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REVIEW OF CRITERIA FOR ASSESSING SHIFT SCHEDULES IN THE NUCLEAR INDUSTRY

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EXECUTIVE SUMMARY

The CNSC is planning to formalize their fatigue management and hours of work requirements in a regulatory document intended for use by licensees of nuclear power plants and facilities. The CNSC currently specifies mandatory rest periods and limits to hours of work that are based on criteria originally developed in 1989 and later updated in 2005. Accordingly, it is important to review the existing 2005 criteria and to identify any opportunities for improvement, in terms of current research, evidence-based best practices, and benchmarks.

Human Factors North Inc. (HFN) was contracted by the CNSC to conduct research to identify gaps between the 2005 criteria and current scientific evidence and benchmarking related to hours of work and managing fatigue. The specific project objectives were to: update the review of the literature; compare the existing 2005 criteria to current science and benchmarking on hours of work and managing fatigue; identify opportunities for improving the existing 2005 criteria; and make recommendations for improving the existing 2005 criteria that are supported by findings from benchmarking and the review of the literature.

Research and unpublished "grey" literature, including regulatory documents, for the period 1995 to November 2012 were searched. The search strategy included a variety of search terms relating to shift work, hours of work and rest, and scheduling. Some of the literature reviewed referred to recommendations made by various industry organizations regarding hours of work and rest. Comparisons were made between the 2005 criteria and these benchmarks in order to generate best practice guidelines and recommendations for the Canadian nuclear industry. Project objectives were to answer five broad research questions. The questions and their answers are summarized below:

1. **Are the hours of work limits and mandatory rest periods in the 2005 criteria (see Appendix – 2005 Hours of Work Limits and Mandatory Rest Periods) aligned with current science and benchmarking?**

   Yes, with the exception of the following:

   a) The maximum night shift (i.e. a shift including the period between midnight and 5:00 a.m.) duration should be 12 hours; otherwise, a day shift could be extended to 16 hours in a 24-hour period. (Original limit allowed 16 hours in 24 hours on rare occasions with no restriction to day shifts.)

   b) The number of hours worked in a 48-hour period shall not exceed 26. (Original limit was 28 hours.)

   c) The maximum number of hours worked in a 7-day rolling period shall not exceed 60. (Original weekly limit was not a rolling limit.)

   d) Work hours should be limited to 260 hours for a 5-week cycle. (Original limit was 268 hours for a 5-week cycle.)

   e) For the purpose of determining compliance with the limits, all time should be included from the time that the worker reports to work until the time that the worker is relieved from all responsibility for work, including unpaid lunch or rest breaks, with the exception of

restorative naps (with guidance as to appropriate conditions for naps to be established). (Original limit was not to make an exception of naps.)

f) For blocks of 12-hour shifts,

   a. A minimum recovery period of 48 hours shall follow a block of 5 consecutive day shifts, excluding shift turnover time (original limit was to have 48 hours recovery after 3 consecutive day shifts.)

   b. Due to lack of specific studies supporting such a requirement, no minimum recovery period was specified after a block of 3 or 4 consecutive day shifts or after a block of 2 consecutive night shifts.

A block, sometimes called a "workset", is defined as a set of consecutive shifts with the same start and end times, that is followed by a minimum recovery period and a subsequent set of consecutive shifts.

2. The current limits on hours of work apply to a day, week, shift cycle, and year. Should limits be set for other time frames?

At this time, there is no scientific evidence to suggest that limits for time frames other than those mentioned above are required.

3. What mandatory rest periods and limits to consecutive shifts should be applied to those working 8-hour or 10-hour day, evening and/or night shifts?

For 10-hour shifts, the recommended maximum is 5 consecutive day shifts or 4 consecutive night shifts. (Original limits did not include mandatory rest periods following a block of 10-hour shifts.)

   a. A minimum recovery period of 48 hours shall follow a block of 5 consecutive day shifts, excluding shift turnover time.

   b. A minimum recovery period of 72 hours shall follow a block of 3 or 4 consecutive night shifts, excluding shift turnover time.

For 8-hour shifts, the recommended maximum is 6 consecutive day or evening shifts or 5 consecutive night shifts. (Original limits did not include mandatory rest periods following a block of 8-hour shifts.)

   a. A minimum recovery period of 36 hours should follow blocks of either 5 or 6 consecutive day or evening shifts, excluding shift turnover time.

   b. A minimum recovery period of 48 hours should follow blocks of either 4 or 5 consecutive night shifts, excluding shift turnover time.

   c. A forward direction of shift rotation should be used for those individuals working 8-hour shifts.

4. Is there any basis for granting exceptions to the hours of work limits or rest periods for short durations at times of peak demand? (If yes, recommend evidence-based, permissible exceptions to the hours of work limits or rest periods and the duration of these exceptions.)

It should be noted that working at the limits for hours of work and rest is not sustainable and may lead to chronic sleep debt. Without decreasing safety, there is no scientific basis for allowing exceptions to the hours of work limits or rest periods.

5. **Using evidence from benchmarking and research, what fatigue management provisions, including hours of work limits and mandatory rest periods, are appropriate during construction of a facility that will require high reliability operations, such as a nuclear power plant?**

   Individuals who perform construction work on safety relevant facilities should be covered under the same CNSC hours of work regulations as power plant operators or others with safety sensitive roles.

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1 INTRODUCTION

1.1 Background

Human factors and performance issues are important safety considerations relevant to any complex system. Within the nuclear industry, impaired performance of power plant operators, as well as others with safety sensitive roles, can lead to serious consequences in terms of health, safety, and security. The Canadian Nuclear Safety Commission (CNSC), established in 2000, regulates the use of nuclear energy and materials in Canada. Like its predecessor, the Atomic Energy Control Board (AECB), the CNSC is responsible for the protection of Canadians' health, safety, and security from unsafe nuclear energy practices.

Various forms of fatigue (e.g., muscular, mental, psychomotor, chronic), and fatigue risk factors (sleep deprivation, sleep debt, circadian variability, time awake, health factors, environmental issues, and workload) have been identified in the research literature (Lerman, Eskin, Flower, George, Gerson, Hartenbaum, Hursh, & Moore-Ede, 2012), as have various causes (e.g., noise, light, physical discomfort, pain, stress, depression, alcohol and other drugs, work time, and sleep disorders) (Dinges, 2012). Performance impairments among workers in safety sensitive roles that result as a consequence of fatigue are widely recognized as safety concerns by human factors researchers and practitioners alike. It is important, therefore, to consider the direct effects of fatigue on performance measures in any consideration of shift work scheduling characteristics. Further, performance decrements associated with shift work-related fatigue are established as significant risk factors and predictors of occupational accidents and injuries (Dawson et al., 2011). Consequently, it is useful to also consider the effects of shift work and its features on rates of occupational accident and injuries, as a surrogate measure of performance impairments. These impairments can include, for example, slowed reaction time, reduced vigilance, impaired decision-making ability, poor judgment, distraction, and loss of awareness in critical situations (Lerman et al. 2012). In extreme cases, excessive fatigue can lead to falling asleep. Because of the possibility of these various impairments, many safety-sensitive industries, including nuclear, have requirements designed to minimize the likelihood for on-duty workers becoming excessively fatigued. These requirements often include maximum and minimum time periods for workers' hours of work and rest.

The CNSC currently specifies mandatory rest periods and limits to hours of work at nuclear power plants with the aim of minimising the likelihood for fatigue among workers. The present criteria, originally developed in 1989 and later updated in 2005 ("Proposed objectives and criteria for hours of work in Canadian nuclear generating stations", or "the 2005 criteria" – see Appendix), are based on earlier research and literature review undertaken on behalf of the AECB (Smiley & Moray, 1989; Kulp, 1999), and stipulate criteria such as the nature of rest – or recovery – periods between shifts, acceptable amounts of overtime, the normal length of shifts, maximum numbers of hours in various time periods, and the direction of shift rotation. The 2005 criteria do not address the direction of shift rotation.

