Performance, alertness, and sleep after 3·5 years of 12 h shifts: A follow-up study

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Control room operators at a continuous processing plant have been working a 12 h/3–4 day rotating shift schedule for over 3 years. After 7 months on this schedule, our initial assessment indicated decrements in performance and alertness, and a mild to moderate sleep debt, when the 12 h shift schedule was compared to the previously-worked 8 h shift schedule. In an effort to track long-term adaptation to the schedule, we conducted a 3·5 year follow-up evaluation using the same set of measures. Long-term follow-up testing revealed persistent decrements in performance and alertness attributable to 12 h shifts, and 1–3 h reductions in total sleep time after 12 h night shifts. Little deterioration in performance or alertness was observed across the workweek, which suggested day-to-day recovery from the extended workshift. The popularity of the 12 h shift schedule at this worksite indicates that the workers are willing to tolerate extra fatigue to derive other benefits from this schedule.

Keywords: Shiftwork; Compressed workweek; 12 h shifts; Fatigue; Alertness; Performance stress.

1. Introduction

Many alternative work schedules 'compress' the workweek into a smaller number of days by adding more work hours per day (usually extending the workshift to 10–12 h). These types of schedules are becoming popular among shiftworkers because the extra non-work days off allow large blocks of time for recuperation from night work, for family and friends, and for other leisure pursuits. A disadvantage of such schedules, however, is the potential for excessive fatigue from long workshifts leading to safety or health hazards (Hodge and Tellier 1975). Night workers may be especially at risk because the fatigue of long workshifts could add to reduced alertness attributable to the circadian rhythm of arousal (Wever 1981).

Concern about the safety and health effects of excessive fatigue was the impetus for a National Institute for Occupational Safety and Health (NIOSH) research programme evaluating extended workshifts at the worksite. The evaluation approach utilizes a microcomputer to measure worker responses to a battery of standard performance tests and self-report scales that are sensitive to variations in alertness and fatigue (see Rosa and Colligan 1988, Rosa et al. 1985, for descriptions of the battery and demonstrations of its sensitivity.) The system was designed to be placed at the worksite to allow workers to take brief breaks from their jobs to self-administer the tests and scales. With this approach, we have tracked worker alertness and fatigue on all shifts so that 'around-the-clock' alertness could be monitored over a period of several weeks. Workers at two sites that switched from an 8 h to a 12 h shift schedule have been evaluated with this system.

One worksite study occurred at a natural gas utility (Rosa and Bonnet 1991). Control room operators doing sedentary, mentally-demanding tasks, and field operators doing

active, physically-demanding tasks, served as subjects. Comparisons of a 12 h/2–4 day shift rotation to the original 8 h/5–7 day shift rotation were made after 10 months of adaptation to the 12 h shift schedule. Decrements in performance and alertness, attributable to the extra 4 h on-shift, were observed. These decrements were especially apparent on the night shift.

At the other worksite, the test battery was used to compare an 8 h/5–7 day shift rotation to a 12 h/3–4 day shift rotation in a group of control-room operators at a continuous processing plant. In our initial evaluation, after 7 months on the 12 h shift schedule, we observed poorer test performance and increased subjective fatigue on 12 h shifts compared to 8 h shifts (Rosa et al. 1989). In addition, daily sleep logs kept by each operator indicated a mild sleep debt by the end of the 12 h/3–4 day workweek. Test battery scores, however, did not deteriorate across the workweek, which suggested day-to-day recovery from the fatigue of the longer workday.

In the present report, we describe a 3·5 year follow-up study of the control-room operators at the continuous processing plant noted above. Such long-term evaluations of adaptation to a work schedule are rare, and we know of none attempting to measure on-the-job fatigue or alertness in association with extended workshifts. The importance of long-term follow-up study of work schedules is illustrated by Ivancevich and Lyon (1977). In their comparison of a 4 day, 40 h compressed workweek to a 5 day, 40 h conventional workweek, they observed increased ratings of satisfaction and productivity, and decreased ratings of anxiety and stress, after 13 months on the compressed work schedule. After 25 months, however, these differences were no longer observed. These results suggest that psychological responses to a work schedule can extend far beyond the 7 month observation period of our initial evaluation. The possibility of long-term work schedule effects points to the value of the 3·5 year follow-up described in the present report.

