learning effect that would be experienced during the worker's 1st and 2nd performance of the actual test on the in-plant valve, the mock-up was excluded from the study.

Fatigue Factor

Workers 1 and 2 practiced the task once in the morning of the day they were to be tested. After this practice performance, they completed the task two more times that same day for testing. It was observed that these workers were very tired during their third task performance of the day, regardless of whether they were wearing a respirator. To keep this fatigue factor from influencing the test results, workers 3, 4, 5, and 6, did not practice the task on the morning of test day, and therefore, only performed the task two times on the day they were being tested.

Competition Between Workers

Study participants appeared to perform their test trials more diligently, when they realized they were being timed and videotaped. Four of the six participants inquired about their completion time after each test performance. It appeared that the workers were trying to improve their completion times, and compete against their co-workers. This was especially true if co-workers were allowed to watch the test trials.

To minimize this competition, later workers were: 1) separated such that they could not observe their co-workers performance, 2) told that although we were videotaping their performance, they should work quickly without rushing, and 3) told they would be informed of their completion times and study objective when the testing was complete.

Rushing With Respirator

It appeared that those workers that could rush through the task while wearing a respirator, would. Their goal appeared to be to remove the mask as soon as possible. Only one out of the six workers interviewed after testing, stated that he really didn't mind wearing the respirator. Two of the remaining five workers had body weights of about 160 lbs. These workers were unable to rush through the task while wearing the respirator, because the task was too strenuous. Both of these workers had to take significant rest periods during their performance with a respirator. The remaining three workers were over 200 lbs. in body weight, and were physically capable of rushing through the task. These three workers did not show significant increases in their completion times when performing the task with a respirator; however, upon completion of the task with a respirator, they were significantly more fatigued. One of these workers stated that he couldn't have kept up the pace with the respirator, if the task had been any longer.

Further Reduction of Learning Factor

Workers 1 through 4 practiced the task two times before testing to reduce the learning effect. The greatest difference between the 1st and 2nd training completion times for this group was 25%. In order to further reduce the learning effect, workers 5 and 6 practiced the task three times before testing, and the greatest difference between the 2nd and 3rd training was 6.5%.

Questionnaires

The questionnaires used in this study contained questions regarding the workers' views on respirator use, internal versus external dose, and specific questions regarding work experience and health. The questions concerning respirator use and internal versus external dose could have informed the workers of the study objective. If the worker is aware of the study objective his performance could be biased. In an attempt to reduce any bias, the last two workers were given the questionnaire after they completed the testing.

Phase II will have workers complete a questionnaire before testing. The questionnaire will only contain questions regarding work experience and medical status for population grouping within the study. After the workers have completed their testing, a second questionnaire (survey) can be distributed to the workers asking for their views on working with respirators, and external versus internal dose.

Mask Fogging

Mask fogging in all six workers was only observed during exhalation; however, this fogging effect immediately disappeared upon inhalation. Nose cups were used in the respirators of two of the six workers to see if mask fogging could be reduced. There were no observed differences of this fogging effect between those respirators with nose cups, and those without nose cups.

PHASE I DATA ANALYSIS

Overall, the results showed subjects performed the task 10% slower when using the respirator (Figure 1). This result is not statistically significant, due to the small population of six workers.

Subtask times were obtained from reviewing the videotape of each worker's performance. The average subtask times with and without a respirator are shown in Figure 2. These subtasks were analyzed individually for the respirator effect with a Repeated Measures Analysis of Variance test. This statistical test is similar to a Paired T-Test, in which each individual competes against himself. Of the nine subtasks, only subtask 5, Replacing the Bonnet Cover, was statistically significant at the 95% confidence level ($p<0.05$). The magnitude of this difference was a 20% slower performance time with the use of a respirator. This subtask required clear vision to allow the worker to line up the 20 bolt holes as the Bonnet Cover was lowered onto the valve. This high visual component of subtask 5 seems likely to have contributed to this result.

The reason most of the subtask analyses were not statistically significant is because of the small sample size, and that there was considerable variability between subjects. In particular, the lighter subjects (subjects 2 & 4) showed a much larger increase in task completion time (19%) when using the respirators as compared to the heavier subjects (subjects 1,3,5, & 6) who showed a 3% decrease in completion time. This can be seen in Figures 3 & 4, where the effect of the respirator on each task is shown separately for the light and heavy subjects. Note that the effect of the respirator is much larger for the lighter subjects in the later strenuous subtasks.

This greater effect of the respirator on light weight subjects, especially for later tasks, indicates worker fatigue was probably playing an important part in the results. The lighter workers were also older than the heavier workers in this study. The average age of the lighter workers was 50, and that of the heavier workers was 37.

A statistical power analysis of a respirator effect on the overall task, based on the Phase I performance times of the two lighter workers, shows that in order to have a greater than 90% chance of detecting a significant difference in performance time due to wearing a respirator, at the 0.05 significance level, 20 workers would be needed.

CONCLUSIONS

The conclusions of the Phase I test program are:

1. Overall, the average completion times for the six workers showed a 10% increase when respirators were worn. This increase was not statistically significant due to the limited number of workers tested.

2. When lighter workers were analyzed separately, they showed a 19% increase in completion times. The increase in performance time for these lighter workers was apparently due to the physical demands of the task relative to the strength of the worker.

3. The heavier workers showed essentially no difference in their completion times.

4. The lighter workers coincidentally were older (average age 50) than the heavier group (average age 37), and this may have contributed to the increased respirator effect for the lighter workers.