1.2 Project Scope and Research Questions

The CNSC is planning to formalize their fatigue management and hours of work requirements in a regulatory document intended for use by licensees of nuclear power plants and large research reactors. Accordingly, it is important to review the existing 2005 criteria and to identify any opportunities for improvement, in terms of current research, evidence-based best practices, and benchmarks.

Human Factors North Inc. (HFN) was contracted by the CNSC to conduct research to identify gaps between the 2005 criteria and current scientific evidence and benchmarking related to hours of work and managing fatigue. The specific project objectives were to:

- Update the review of the literature;
- Compare the existing 2005 criteria to current science and benchmarking on hours of work and managing fatigue;
- Identify opportunities for improving the existing 2005 criteria; and
- Make recommendations for improving the existing 2005 criteria that are supported by findings from benchmarking and the review of the literature.

The project objectives were developed to answer the following five research questions:

1. Are the hours of work limits and mandatory rest periods in the 2005 criteria aligned with current science and benchmarking?
2. The current limits on hours of work apply to a day, week, shift cycle, and year. Should limits be set for other time frames?
3. What mandatory rest periods and limits to consecutive shifts should be applied to those working 8-hour or 10-hour day, evening and/or night shifts?
4. Is there any basis for granting exceptions to the hours of work limits or rest periods for short durations at times of peak demand? (If yes, recommend evidence-based, permissible exceptions to the hours of work limits or rest periods and the duration of these exceptions.)
5. Using evidence from benchmarking and research, what fatigue management provisions, including hours of work limits and mandatory rest periods, are appropriate during construction of a facility that will require high reliability operations, such as a nuclear power plant?

2 METHOD

The aim of the literature search was to update and augment the earlier reviews conducted on behalf of the AECB in 1989 (Smiley and Moray 1989) and 1999 (Kulp 1999). Therefore, the literature search was developed to identify research reports and review publications in the area of shift work, fatigue management, and hours of work that had been published since 1995, including those published up until November 2012 and available within the databases.

2.1 Search Strategy

2.1.1 Search terms used and their selection

A number of search terms were put forward by the research team and the most relevant terms were selected. The search terms included:

- “Shiftwork” or “shift work” or “hours of work” or “hours of work and rest” or “hours of service” or “circadian rhythms” and “overtime”, “recovery periods”, “rest periods”, “exceptions”, “night work”, “shift length”, “sleep quality”, “sleep length”, “sleep duration”, “performance”, “workload”, “fatigue”, “sleepiness”
- ADD “work week”
- ADD “working time arrangements”
- NOT “health”

2.1.2 Databases searched

Literature available through MedLine and PsycInfo bibliographic databases for the period 1995 to November 2012 was searched. MedLine is the bibliographic database of the U.S. National Library of Medicine, and covers the fields of medicine, nursing, dentistry, veterinary medicine, the health care system, and pre-clinical sciences. MedLine contains bibliographic citations and author abstracts from approximately 5,000 biomedical journals published in the United States and in over 70 other countries. PsycInfo is a database of the American Psychological Association, which consists of abstracts of scholarly journal articles, book chapters, books, and dissertations, and is the largest resource devoted to peer-reviewed literature in the behavioural sciences.

2.1.3 Grey literature

“Grey” literature is defined as research reports, regulatory documents, and other articles that may not be peer-reviewed, but are available either through the Internet or directly from regulatory organizations. Grey literature was identified through several means, including through the CNSC project manager, through the project team’s national and international contacts in transportation and human factors, and through an online search of the search terms listed above.

2.1.4 Benchmarking

Some of the literature reviewed – both published and grey – refers to recommendations made by various organizations (e.g., European Community Directive on Working Time, European Aviation Safety Agency, U.S. Nuclear Regulatory Commission) regarding hours of work and rest. Comparisons were made between the 2005 criteria and these benchmarks in order to generate best practice guidelines and recommendations for the Canadian nuclear industry.

2.1.5 Prioritization of literature

The search of MedLine and PsycInfo databases yielded 110 relevant articles. In order to stay within project time and budget constraints, priority was given to peer-reviewed publications of literature reviews, meta-analyses, recommendations based on the scientific evidence, as well as field or laboratory studies dealing with issues such as performance or safety impacts of specific shift schedule features such as length of individual shifts, number of shifts in a sequence, etc. Articles dealing with individual differences (morningness/eveningness) or with health impacts were, for the most part, not reviewed unless the health impacts were also related in some way to safety and performance. In addition, grey literature concerning shift schedule recommendations in various industries including nuclear, aviation, road transport, and industrial, was reviewed. The final reference list comprises 88 peer-reviewed journal articles, reports, and regulatory documents.

3 RESULTS

Research literature identified through database searches, as well as grey literature identified by the CNSC project manager and the research team members, was prioritized by the study team. Those documents categorized as being of high priority and relevance were subsequently scrutinized for their applicability to the 2005 criteria. The research literature presented and discussed below in Sections 3.1 and 3.2 addresses Research Question 1: Are the hours of work limits and mandatory rest periods in the 2005 criteria aligned with current science and benchmarking?

3.1 Limits on Hours of Work

The practice of limiting the number of hours a worker works is based on the belief that increased work duration results in negative effects on performance, including that related to safety. Often performance is measured using tests designed to simulate work tasks or which involve skills that are typically regarded as being essential to such tasks; for example, attention. Spurgeon et al. (1997), in a review of the health and safety problems associated with long working hours (or overtime), emphasize that the extent of impairment of performance in any given situation is far more complex than previously believed (Spurgeon, Harrington, & Cooper, 1997). The nature of a task—for example, whether it is routine and monotonous or complex and stimulating, the motivation of the person, and the presence or absence of other stressors are all determinants of performance impairment which occur over and above any contribution of work hours. It is important for those involved in shift work scheduling and fatigue management to appreciate the complex nature of the relationship among fatigue, performance, and other contributory factors – particularly biological factors such as circadian rhythms. It is equally important for shift work and fatigue management best practices to be based on principles that incorporate an understanding of this complexity.

The European Community Directive on Working Time (European Community, 2003) was introduced to protect European workers' health and safety. It contains several requirements related to working hours, including most notably a limit to weekly working time, which must not exceed more than 48 hours per week on average, including any overtime. While the EU weekly work time requirement applies to all employees regardless of the nature of their work, safety sensitive employment roles are addressed only insofar as they entail the requirement to work night work. In their review of the literature pertaining to health and performance effects of extensions to the working day, Spurgeon et al. (1997) conclude that most shift work studies tend to support the view that safety is more likely to be compromised during the night shift, particularly where night work is coupled with extended hours, or overtime. The European Directive defines night work as any period of not less than seven hours, which includes the period between midnight and 5:00 a.m. **For night work**, the European Directive recommends that:

- Average working hours must not exceed eight hours per 24-hour period
- Night workers must not perform heavy or dangerous work for longer than eight hours in any 24-hour period
- There should be a right to free health assessments and, in certain situations, to transfer to day work.

Operational shift work systems used in applied settings around the world are commonly based on the assumption that levels of fatigue amongst workers can be predicted based on work schedules, and that the safety risks associated with fatigue-related performance decrements can therefore be managed by quantifying and scheduling employees' hours of work and by providing periods of rest that are adequate to restore alertness. These assumptions reflect the tenets of what are known as "bio-mathematical models" of fatigue. These data-driven models apply what is currently known with regards to interactions among work hours, sleep, and performance, in order to predict, and therefore limit, fatigue and its performance deficits (Dawson, Noy, Härmä, Akerstedt, & Belenky, 2011).