2. Method

2.1. Measurements

2.1.1. NIOSH Fatigue Test Battery: The computerized test battery is a flexible system designed to evaluate a range of psychological functions including cognitive, perceptual–motor, and motor skills, as well as subjective alertness or fatigue. The tasks are brief to minimize interference with the worker's regular job. Any number of tests can be selected as general performance measures or as analogues to specific job demands. Details about the components of the battery and its development are reported in Rosa and Colligan (1986, 1988) and Rosa et al. (1985).

The same set of measures were used in all phases of the study (see Rosa et al. 1989). To evaluate cognitive abilities, we included a 3 min test of mental arithmetic (a digit-addition task adapted from Williams and Lubin 1967), and a 4 min dual task consisting of grammatical reasoning combined with auditory reaction time. (The reasoning component of the dual task was based on Baddeley's [1968] test, except that response time was measured for each conditional statement rather than for the entire test.) Four minutes (60 trials) of simple auditory reaction time (adapted from Lisper and Kjellberg 1972), and a 2 min hand steadiness task were included as more general indices of alertness and fatigue. A self-reported measure of sleepiness (Hoddes et al. 1973) also was recorded. Data from the digit-addition task will not be reported because the task was revised after testing on the 8 h shift schedule (see Rosa et al. 1989).

2.1.2. Daily sleep and habits questionnaire: A questionnaire containing items about sleep and

other personal factors potentially affected by shiftwork (see Johnson *et al.* 1981, Rutenfranz *et al.* 1977, for reviews) was given at the beginning of every workshift. The workers were queried on their times of retiring and arising (including nap times), sleep latency, number of awakenings, and depth and quality of sleep (see Bonnet and Johnson 1978) for the 24 h period immediately preceding the workshift. The workers also gave their subjective evaluation of psychological stress and gastro-intestinal state, and reported personal schedule adjustments attributable to shiftwork (including adjustments of mealtimes, exercise periods, and absenteeism).

2.2. Subjects

Control panel and computer monitoring were the main activities required of the study participants. Cognitive/problem-solving functions and maintenance of attention were the primary task factors associated with these activities. Physical demands were light. Subjects selected for the present analysis had participated in all phases of the project. These phases included testing on the 8 h shift schedule, and testing after 7 months and 3·5 years on the 12 h shift schedule. Fifteen subjects (14 male, ages 28–41) completed the NIOSH Fatigue Test Battery at all test phases. A total of 674 observations were obtained from these subjects. Twenty subjects (18 male, ages 26–41) completed the questionnaire at all test phases. A total of 571 observations were obtained from these subjects. Participation in the study was strictly voluntary. Pseudonyms unique to each subject were used on all tests and scales to preserve anonymity.

2.3. Work schedules

The 8 h and 12 h rotating shift schedules are illustrated in figure 1. Under the 8 h schedule, operators often worked up to 7 consecutive days, while under the 12 h schedule, they typically worked 3 or 4 consecutive days. Training/support days were 8 h day shifts 0730 to 1600 h) regardless of schedule. Shift times under the 8 h schedule were: 0730 to 1600 h (1st or day shift), 1530 to 2400 h (2nd or evening shift), and 2330 to 0800 h (3rd or night shift). Shift times under the 12 h schedule were: 0630 to 1900 h (day shift) and 1830 to 0700 h (night shift).
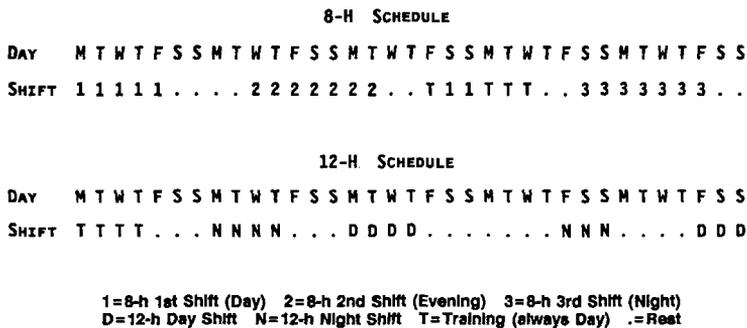
8-H SCHEDULE

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DAY    M T W T F S S M T W T F S S M T W T F S S M T W T F S S M T W T F S S
SHIFT  1 1 1 1 1 . . . . 2 2 2 2 2 2 2 . . T 1 1 T T T . . 3 3 3 3 3 3 . .
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12-H SCHEDULE