5. Figure 3 shows that the increase in performance time for the lighter workers when wearing a respirator is greater for the latter subtasks. Fatigue seems to play a very important role in these findings. Understanding this relationship is important for evaluating jobs with different completion times and/or jobs requiring various degrees of physical strength.

RECOMMENDATIONS FOR PHASE II

Based on the results from Phase I, Phase II will consist of two groups of 25 workers each, where the confounding variables such as body size and age are balanced between the two groups. After four training performances, Group 1 will perform the test first without a respirator, and then a second time with a respirator. Group 2 will perform the test first with a respirator, and then the second time without a respirator. This will allow comparison of Group 1 performances without the respirator to Group 2 performances with the respirator. Because the two groups will be balanced, this analysis will show the effect of the respirator on the general nuclear plant work force.

Also, a Paired T Test analysis can be performed, where each worker's performance, with and without a respirator, is analyzed. In this analysis, each worker is competing against him/herself such that the respirator effect can be evaluated independent of the great variances between human subjects. This will also allow for the confounding variables, such as age and body size, to be evaluated separately.

Figure 3 shows that for the lighter workers, the differences in task performance with and without a respirator were greater in the later subtasks. This strongly suggests that fatigue plays a very important role in understanding the effect of respirator use on worker efficiency. To measure the effects of fatigue, and to examine other work tasks in addition to physically strenuous ones, the work task in Phase I should be extended to include a specific dexterity test. This will allow the results of Phase II to be applied to nuclear power plant work tasks that are not strenuous, as well as to those that are. The extended work task will be designed such that a heat stress problem is not created.

The lighter workers in the Phase I study were older (average age 50), than those in the heavy body weight group (average age 37). This may have played a role in the different performances between these groups. Age, as well as physical condition and size (strength), will be examined in Phase II to see if they contribute to the respirator effect.

All testing will be conducted in an environmental chamber to simulate actual work environments and to keep the testing area heat and humidity constant for all tests. Also, the Powered Air Purified Respirator, as well as the Full Face Negative Pressure Respirator, will be evaluated.

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Author Biography

Ron Cardarelli has worked for Yankee Atomic Electric Company (YAEC) as a Health Physicist since April 1986. In addition to providing health physics support for a number of nuclear power utilities, he is the Principal Investigator of the EPRI-sponsored Respiratory Effects Study. Before joining YAEC, Mr. Cardarelli was a Radiation Specialist for the U.S. NRC at the Office of NMSS. While working for the NRC, Mr. Cardarelli attended the Radiation Science Graduate Program at Georgetown University. As part of his thesis, he conducted a study at TMI involving 48 plant workers in which he examined the effects of respirator use on worker efficiency. Mr. Cardarelli has a M.S. in Radiation Science from Georgetown University and a B.S. from U-Mass, Amherst, in Environmental Health.

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DISCUSSION

Tucker: You mentioned a dexterity test and you talked about the fatigue. I wonder, what is your feeling about how this affects concentration and a person's ability to actually complete the task correctly?

Cardarelli: We are hoping that this dexterity test will actually measure concentration. This is the reason for using a dexterity test. We saw fatigue at the end of the 1993 vigorous task and we want to try to measure it.

Westbrook: I noticed your people, with and without respirators, were wearing short-sleeved outfits. How representative is that of the real situation. If we were to put someone in a respirator, he would be wearing at least a single suit of anti-Cs and possibly a double suit, and if it were wet work, he'd be wearing a waterproof suit. In the results, even though you find an advantage without the respirator, the difference doesn't seem to be very strong. You understand, of course, when you try to make this study scientific, you are going against a huge amount of anecdotal evidence.

Cardarelli: I have to stop you for a second. What you saw was just a mock-up. It was the training of the subjects. That photo you are referring to was taken while the subjects were being trained to reduce the learning effect. It is after this training that the subjects are tested. During testing they wear full PCs. the subjects are tested in PCs twice, once with a respirator and once without a respirator.

Westbrook: My second point is that I assume your results are for people wearing full PCs, but one hears from every site, and practically every nuclear facility and for every nuclear activity that there is, that they do notice a significant difference when people wear respirators. If you are finding skinny results like 15-20% difference, that would seem to run counter to this huge bulk of anecdotal experience over time and numbers of people.

Cardarelli: I have looked at tons of those studies, and with the exception of a Canadian study, I have not found one study with human testing that significantly quantified worker efficiency. I was leery to even show the 10% at this time because this is only based on six people, and starting in the next couple of weeks we will be doing it with 50 people. But in 1985, when I did the study at TMI, there were 48 workers, and there was no significant respiratory effect for the 25-minute task used in that study. You watch them do the two tasks and you say, "I know they will do it slower with a respirator," but the video tape and the clock really didn't show that. In a lot of these informal studies conditions with and without the respirator are not the same. For example, last year they had heavy PCs and respirators on. This year they didn't have a respirator, but they also didn't have all those PCs on because they engineered and sandblasted. It is very tough to use those studies, and that is why we are trying to do a detailed study and really just focus on the respirator effect.

Khan: We did similar work, as you know, in Canada, using Canadian attire, and we found results that tend to agree with yours. The respirator had a small effect. But the largest effect was the type of gloves that they wore. The heavier the gloves, the more inefficient they got. Did you look into that aspect at all?

Cardarelli: We are training the subjects with double rubber gloves because the effects that the rubber gloves have on efficiency are probably greater than those from the respirator. We are going to pretrain them and try to remove that variable since this study is looking just at the respirator effect.