One of the most obvious ways to limit the opportunity for fatigue to develop is to impose limits on the number of hours an employee may work. Limitations on the permissible number of hours that a worker may work formed the basis of the 2005 requirements, and current research and best practices in shift work scheduling continue to reflect this viewpoint. For example, the U.S. Nuclear Regulatory Commission (NRC), in its fitness for duty (FFD) programs requirements, declares that work hours of individuals who have access to protected areas and who perform safety sensitive duties shall be scheduled with the objective of "preventing impairment from fatigue due to the duration, frequency, or sequencing of successive shifts" (NRC, 2012b). Previously in 2001, the NRC reviewed and assessed its own "Policy on factors causing fatigue of operating personnel at nuclear reactors" (NRC, 2001) and determined that a large body of scientific literature demonstrates that long work hours cause fatigue and degraded human performance. Likewise, the European Aviation Safety Agency (EASA, 2008), as part of their Subpart Q – Flight and Duty Time Limitations, stipulates maximum flight duty period limits, as well as limits on other work-related time frames. Similar limitations on hours of work exist in a myriad of Canadian and international industries, including for example, road transport (Transport Canada, 2012; NTC, 2011), aviation (EASA, 2012; NAV Canada, 2012), petrochemical (Fischer, 2004), and medical residents (ACGME, 2011).

The American College of Occupational and Environmental Medicine (ACOEM) recently published a guidance statement from a Presidential Task Force on Fatigue Risk Management in the workplace (Lerman et al. 2012). These authors characterize "hours-of-service" guidelines as an "early" attempt to address fatigue in workers, and assert that there is an increasing realisation that hours-of-service guidelines alone may not achieve the objective of maximizing alertness and an employee's FFD. The task force concludes that, instead, it is critical to also enact comprehensive fatigue risk management systems (FRMSs) that are designed to promote alertness, minimize fatigue, identify evidence of excess fatigue, and mitigate either the fatigue itself or its potential consequences. FRMSs are discussed further in Section 3.4.

3.1.1 Normal shift shall not exceed 12 hours.

The 2005 criteria recommend that a normal scheduled work shift shall not exceed 12 hours plus shift turnover.

3.1.1.1 Scientific Evidence

Spurgeon et al. (1997) note that information from studies of 12-hour shifts in industrial settings does not tend to support the notion that an extended work day contributes to higher occupational accident rates. However, they also note that, because those workers who are scheduled to work 12-hour shifts are commonly provided an extended (beyond eight hours) period of rest, it is likely that studies comparing the accident rates of those working 12-hour versus 8-hour shifts are confounded by differences in rest time duration.

In a systematic review of the experimental (randomized controlled trials, cohort studies, and before-and-after studies) shift work research literature published up until 2006, Driscoll et al. (2007) concluded that 12-hour shifts were neither significantly better, nor worse, than 8-hour shifts in terms of sleep indices or measures of alertness (Driscoll, Grunstein, & Rogers, 2007). However, it is important to note that the statistical power of the studies reviewed was limited, and so it is possible that actual differences in dependent performance measures did exist but were overlooked due to insufficient sample sizes.

Bourdouxhe et al. (1999) studied the effects of over 20 years of rotating 12-hour shifts on petroleum refinery workers in Canada and concluded that, compared to shorter shifts, there were a number of drawbacks of 12-hour shifts, including chronic fatigue, impaired recovery, and sleep disorders (including what is known as “shift worker syndrome” – a constellation of digestive, cardiovascular, and psychological symptoms) among some workers (Bourdouxhe, Quéinnec, Granger, Baril, Guertin, Massicotte, Levy, & Lemay, 1999). Furthermore, the authors concluded that12-hour shift schedules and the resultant fatigue had unfavourable effects on work itself, which in turn was found to impair safety and reliability. Due to the report’s succinct nature and the lack of detail reported by Bourdouxhe and co-authors, it is difficult to assess the reliability and validity of the research methods used.

Twelve-hour shifts in the medical (nursing) domain are associated with more work-related accidents and injuries, such as needle-stick injuries, as well as increased patient care errors, as compared to shifts of shorter duration. A recent experimental study of nurses working blocks of day versus night 12-hour shifts found that intershift sleep duration may underpin these adverse outcomes (Geiger-Brown, Rogers, Trinkoff, Kane, Bausell, & Scharf, 2012). Nurses’ average sleep durations were significantly longer both the day before, and the day after, a block of either three day, or three night, shifts compared to the sleep durations between shifts. This finding suggests that the nurses were achieving an inadequate amount of sleep between shifts to recover physically or cognitively, irrespective of whether they were working during the day or night. The nurses also experienced greater subjective fatigue during the third consecutive shift than during the first two shifts, with night nurses being particularly vulnerable to sleepiness by the end of their shift. Further, reaction times to a vigilance test increased significantly following a 12-hour shift as compared to pre-shift. While the authors note that in 2004 the U.S. Institute of Medicine recommended a maximum shift duration for nurses of 12 hours, the study data suggest that 12 hours per day of work leads to a considerable sleep deficit and consequent performance impairments. The authors were particularly concerned regarding 12-hour night shifts, where inadequate sleep combines with the circadian trough to produce drowsiness. The authors conclude that improving the quantity and quality of sleep for nurses working 12-hour shifts should be a priority, including implementing scheduling and educational interventions, and planned napping.

Working long night shifts is a particular concern for safety. Night shift workers experience shorter sleep durations than day shift workers and more negative safety consequences. A study by Pternitis (1977) (cited in Grandjean, 1982, p.249) of shift workers in a thermal power station found average sleeping times of 6h 3 min, 7h 35 min and 6h 47 min after the night, afternoon and morning shifts, respectively (Pternitis, 1977; Grandjean, 1982). A study by Steele et al. (1999) involved a survey of 957 shift-working emergency medicine residents (Steele & et al., 1999). Motor vehicle crash risk was significantly higher after night shifts than after day shifts (74% vs. 12%), as was the risk of having a near crash (80% vs. 7%). Further, the likelihood of having a crash increased significantly with the number of night shifts that had been worked in a sequence. A study by Gold et al. (1992) found that permanent night shift nurses had 3.6 times the risk of "nodding off" at the wheel while driving to or from work during the previous year as compared to nurses on day or evening shifts (Gold, Rogacz, Bock, Tosteson, Baum, Speizer, & Czeisler, 1992).

A study by Son et al. (2008) of auto workers on 12-hour shift systems of five to seven consecutive shifts used questionnaires and sleep-wake diaries to assess severe sleepiness (Son & et al., 2008). Night shifts and long working hours were the main risk factors for severe sleepiness, with working the night shift increasing the risk of severe sleepiness by a factor of 4.7. Moreover, long working hours in combination with night shift work had a significant interactive effect.

Finally, a prospective study examined the impact of a change to 12-hour shifts (from 8-hour shifts) on objective performance degradation in air traffic controller and nuclear plant workers in Canada compared to the anticipated changes by workers. Negative effects were reported with the extension of working hours to 12 hours (Heslegrave, Reinish, Beyers, Picard, Horbul, Huterer, Jovanovic, Sabanadzovic, Kayumov, Chung, Flint, Hall, & Shapiro, 1999). Interestingly, however, in another study, when both the shift duration and the timing of the night shift were changed to allow more night sleep during the circadian trough (3:00 to 6:00 a.m.), longer shifts showed positive effects (Heslegrave, Reinish, Beyers, Picard, Horbul, Huterer, Jovanovic, Sabanadzovic, Kayumov, Chung, Flint, Hall and Shapiro, 2000).