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DAY    M T W T F S S M T W T F S S M T W T F S S M T W T F S S M T W T F S S
SHIFT  T T T T . . . N N N N . . . D D D D . . . . . . . . . N N N . . . . D D D
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1 = 8-h 1st Shift (Day)   2 = 8-h 2nd Shift (Evening)   3 = 8-h 3rd Shift (Night)
D = 12-h Day Shift   N = 12-h Night Shift   T = Training (always Day)   . = Rest

Figure 1.   8 h and 12 h rotating shift schedules for a typical crew. Note: *Five crews with staggered shift cycles are required to completely staff the continuous operation.*

2.4. Test schedule

Data are reported from three test phases. The first phase occurred during the final 5 weeks of the 8 h schedule. The second phase occurred after approximately 7 months on the 12 h

schedule, and lasted 10 weeks. The third phase occurred after approximately 3·5 years on the 12 h schedule, and lasted 6 weeks.

Test battery performance was sampled on all shifts under both the 8 h and 12 h schedules. Our original test schedule was designed so that the beginning, middle, and end of each workshift or workweek could be compared. In practice, however, test times varied considerably because of job demands and worker preferences.

2.5. Procedure
Six microcomputers for administering the test battery were distributed in accessible places in the plant. These computers controlled the instructions for, and presentation of, all tasks and scales, and also stored all data. Because the test battery was designed for ease of use by the average person, a brief introduction to the computers and test battery was the only experimenter intervention required before regular testing began. During regular testing, the subject sat before the computer console and typed a simple command to begin the battery.

2.6. Test battery data analysis
2.6.1. *Data transformations*: Several dependent variables in the test battery were transformed to approximate the normal distribution (see Myers 1979: 72–73). Grammatical reasoning response time, dual reaction time, and simple reaction time were transformed to their inverses. Proportion scores, including grammatical reasoning errors, dual and simple reaction time misses, and hand steadiness time off-target, were transformed to the arcsine of their square roots.

2.6.2. *Stepwise regression analysis*: A multiple regression approach was chosen to (i) simultaneously test several correlated parameters assumed to affect subject responses; and (ii) partition variance attributable to practice (i.e., 'de-trend' the data). These considerations, along with the fact that subject participation rates were highly variable, made the regression approach more desirable than the traditional analysis of variance requiring independent treatment effects and equal cell frequencies. By using the regression approach, we violated the statistical assumption of independence of observations, and we recognize the potential for biased significance tests. We consider this approach to be the most economical way to express the data, however, so we have accepted the possibility of greater bias to obtain more statistical power.

A separate regression equation was calculated for each dependent variable in the test battery. The following variables, assumed to affect performance or alertness, were entered stepwise into each regression equation:

(a) Test phase.
(b) Number of hours worked or time on-shift.
(c) Consecutive days worked.
(d) Circadian rhythm: This variable was determined by the cosine curve fitting method of Naitoh *et al.* (1985). With this method, a sinusoidal 24 h rhythm is calculated from a weighted combination of the sine and cosine of time.
(e) The two-way interactions among the above variables. Separate terms were entered for interactions with the sine and cosine of time.
(f) Practice: Because we had only short notice before implementing the study, there was no opportunity for the workers to practice the tasks before the first test phase. Thus, they were not at an asymptotic level of performance before critical testing

began. To partition variance attributable to practice, both linear and curviliner practice effects were entered in the regression equation. When significant practice effects were obtained, this procedure 'de-trended' the data and clarified effects from other variables. Several possible practice curves were entered in the regression analyses to maximize the possibility of obtaining a 'best-fit' practice effect. The stepwise regression approach determines statistically the practice effect (or effects) which partition(s) the greatest portion of variance.

The linear effect entered in the regression equation was the cumulative number of times the test battery was taken at the time of a particular observation (i.e., number of repetitions). The curvilinear effect was the natural logarithm of this value. A third practice effect was modelled by accumulating the number of repetitions through the first and second test phase, and then resetting this counter to 1 before the third test phase. The third practice curve allowed for the possibility of completely forgetting the test battery in the three years between the second and third test phases.

(g) Dummy codes for subjects also were included in the model to partition variance attributable to individual differences. These codes were entered in the model before stepwise analysis of the other effects.

2.7. *Questionnaire data analysis*

Because of variable participation rates, stepwise regression also was used to test for shift and workday differences in the questionnaire. The parameters entered stepwise into each equation included the 8 h second and third shifts and the 12 h day and night shifts from each test phase (all tested against the 8 h first [day] shift), consecutive days worked, and the interaction of consecutive days worked with each shift at each test phase. Codes for subjects were included in the model to partition variance attributable to individual differences.

An alpha level of $p < 0.05$ was considered statistically significant in all analyses.

3. Results

3.1. *NIOSH fatigue test battery*

Table 1 lists significant effects from the regression analysis along with a brief description of each effect. The descriptions in the table characterize each effect with the variance from all other effects held constant.

Examples of the time-based interdependence of these effects are shown in figures 2–4. The scores plotted in these figures were derived from the regression equations to conform to the 8 h and 12 h shift schedules used at the worksite. Values for test phase, time on-shift, sine and cosine of time, and practice were inserted in the regression equations when these effects were statistically significant for a particular dependent variable. The median level of 43 repetitions of the test battery was used when a practice effect was statistically significant.

Figure 2 shows percentage of errors in the grammatical reasoning task as a function of the 8 h and 12 h shifts. On day and night shifts in general, error rate increased as a function of time on-shift. Errors were more frequent in the early evening at the end of the 12 h day shift compared to the 8 h second (evening) shift. They were also more frequent in the early morning at the end of the 12 h night shift as compared to the 8 h third (night) shift. No differences in errors were observed between the 7 month and 3·5 year test phases of the 12 h shift schedule. Grammatical reasoning response time, however, increased from

Table 1.   Significant regression effects from the fatigue test battery.

Dependent variable (intercept) significant effects	Nature of the effect
Grammatical reasoning RT (4·57 s)	
Test phase 2 vs phase 1	0·48 s slower in phase 2
Test phase 3 vs phase 1	1·57 s slower in phase 3
Phase 2 by sine of time	Circadian rhythm in phase 2, slower at night
Phase 2 by cosine of time	Circadian rhythm in phase 2, slower at night
Practice	Improvement
Grammatical reas. errors (10·93%)	
Time on-shift	0·30% more errors per hour
Time on-shift by cosine of time	Decreased amplitude with time on-shift
Practice	Improvement
Dual reaction time (379 ms)	
Test phase 2 vs phase 1	64 ms slower in phase 2
Time on-shift	3 ms slower per hour
Time on-shift by sine of time	Increased amplitude with time on-shift
Phase 2 by cosine of time	Circadian rhythm in phase 2, faster at night
Practice	Improvement
Dual reaction time misses (0·07%)	
Test phase 2 by time on-shift	0·017% more misses per hour
Test phase 3 by time on-shift	0·014% fewer misses per hour
Time on-shift by sine of time	Increased amplitude with time on-shift
Simple auditory reaction time (124 ms)	
Test phase 3 vs phase 1	3 ms faster in phase 3
Time on-shift	1 ms slower per hour
Sine of time	Circadian rhythm, slower at night
Phase 3 by cosine of time	Circadian rhythm, faster at night
Simple reaction time misses (0·11%)	
Test phase 2 vs phase 1	0·24% more misses in phase 2
Test phase 2 by time on-shift	0·03% more misses per hour in phase 2
Hand steadiness (13·2%)	
Test phase 2 vs phase 1	5·6% more steady in phase 2
Phase 3 by time on-shift	0·4% less steady per hour in phase 3
Time on-shift by sine of time	Increased amplitude with time on-shift
Practice	Improvement
Subjective sleepiness (2·28; 1 = least sleepy, 7 = most sleepy)	
Time on-shift	0·10 more sleepy per hour
Cosine of time	Circadian rhythm, more sleepy at night
Sine of time	Circadian rhythm, more sleepy at night
Time on-shift by sine of time	Increased amplitude with time on-shift
Time on-shift by cosine of time	Decreased amplitude with time on-shift

the 7 month to the 3·5 year test phase, and both of these values were significantly longer than that observed on the 8 h shift schedule (0·48 s slower in phase 2; 1·57 s slower in phase 3).