3.1.1.2 BENCHMARKING

Nuclear/petrochemical

The U.S. NRC, in reviewing the requirements of their 1999 "Policy on factors causing fatigue of operating personnel at nuclear reactors", found that the scientific literature published up until 2001 did not support their policy, which allowed a worker to work up to 16 hours straight (excluding shift turnover time), which was the proposed criteria at the time (NRC 2001). Instead, they recommended that workers be permitted to work a maximum of only 12 consecutive hours per shift. To support this recommendation, they pointed to research showing that the relative risk of having an occupational accident increases dramatically after only nine consecutive hours on the job (Hanecke, Tiedemann, Nachreiner, & Grzech-Sukalo, 1998; Colquhoun, Costa, Folkard, & Knauth, 1996), and other studies in which task performance declined after 12 hours on a task (Folkard, 1997; Dawson & Reid, 1997; Rosa, 1991). Further, they relied on the nine experts who met in 1984 to develop recommendations for the NRC "Policy on shift scheduling and overtime at nuclear power plants", who recommended a time limit of 12 hours per day. Finally, the maximum hours of work per day stipulated by most of the foreign nuclear regulators at the time of the 2001 review (including France, the UK, Japan, Hungary, Spain, and Canada) and most other domestic (to U.S.) safety sensitive industries (including commercial aviation, air force, air traffic control, marine, rail, and road transport) was 12 hours or less.

Parenthetically, it appears that the NRC based their actual shift length recommendation on more practical concerns, as the current U.S. NRC FFD programs (NRC, 2012a) stipulate that employees' work hours not exceed 16 hours in any 24-hour period. According to the 2001 review, the impracticality of limiting workers to 12 hours of work in any 24-hour period was particularly relevant in terms of potential night shift overtime when a worker was called in unexpectedly. Because the 12-hour limit would require personnel who were working 8-hour shifts to split shifts when working overtime, it would mean that an extra employee would need to be called in the middle of the night to cover the second half of an unexpectedly available night shift.

Because of the similar nature of the work and process controls used, as well as the potential for catastrophic consequences of operator errors in both industries, the American National Standards Institute (ANSI) recommendation made by the American Petroleum Institute (ANSI/API 2010) is of particular relevance to considerations concerning the CNSC criteria. This document stipulates that a normal shift for operators in the petrochemical industry should be a maximum of 12 hours.

Industry in General

Although not making any specific recommendations regarding maximum permissible shift length, the recently published ACOEM Task Force guidance statement on fatigue, Lerman et al. (2012) cited research by Folkard Lombardi, & Tucker (2005) showing that the risk of work-related accidents or injuries increases in an approximately exponential fashion with increasing shift length over eight hours. Interestingly, using data from three relatively recent (2003 – 2004) shift work studies (Folkard & Akerstedt, 2004; Folkard & Lombardi, 2004; Folkard & Tucker, 2003), relative risk indices were calculated based on the occupational incident risk associated with 8-hour shifts. Ten-hour shifts were associated with a 13 per cent increase in risk, while 12-hour shifts were associated with a 27 per cent increase in risk over 8-hour shifts (Folkard et al. 2005).

The European Community Directive on Working Time (2003) recommends a minimum daily rest period of 11 consecutive hours in every 24 and at least one "rest break" during working time, if the worker is on duty for longer than six hours. The proposed normal *day* shift duration of 12 hours would therefore be compliant with the European Directive. On the other hand, the European Directive recommends a regular *night* shift duration of only eight hours in any 24-hour period. The CNSC proposed night shift length of 12 hours, therefore, would not be compliant with the recommendations of the Community Directive, although it is important to note that the Directive does allow derogations from these requirements if the nature of the work requires "continuity of service or production" (Article 17[3]).

Aviation

The European Aviation Safety Agency (EASA) recently reviewed their flight duty time limitation requirements (EASA 2012) and made a number of recommendations. The current daily limit of pilots' flight duty period is 13 hours, a limit that is accepted and commonly used across the European aviation industry. This limit is reduced as a function of the time of day a flight duty period commences, as well as the number of sectors flown. The current method of applying a mathematical formula to calculate maximum flight duty period has been identified by stakeholders as leading to some ambiguity. Therefore, recently proposed legislation would provide a table that would be used to more clearly define the appropriate flight duty period depending on the time of day (within a pilot's circadian cycle) a shift begins, and the number of sectors flown. Flight periods that begin near a pilot’s circadian nadir (low point) would thus have stricter requirements than those that begin after other points in the circadian cycle.

North American work and rest requirements for aviation personnel specify flight times that are shorter than the CNSC shift length recommendation of 12 hours. The U.S. Federal Aviation Administration (FAA) allows flight duty periods (which include non-flying work time) for single crew operations to extend to between nine and 14 hours, and flight time limits (when an airplane is moving under its own power) to extend to eight or nine hours, depending on the time at which a pilot’s work day begins and the number of flight segments that he or she is expected to fly (FAA, 2011). In Canada, pilots are currently allowed to accumulate only eight hours of flight time in any 24 consecutive hours when conducting single-pilot instrument flight rules flights, with a corresponding maximum flight duty period of 14 consecutive hours in any 24 consecutive hours (Transport Canada, 2010). Amendments to flight duty and time requirements in Canada are currently being considered. These amendments, which incorporate the latest developments in sleep research, would bring Canadian requirements in line with U.S. and other international requirements. Changes include limiting daytime flight duty periods to 13 hours and some night time periods to only nine hours, depending on the flight duty period start time (Adamus & Booth, 2012).

The 2005 criteria’s recommendation that a normal scheduled work shift not exceed 12 hours is not in line with requirements of the collective agreement between NAV Canada and the Canadian Air Traffic Control Association (CATCA) (NAV Canada 2012), in which NAV Canada is required to not schedule operating employees to regular shifts other than those which are eight hours and 28 minutes in duration (Section 16.04e[ii]). It is probable that consideration of the high workload and time pressure associated with air traffic control (ATC) duties underpinned the decision to limit air traffic controllers’ regular, scheduled shift duration to only 8.5 hours. Although shift duration is shorter in the ATC field in Canada than in the nuclear industry, the nature of duties carried out by operating employees at nuclear power plants compared to those in ATC may make it acceptable to allow for longer duration regular shifts. However, it is difficult to provide comment without first conducting task analyses of the two roles and comparing the results.

Normal shift length considerations for air traffic controllers in Canada were informed by an earlier tri-partite task force composed of the air traffic controller union (CATCA), the regulator (Transport Canada), and the employer (NAV Canada), with scientific expertise provided to this group. A maximum of 10 consecutive hours per shift for ATC operations was indicated by the literature that was reviewed by the task force and, although a formal hour-based general recommendation for maximum shift length was not made, the task force recommended that NAV Canada review its maximum shift length criteria and “actively apply fatigue management countermeasures when consecutive hours of work will exceed 10 hours”. The task force’s other recommendations (e.g., regarding minimum rest periods) were also associated with exemptions to the NAV Canada/CATCA requirements in a variety of circumstances, e.g. emergency situations or staffing issues. These exemptions were conditional upon the implementation, by NAV Canada, of fatigue management strategies designed to mitigate anticipated fatigue effects. In addition, the concept of “meaningful” breaks was introduced, where a meaningful break was defined as a relief of all air traffic controller responsibility for the break period in order to enhance recovery during breaks

(Mein, Heslegrave, David, Dooling, Fox, & Labrosse, 2001). The reader is referred to Section 3.4 "Other Recommendations" for further discussion of fatigue risk management and naps.

Road Transport

Canadian and Australian road transport and heavy vehicle hours of service rules were consulted. In Canada, drivers of commercial and heavy vehicles who are driving south of the 60th parallel are limited to 13 hours of driving time, and 14 hours of on-duty time, in a day. Those drivers who are driving north of the 60th parallel are limited to 15 hours of driving time and 18 hours of on-duty time (Transport Canada 2012).