Figure 3 shows dual reaction time for the 8 h shifts (phase 1) and the 12 h shifts at 7 months (phase 2) and 3·5 years (phase 3). Dual reaction time was slower on 12 h shifts compared to 8 h shifts, and slowest overall after 7 months of 12 h shifts.
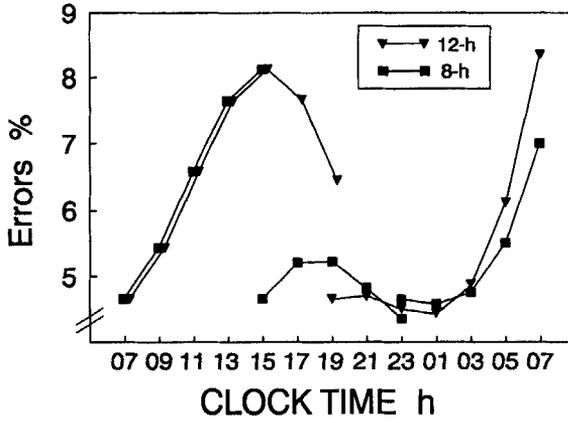
Figure 2.   Grammatical reasoning errors for each 8 h and 12 h shift. Note: 8 h and 12 h day shifts overlap. 12 h shift scores at 7 months and 3·5 years did not differ.
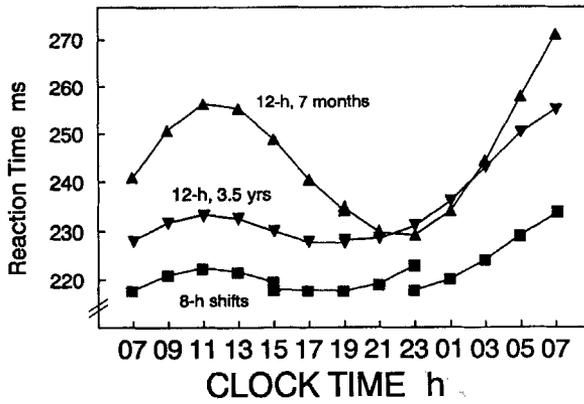

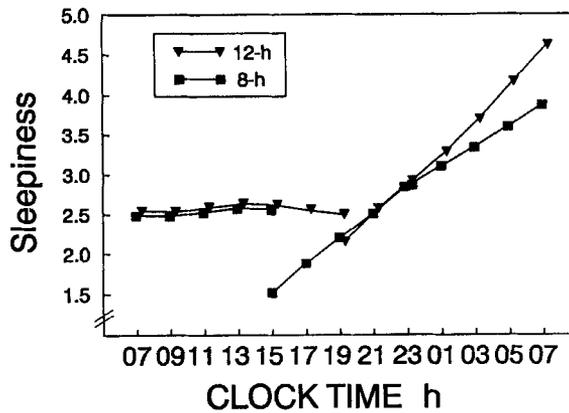Figure 3.   Dual reaction time for each shift at each test phase.

Figure 4.   Subjective sleepiness for each 8 h and 12 h shift. Note: 8 h and 12 h day shifts overlap. 12 h shift scores at 7 months and 3·5 years did not differ.

Figure 4 shows subjective sleepiness as a function of the 8 h and 12 h shift. Sleepiness increased across both 8 h third shift and 12 h night shift, with the greatest increase observed on the 12 h night shift. No differences in sleepiness were observed between the 7 month and 3·5 year test phases of the 12 h shift schedule.

3.2. *Daily sleep and habits questionnaire*

Table 2 lists significant effects from the regression analysis for selected dependent variables in the questionnaire. Brief descriptions of these effects also are listed in the table. In comparison to the 8 h first (day) shift, notable sleep effects shown in the table include longer sleep latencies after 12 h day shifts, and more awakenings from sleep after 12 h night shifts (regardless of test phase). In addition, the shortest total sleep times were evident early in the week of 12 h night shifts at the 3·5 year test phase (despite more frequent napping). Stress ratings were lower on 12 h day shifts compared to 8 h first shifts, but these ratings increased across the workweek. Gastrointestinal distress was rated higher on 12 h day shifts at the 3·5 year test phase compred to 8 h first shifts. Scheduling of exercise, social events, and mealtimes (not shown in table 2) were disrupted more on 12 h shifts than on 8 h shifts.

Table 2. Significant regression effects from the daily sleep and habits questionnaire.

Dependent variable (intercept) significant effects	Nature of the effect
Sleep latency (7·61 min)	
Day shift, phase 3	6·85 min longer
Day shift, phase 2	11·15 min longer
Day shift, phase 2 by workday	1·55 min shorter per day
Evening shift by workday	0·49 min longer per day
Day shift, phase 3 by workday	0·92 min shorter per day
Number of awakenings (0·58)	
Night shift, phase 2 by workday	0·09 more awakenings per day
Night shift, phase 3 by workday	0·05 more awakenings per day
Total sleep time (6·33 h)	
Night shift, phase 3	2·50 h shorter
Night shift, phase 3 by workday	0·79 h longer per day
Nap frequency (25·3%)	
Day shift, phase 2	22·2% less frequent
Day shift, phase 3	22·1% less frequent
Night shift, phase 2 by workday	5·2% less frequent
Night shift, phase 3 by workday	12·1% less frequent
Night shift, phase 3	24·1% more frequent
Evening shift	13·3% less frequent
Self-reported stress (5·74; 1 = stressed, 9 = relaxed)	
Day shift, phase 2 by workday	0·82 units increased stress per day
Day shift, phase 2	1·42 units less stress
Day shift, phase 3	1·26 units less stress
Day shift, phase 3 by workday	0·34 units increased stress per day
Gastrointestinal distress (6·92; 1 = nauseated, 9 = fine)	
Evening shift	0·64 units less distress
Day shift, phase 3	0·29 units more distress

4. Discussion

Long-term follow-up testing of the control room operators revealed decrements in test battery performance and alertness that were still attributable to the 12 h shift schedule. After controlling for practice effects, grammatical reasoning response time was slowest, and time off-target for the hand steadiness test was greatest at the 3·5 year test phase (see table 1). Poorer performance or alertness at certain times on 12 h shifts was evident in other test battery measures when data from the second test phase (7 months) and the third test phase (3·5 years) were combined. Grammatical reasoning errors were more frequent (figure 2), dual reaction time was slower (figure 3), and subjective sleepiness was higher (figure 4) on 12 h night shifts (combined phases 2 and 3) compared to 8 h third shifts (phase 1). Between the first and third test phases, improvements in test performance were apparent for simple reaction time and dual reaction time misses (see table 1).

Overall, the results suggest that test performance and alertness were generally lower after 12 h than after 8 h shifts. The lowest scores were evident at the end of the 12 h night shifts. This was the conclusion in our initial report on this worksite (Rosa *et al.* 1989), and in our report on the natural gas utility (Rosa and Bonnet 1991). Over three years of working 12 h shifts at the present worksite has not altered this conclusion substantially. Also consistent with our previous report on the present worksite is the lack of observed decrements in performance or alertness across the workweek. Those results suggest the possibility of day-to-day recovery from the extended workshift. Another possibility, however, is that the operators began the workweek at a low level of performance and remained at that level throughout the week. Neither possibility can be stated with certainty without the opportunity to test the operators on off-duty days.

The results from the daily sleep and habits questionnaire (see table 2) also indicated more disruptions on the 12 h shift schedule (test phases 2 and 3) compared to the 8 h shift schedule (test phase 1). Little improvement or adaptation over 3·5 years was apparent in any of the questionnaire measures. The only improvement associated with 12 h shifts was in self-reported stress which, early in the workweek, was rated lower on 12 h day shifts compared to 8 h day shifts.

Of notable concern in the questionnaire results was reduced total sleep time after night shifts at the 3·5 year test phase. Similar reductions in sleep time were observed at the natural gas utility after 10 months on the 12 h shift schedule. In the laboratory, these levels of sleep loss have been associated with increased sleepiness and decrements in performance (Carskadon and Dement 1981, Webb and Agnew 1974). It is possible, then, that this partial sleep deprivation contributed to reduced alertness on the 12 h night shift. The reduced sleep time observed in both worksite studies indicates a need for workers to make an effort to obtain more sleep during the workweek, even at the expense of other activities.

Despite measurable increases in fatigue while working 12 h shifts, we are not aware of major adverse incidents over the past 3·5 years that can be attributed, at least anecdotally, to operator fatigue during these shifts. Without a systematic analysis of plant accidents and incidents over the past 3·5 years, however, we can not verify the anecdotal reports. An analysis of accidents and incidents away from the job also would be informative. We have little knowledge of the extent to which workplace fatigue affects safety outside of the workplace.

The popularity of the compressed workweek with both management and the control room operators suggests that the present work schedule will continue indefinitely. Among other reasons, management is in favour of the present system because they expect a popular work schedule to reduce attrition. Retention of experienced workers is considered an

advantage because of reduced training costs, and because experienced workers are assumed to work more safely and efficiently than inexperienced workers. The operators favour the present work schedule because of the extra days off-duty, especially the extra 7 consecutive days off-duty that occur during each 5 week work cycle (see figure 1). They admit to feeling more fatigued, but they are willing to tolerate it to derive other benefits.

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