Australia introduced heavy vehicle driver fatigue legislation in 2008 that allows for different restrictions on hours of work depending on whether an operator is certified by the National Heavy Vehicle Accreditation Scheme, which specifies standards relating to scheduling and rostering, fatigue knowledge and awareness, responsibilities, and documentation. Under the "Standard Hours" option, in which an operator is *not* accredited, drivers are limited to 12 hours of work time (NTC, 2008c). Under the "Basic Fatigue Management" regime (wherein operators are accredited), a driver can work up to 14 hours in a 24-hour period, but the 24-hour period must contain at least a 7-hour continuous rest break (NTC, 2008b). Finally, under "Advanced Fatigue Management", in which an operator is required to be accredited *and* to comply with ten standards, operators propose their own maximum requirements, which are "specific to the fatigue risks of a particular business". The outer daily work limit (which represents the point at which further work would pose an unacceptable fatigue risk) under this scheme is 16 hours. This limit is based on "robust advice from fatigue experts, and experience from current transport industry practices" (NTC, 2008a).

Table 1: Summary of recommendations and requirements regarding regular shift duration across industries

Industry	Maximum regular shift length	Reference
Nuclear (U.S. and international)	12 hours	NRC (2001)
Petrochemical	12 hours	ANSI/API (2010)
General (EU)	Day shift = 13 hours Night shift = 8 hours	EC Directive (2003)
Aviation (EU)	12 hours	EASA (2012)
Aviation (U.S)	9 to 14 hours (flight duty) 8 to 9 hours (flight time)	FAA (2011)
Aviation (Canada)	14 hours (flight duty) 8 hours (flight time)	Transport Canada (2010)
Air traffic control	8.5 hours 10 hours	NAV Canada (2012) Mein et al. (2001)
Road transport (Canada)	13 hours driving (south of 60°) 14 hours duty time (south of 60°) 15 hours driving (north of 60°) 18 hours duty time (north of 60°)	Transport Canada (2012)
Road transport (Australia)	12 hours (Standard Hours) 14 hours (Basic Fatigue Mgmt)	NTC (2008a-c)

	16 hours (Advanced Fatigue Mgmt)	

Recommendation #1:

Based on the scientific research reviewed and benchmarking to other safety relevant industries, the recommended regular shift limit of 12 hours is reasonable.

3.1.2 Maximum of 16 hours in a 24-hour period

The 2005 criteria recommend that the number of hours worked in a 24-hour period shall not exceed 16 hours, including shift turnover

The scientific evidence reviewed in Section 3.1 in relation to the normal shift length being limited to 12 hours also applies to the limitation on the number of hours worked in a 24-hour period.

3.1.2.1 BENCHMARKING

Nuclear/Petrochemical

The recommendation to limit the number of hours worked in a 24-hour period to 16 is consistent with the U.S. NRC (see Section 3.1.1.2). However, it should be noted that this recommendation is not supported by the majority of scientific evidence or best practices in other countries and industries. As stated above, research reported in NRC (2001) (e.g., Hanecke et al., 1998; Colquhoun et al., 1996) showed the relative risk of having an occupational accident (i.e., an accident at work that is registered with the applicable workers' compensation board and which leads to a worker being absent from work for more than three days) increases dramatically after only nine consecutive hours on the job, and task performance declines after 12 hours on a task (NRC 2001). Further, the recommendation of nine experts who met in 1984 to develop recommendations for the NRC "Policy on shift scheduling and overtime at nuclear power plants" was a 12 hours per day time limit. And again, according to the NRC review (NRC 2001), the maximum allowable hours of work per day reported by most foreign nuclear regulators in 2001 (including France, the UK, Japan, Hungary, Spain, and Canada) and most other safety sensitive industries (including commercial aviation, air force, air traffic control, marine, rail, and road transport) was 12 hours or less.

Without even considering a maximum of 16 hours in 24, it is important to mention that the ANSI/API recommended practice (2010) for fatigue management in the refining and petrochemical industries pointedly notes that "consistently working at the limits (shown in a FRMS, and which are listed in the ANSI/API document) is not sustainable and may lead to chronic sleep debt" (ANSI/API 2010). ("At the limits" would imply 7 night shifts in a row with 2 days off, or 14 shifts in a row during outages.) "The overall FRMS shall be designed to prevent employees from frequently working at or near these limits over the long term." (p.4). This statement is relevant to all maximum limits across the various time periods, from one day to one year.

The ANSI/API recommended practice (2010) stipulates that a normal shift for operators should be a maximum of 12 hours. Extended shifts (i.e., greater than 14 hours) are permitted, but only "when necessary to avoid an unplanned open safety critical position or to accomplish an unplanned safety critical task" (p.5). The document allows for extended shifts of greater than 16 hours; however, there are requirements that these shifts should be managed as per "an established management process" (p.5). The recommended practice specifies that extended work hour shifts shall not exceed 18 hours and that no more than one (1) extended shift longer than 14 hours should occur in a "work set" (series of consecutive work shifts). Interestingly, the ANSI/API (2010) document allows a maximum extended shift duration of only 16 hours for those individuals who normally work 10- or 8-hour shifts (compared to a maximum of 18 hours for those who usually work 12-hour shifts). This recommendation is based on two reasons: 1) that longer blocks of consecutive days are allowed in 10-hour shift work sets, and therefore the risk of cumulative fatigue needs to be carefully managed; and 2) that there is a good operational reason to allow up to 18 hours in 12-hour shift operation to allow for coverage of an unplanned open shift (for example, by covering the first half of an open shift by extending the shift of the prior worker and bringing in the employee working the subsequent shift six hours [half a shift] early), but no such justification exists for 10- or 8-hour shifts. A summary table of the ANSI/API hours of service guidelines is reproduced here (Table 2).

Table 2: Hours of Service Guidelines for 8-, 10-, and 12-hour Shifts (ANSI/API, 2010)

Operational Situation	12-Hour Shift	10-Hour Shift	8-Hour Shift
Maximum Consecutive Shifts (Day or Night) In a Work set			
a) Normal Operations	7 shifts	9 shifts	10 shifts
b) Outages	14 shifts	14 shifts	19 shifts
Minimum time off after a work set			
a) Normal Operations	36 hours	36 hours	36 hours
• Work set of 4 or more night shifts	48 hours	48 hours	48 hours
• After 84 hours or more regardless of day or night	48 hours	48 hours	48 hours
b) Outages	36 hours	36 hours	36 hours
Extended Shifts			
a) Unscheduled maximum shift	18 hours	16 hours	16 hours
b) Time off after shift			
• 10 to 16 hour shift	N/A	N/A	8 hours
• 12 to 16 hour shift	N/A	8 hours	N/A
• 14 to 16 hour shift	8 hours	8 hours	N/A
• >16 to 18 hour shift	10 hours	N/A	N/A
Maximum Number of Extended Shifts per Work set	1	1 for 14 hour shift or 2 for 12 hour shifts or for 3 or more 12 hour shifts, follow 12 hour normal operations guidelines above	2 if greater than12 hours in duration; extended shifts must be non-consecutive. If >2, follow 12 hour normal operations above

General

The European Community Directive on Working Time (2003) recommends a minimum daily rest period of 11 consecutive hours in every 24. The proposed maximum shift duration of 16 hours would thus not be compliant with the European Directive.

Aviation

The EASA (2012) requirements, which specify a maximum flight duty time of 13 hours per day, would allow small extensions of up to one additional hour, and only up to twice per week. However, **no extensions would be allowed for flights that occur at night.** These requirements are significantly more restrictive than the proposed CNSC requirement.

A collective agreement between NAV Canada and CATCA specifies a maximum allowable shift length of 12 consecutive hours (NAV Canada 2012). It allows for shift durations greater than 12 hours duration in an "emergency"; however, "emergency" is not defined. Recommendations from the NAV Canada/TC/CATCA tri-partite task force (Mein et al. 2001) was a maximum shift length of 10 hours, unless "appropriate fatigue countermeasures" were applied.

While scientific evidence suggests that the CNSC proposed 16-hour limit is excessive, there are two practical reasons it may be considered. One reason is because, when a limit of 24 hours in 48 was recommended in 2001 by the U.S. NRC, stakeholder comments at the time indicated that it was problematic for personnel on 12-hour shifts because it would require an authorized deviation in instances where even small amounts of overtime are worked (NRC 2001). Another reason is because a 12-hour limit would require personnel who were working 8-hour shifts to split shifts when working overtime, resulting in the need to call in an extra employee in the middle of the night to cover the second half of an unexpectedly available night shift. However, back-to-back 8-hour shifts should be avoided and especially those that involve shift workers continuing from night onto morning, or continuing from evening onto night.

Table 3 summarizes recommendations concerning shift durations.

Table 3: Summary of recommendations and requirements regarding extended shift duration across industries

Industry	Maximum regular shift length	Reference
Nuclear (U.S.)	16 hours	NRC (2001)
Nuclear (international)	8 to 16 hours	NRC (2001)
Petrochemical	16 (for those working 8- or 10-hour shifts); 18 hours (for those working 12-hour shifts)	ANSI/API (2010)
General (EU)	Day shift = 13 hours Night shift = 8 hours	EC Directive (2003)
Aviation (EU)	13 hours + 1 hour up to twice per week (day) 11 hours + 45 minutes up to twice per week (night)	EASA (2012)
Aviation (U.S)	9 to 14 hours (flight duty)* 8 to 9 hours (flight time)**	FAA (2011)
Aviation (Canada)	14 hours (flight duty)* 8 hours (flight time)**	Transport Canada (2010)
Air traffic control	12 hours; > 12 hours in "emergency" 10 hours	NAV Canada (2012) Mein et al. (2001)

Industry	Maximum regular shift length	Reference
Road transport (Canada)	13 hours driving (south of 60°) 14 hours duty time (south of 60°) 15 hours driving (north of 60°) 18 hours duty time (north of 60°)	Transport Canada (2012)
Road transport (Australia)	12 hours (Standard Hours) 14 hours (Basic Fatigue Mgmt) 16 hours (Advanced Fatigue Mgmt)	NTC (2008a-c)

* "*Flight duty time*" means the total time that starts when a pilot reports for a flight, or reports for standby that has a reporting time of one hour or less, or performs any duty required by the company, or performs any duty delegated by the Minister of Transport, and finishes when the engine is turned off at the end of the final flight (Transport Canada, 2010).
** "*Flight time*" means when the plane is moving under its own power before, during or after flight (FAA, 2011).

Recommendation #2: A recommendation that is better supported by the above scientific evidence as well as with benchmarking to other industries, and which also deals with the practical problem of 8-hour shifts, would be to limit shifts that include the period from midnight to 5:00 a.m. to 12 hours; otherwise, the maximum shift length is 16 hours in a 24-hour period. This allows for normally scheduled, 12-hour day shifts to be extended to 16 hours, or morning or 8-hour shifts to be extended to 16 hours. Thus, an 8-hour evening or night shift could not be followed by an additional 8-hour shift, nor could a 12-hour night shift be extended to 16 hours.

3.1.3 Maximum 28 hours in a 48-hour period

The 2005 criteria recommend that the number of hours worked in a 48-hour period shall not exceed 28 hours, including shift turnover.

This recommendation is not consistent with the U.S. NRC's past (2001) or present requirements. In the 2001 NRC review, the scientific literature review pointed to the recommendation that an individual worker should not be permitted to work more than 24 hours in any 48-hour period. However, stakeholder comments at the time indicated that it was problematic for personnel on 12-hour shifts because it would require an authorized deviation in instances where even small amounts of overtime are worked.

The requirements of the current U.S. NRC's FFD programs (NRC 2012b) are that an individual's work hours should not exceed 26 hours in any 48-hour period. This allows for a 12-hour and a 14-hour shift in 48 hours. This seems a reasonable compromise with the scientific evidence. In addition, the impact will be limited by the 60 hours per week provision discussed next.

Recommendation #3: The maximum number of hours that should be worked in a 48-hour period is 26.

3.1.4 Maximum 60 hours per week

The 2005 criteria recommend that the maximum number of hours worked in a week shall not exceed 60 hours plus shift turnover.

3.1.4.1 SCIENTIFIC EVIDENCE

The number of hours worked in a one-week period (over and above a "normal" work week of about 40 hours) is associated with increased risk of work-related injury. More specifically, Vegso et al. (2007) found an 88 per cent increased risk in those individuals who worked more than 64 hours per week compared to those working less than 40 hours per week, after controlling for within-subject demographic variables (Vegso, Cantley, Slade, Taiwo, Sircar, Rabinowitz, Fiellin, Russi, & Cullen, 2007). It is unclear whether this increased risk would continue to increase in a linear fashion with the number of hours worked per week increasing beyond 64; however, we can assume that, if the risk is related to lack of rest and/or increased time on shift, then it would continue to increase.

Other authors have also found injury rates to increase depending on the number of hours worked. Using data from the U.S. National Health Interview Survey, Lombardi et al. (2010) found that annual injury rates per 100 workers increased in a linear fashion over the 40-hour work week. Unadjusted injury rates/100 workers were 2.45 for those working between 31 and 40 hours per week, while for those working 41 – 50 hours per week the rate was 3.45. For 50 – 60 hours per week the rate was 3.71, and for over 60 hours/week, 4.34 (Lombardi, Folkard, Willetts, & Smith, 2010).

3.1.4.2 BENCHMARKING

Nuclear/petrochemical

While it is inconsistent with U.S. NRC policy, both past and present, which stipulates a maximum of 72 hours per week, a limit of 60 hours per week is consistent with best practices and the scientific literature. The U.S.'s own independent researchers who developed the initial recommendations on work hours in 1985 recommended "a maximum of 60 hours in any 7-day period" (NRC 2001) (and 100 hours in any 14-day period), noting that fatigue from long work hours can result in employees developing their own strategies and standards for deciding how much work is enough (Lewis, 1985). While employees are "off", other work is not counted, nor is rest monitored, making fatigue education an important factor in ensuring employees are well-rested on the job.

Also in the U.S. 2001 review (NRC, 2001), it was noted that the NRC's 72-hour limit was less restrictive than limits imposed in nuclear power plant workers in other countries (including France, the UK, Sweden, Switzerland, Japan, Canada, and the EU) and in several other industries (e.g., commercial aviation, air traffic control, and road transport) at the time. The NRC also notes "while the weekly limit is intended to prevent cumulative fatigue, a limit of 72 hours in any 7-day period is inconsistent with research findings and with use in other applications" (p.8). It appears that the NRC did not follow the recommendations of their experts and proceeded instead with a more liberal weekly hours' requirement.

Industry in General

The European Community Directive on Working Time (2003) recommends a minimum weekly rest period of 24 uninterrupted hours for each seven-day period, which is added to the 11 hours' daily rest. When multiplied by six, the maximum number of days allowed to be worked per week, this amounts to a weekly maximum work hour total of 78 hours for day workers. For night workers, the European Directive recommends that normal hours of work do not exceed an average of eight hours in any 24-hour period. When those hours are combined with the minimum uninterrupted rest period of 24 hours in each 7-day period, the maximum number of hours allowed for night workers is only 48. Based on these calculations, the proposed maximum of 60 hours per week would be compliant with the European Directive for day workers, but not for night workers. It should also be noted that the European Directive stipulates a limit of 48 hours per week, on average, using a maximum averaging period of four months.

Aviation

The U.S. FAA limits flight duty time to 60 hours per week (FAA, 2012). The same 60-hour weekly requirement for pilots and flight crew exists in Canada (Transport Canada 2010). Interestingly, the NAV Canada/CATCA collective agreement does not specify a maximum allowable number of work hours per week, other than the regular hours of work, which are 36 hours per week, averaged over a 56-day (8-week) period (NAV Canada 2012). An issue with limits that are based on a certain number of days and weeks is that these periods are not considered “rolling”, so the beginning of a new week and the end of a previous week can be deemed to be in compliance, but in reality, if work is concentrated within these two periods, the number of hours may actually be non-compliant.

Road Transport

The Canadian commercial vehicle driver hours of service regulations specify a weekly limit of 70 hours (Transport Canada 2012), while the Australian heavy vehicle driver fatigue regulations stipulate a maximum of 72 hours (under Standard Hours) (NTC 2008c). Under an accreditation scheme, heavy vehicle drivers in Australia are permitted to work up to 36 of their weekly hours at night (NTC 2008b).

Recommendation #4: Based on the above evidence, it is recommended that work hours should have a rolling limit of 60 hours in a 7-day period.

3.1.5 Maximum 268 hours in a 5-week cycle

The 2005 criteria recommend that there shall be a limit on time worked during a shift cycle. The adequacy of the limit for a shift cycle shall be evaluated against a limit of 268 hours in a 5-week cycle plus shift turnover.

The U.S. NRC FFD programs do not specify a limit on permissible time worked during a shift cycle; however, Lewis (1985) recommends a 192-hour limit for any period of 28 days. As stated above, the U.S.’s own independent researchers who developed the initial recommendations on work hours in 1985 recommended “a maximum of 60 hours in any 7-day period” (NRC, 2001) (and 100 hours in any 14-day period), noting that fatigue from long work hours can result in employees developing their own strategies and standards for deciding how much work is enough (Lewis 1985) (NUREG/CR-4248). These limits would be equivalent to 260 hours in a 5-week period (100 hours in any 14-day period, 60 hours in any 7-day period). Currently, the U.S. NRC allows licensees to choose to comply with requirements for maximum average work hours *instead* of providing employees with a required minimum number of days off. The maximum of 54 work hours, on average, are calculated using an averaging period of up to six weeks. This would be similar to the CNSC's recommended maximum of 268 hours in a 5-week cycle.

The FAA specifies a monthly (28-day) limit of 190 flight duty hours (FAA 2012). Similarly, for commercial airline pilots, the EASA (2012) recommends a 190-hour flight duty limit for any period of 28 days, which would be equivalent to 240 hours in 35 days, or 5 weeks. On the other hand, the Canadian flight crew duty requirements specify a limit of only 120 flight time hours in any 30 consecutive days (Transport Canada, 2010).

In the road transport domain, the most flexible option of the Australian heavy vehicle fatigue regulations (Advanced Fatigue Management) specifies an "outer limit" maximum of 288 hours in each 28-day period. The other two schemes, Standard and Basic Fatigue management, do not specify a maximum amount for this time period. Canadian road transport regulations do not specify a limit for this time period.

Recommendation #5: Based on the above limited benchmarking to other industries and jurisdictions, the 268-hour limit (equivalent to 22.3 12-hour shifts in 35 days) is high in comparison to the recommended limit from other industries. We recommend 260 hours for a 5-week cycle as being better supported by the scientific evidence.

3.1.6 Maximum 2400 hours in a one-year period

The 2005 criteria recommend that the maximum number of hours worked in a one-year period shall not exceed 2400, which includes regular working time, overtime and shift turnover.

A limit of 2400 hours would be equivalent to 48 hours a week with two weeks vacation per year. This recommendation does not align with the U.S. NRC's research-based recommendations on worker fatigue (NRC 2001). In its 2001 review, the NRC cited the 1985 Nuclear Regulatory Commission's recommendations of a yearly limit of 2260 hours in one year, unless authorization is first obtained from the NRC. The eventual published policy reviewed in 2001 (NRC 2001) was less prescriptive, simply recommending that "controls shall be included in the procedures such that individual overtime shall be reviewed monthly…to assure that excessive hours have not been assigned" (p.10). Similarly, the current U.S. NRC FFD programs (NRC 2012b) do not specify a yearly limit, but rather require that licensees conduct reviews of their employees' actual work hours and performance once per calendar year. At a minimum, this review is required for those safety sensitive individuals whose actual hours worked during the review period exceeded an average of 54 hours per week.

Scientific studies linking hours of work to performance and safety typically focus on shift lengths, schedule design (rotation, number of shifts in a sequence), and recovery requirements after a sequence of shifts and weekly hours. Studies do not tend to deal with longer time periods such as five weeks or a year. Thus, recommendations for those longer time period must be based on extrapolation. Generally it is the case that, the longer the period under consideration, the fewer the hours on average. A limit of 60 hours in one week would be equivalent to 3120 hours per year, while 268 hours in five weeks would be equivalent to 2787 hours per year.

Both the Canada Labour Code (Part III, Section 171(1)) and the European Community Working Time Directive (2003) (Article 6b) include a limit of 48 hours per week, on average. This equates to a limit of 2496 hours in a year.

The current European requirements for commercial aviation pilots stipulate a maximum cumulative limit of 900 flight hours per calendar year. However, in order to avoid the possibility of a pilot accumulating up to 1800 flight hours in a 12-month period (i.e., the last six months of one year, plus the first six months of the next), the EASA (2012) now recommends an additional rolling limit of 1,000 flight hours per 12 consecutive months.

The NAV Canada/CATCA collective agreement does not specify a maximum yearly number of hours for operating employees; however, it does limit the maximum amount of overtime work to 65 days per year (NAV Canada, 2012). When this amount of overtime (65 x 8.5 hours) is added to a year's worth of "normal" work weeks of 36 hours each (52 x 36), the maximum yearly total would be 2424.5 hours. The proposal to limit yearly work time to 2400 hours is in line with the NAV Canada requirements.

Recommendation #6: Based on limited benchmarking to other industries and jurisdictions, the limit of 2400 yearly hours is reasonable. It should be noted that, while this recommendation appears reasonable and consistent with expert opinion, there is limited empirical data to support it. The yearly limit is useful from an administrative perspective for licensees to guide staffing requirements and ensure that adequate time is taken for vacation in a year of 260-hour (maximum) 5-week periods.

3.1.7 Time considered in determining compliance with the limits

The 2005 criteria recommend that, for the purpose of determining compliance with the limits, all time shall be included from the time that the worker reports to work until the time that the worker is relieved from all responsibility for work, including unpaid lunch or rest breaks.

This requirement is not consistent with the U.S. NRC's current FFD programs (NRC 2012b), which instead permit some time taken at breaks or rest periods to be subtracted from the total work time. The FFD programs stipulate that licensees "may exclude from the calculation of an individual's work hours only that portion of a break or rest period during which there is a reasonable opportunity and accommodations for restorative sleep (e.g., a nap)" (Section 26.205).

The NAV Canada collective agreement includes a 15-minute "briefing period" for each shift worked in the 36 hours-a-week regular hours of work. This 15-minute period is used by employees to "prepare to assume duties prior to the commencement of each shift" (NAV Canada 2012).

Recommendation #7: Based on the scientific evidence that naps (even as short as 10-15 minutes) are restorative if taken under appropriate conditions (e.g., after partial, but not full, sleep restriction) (Smiley & Davis, 2006), the U.S. NRC's exemption for naps is reasonable. It is therefore recommended that CNSC adopt the same provision, with specific guidance to be developed with respect to appropriate conditions.

3.1.8 Limits on other time frames

The 2005 criteria consider time frames of maximum shift length, hours in 24 hours, in 48 hours, in 7 days, in 5 weeks and in 1 year.

This section addresses Research Question # 4: The current limits on hours of work apply to a day, week, shift cycle, and year. Should limits be set for other time frames?

The U.S. NRC's reliability experts in their 1983 report "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications: Final Report" (Swain & Guttmann, 1983) recommend that limits be set of 100 hours in any 14-day period. In his 1985 review, Lewis recommends limits of 112 hours in any 14-day period, and 192 hours in any 28-day period. Lewis also recommends, however, higher limits (i.e., 132 hours [11 12-hour shifts] in 14 days and 238 hours in 28 days) as long as approval is obtained first from the NRC (Lewis 1985).

The EASA (2012) proposes enacting a new limit of 110 hours in every 14-day period. The requirement would avoid the possible accumulation of a pilot's 180 hours in only 21 days (3 x 60 hours per week), which would be contrary to the 28-day requirement referred to above. While the EASA cites research known as the "Moebus Report" (Moebus Aviation, 2008) to support this proposal, Moebus actually recommends a 100-hour per 14-day limit. It is unclear, therefore, as to what other considerations the EASA may have considered to develop the 110-hour proposal.

The Canadian and Australian heavy vehicle and road transport industries specify hourly limits for 14-day periods. In Canada, commercial drivers are permitted to work up to 120 hours in each 14-day period (Transport Canada 2012). Under the "Standard hours" and "Basic Fatigue management" regulatory options in Australia (NTC 2008c; NTC 2008a), drivers are limited to 144 hours in each 14-day period. Under the more flexible "Advanced Fatigue management" option (NTC 2008a), drivers are permitted to work up to 154 hours in each 14-day period.

Recommendation #8: The current recommendations consider time frames of maximum shift length, hours in 24 hours, in 48 hours, in 7 days, in 5 weeks and in 1 year. At this time, there is no scientific evidence to suggest that further time frames need to be considered.

3.1.9 Regulation during new construction

The 2005 criteria do not consider fatigue management provisions during construction of a facility that will require high reliability operations, such as a nuclear power plant.

This section addresses Research Question # 5: Using evidence from benchmarking and research, what fatigue management provisions, including hours of work limits and mandatory rest periods, are appropriate during construction of a facility that will require high reliability operations, such as a nuclear power plant?

3.1.9.1 SCIENTIFIC EVIDENCE

Fatigue arises from both mental and physical effort. Construction workers face both, and the physical demands can contribute to mental fatigue. The psychomotor and cognitive impairment that results as a consequence of fatigue has been compared to the impairment observed following the ingestion of alcohol and night work can lead to performance impairment that exceeds legal limits of driving and alcohol consumption in any jurisdiction globally (Dawson and Reid 1997). There is consensus that the physiological and psychomotor degrading effects of fatigue are influenced by the amount of time an individual has been awake, the duration and quality of recent sleep episodes, and the point at which an individual is in his or her circadian cycle. Armed with this knowledge, it becomes clear that the decision of whether to implement programs that manage fatigue among workers who perform safety sensitive tasks – including those who work at, or oversee, the construction of nuclear power plants – is not debatable.

Recent research (Dong, 2005), in which data from the U.S. National Longitudinal Survey of Youth were analyzed, revealed that construction workers report engaging in more overtime (more than 8 hours/day) work than any other employee group, as well as being more likely to work more than one job. They are also more likely than workers in other industries to report having experienced a work-related injury (11.5% vs. 7.2%). Further, those who work in construction and who report working more than eight hours per day also report higher work-related injury rates than do those who work for between seven and eight hours per day (15% vs. 10.4%). Based on these findings, Dong (2005) concludes that it is more likely that shift length and other dimensions of work hours in construction contribute to safety risks, rather than night shift work, which had been the focus of previous research. While this conclusion is inconsistent with the majority of scientific literature and expert opinion that supports circadian and sleep factors as being a prime causes of fatigue compared to hours of work, it is clear that construction workers are as vulnerable as other nuclear industry workers to the effects of fatigue and its impact on the overall safety of the nuclear environment. Based on these findings, therefore, it is clear that those workers who are involved in the construction of safety relevant facilities should be subject to fitness-for-duty requirements, including measures to limit fatigue.

3.1.9.2 BENCHMARKING

The U.S. NRC's FFD programs (NRC 2012b) comprises a section entitled "FFD programs for construction" (Subpart K). While these programs include requirements for individuals who are responsible for construction activities at a nuclear power plant to be free from impairment caused by drugs or alcohol, they do not include any requirements regarding hours of work and rest or fatigue management. In fact, they specifically exclude the requirements of Subpart I "Managing Fatigue". The NRC's decision to specifically exclude fatigue management and hours of work and rest requirements for those individuals who perform construction work on a nuclear power plant is inconsistent with scientific evidence of what is currently known regarding the performance impairment effects of fatigue.

As noted earlier in this document, and relevant to construction work, the European Community Directive on Working Time (2003) recommends that night workers must not perform heavy or dangerous work for longer than eight hours in any 24-hour period.

Of direct relevance to the CNSC, the recently published recommended practice of the ANSI/API (2010) that recommends the implementation of fatigue risk management systems (FRMSs) in the refining and petrochemical industries states that "on-site contractors involved in process safety sensitive actions shall have FRMS equivalent to the criteria outlined in this document (the recommended practice)" (p.2) (ANSI/API 2010). Whether these contractors include those performing construction activities remains to be determined. Regardless, it will be important to clearly define all terminology used throughout any regulatory documents so that requirements can be easily and efficiently implemented.

Recommendation #9: Based on the above scientific evidence and benchmarking, the CNSC is encouraged to require the same limitations in hours of work for those individuals who perform construction work on safety relevant facilities as for power plant operators or others with safety sensitive roles.

3.2 Limited Number of Consecutive Shifts and Adequate Provision for Recovery

The 2005 criteria recommend that, for workers who perform safety-related tasks or work on safety-related systems, the number of consecutive shifts shall be limited and adequate provision for recovery shall be made.

This section addresses these issues for 12-hour shifts and, in addition, addresses Research Question #3: What mandatory rest periods and limits to consecutive shifts should be applied to those working 8-hour or 10-hour day, evening and/or night shifts?

3.2.1.1 SCIENTIFIC EVIDENCE

Shift scheduling patterns and their potential impact on the adequacy of rest periods are very important considerations. The average amount of sleep required by adults to be fully alert is between seven and eight hours per night, although this can range among individuals from between a low of six, up to needing 10 hours of sleep per night (Lerman et al. 2012). Shift workers have been found to sleep an average of 1½ hours less after 8-hour night shifts as compared to after day shifts. After a series of five 8-hour night shifts, experienced shift-workers slept 10 to 12 hours per night on days off, with the longer sleep occurring on the second night, suggesting that a single night off was insufficient to recover from a week of night shifts (Lille, 1967). A study of nurses working 12-hour shifts (Geiger-Brown et al., 2012) found that their average sleep durations were significantly longer on the first day after a block of day or night shifts than were inter-shift sleep durations, indicating an inadequate amount of sleep between shifts to recover, irrespective of whether they were working during the day or night. The nurses also experienced greater subjective fatigue during the third consecutive shift than during the first two shifts, with night nurses being particularly vulnerable to sleepiness by the end of their shift. Further, Heslegrave (1998) found similar sleep debt accumulation across different shift schedules in air traffic controllers (Heslegrave, 1998). It is clear that the sleep debt that builds up after a sequence of night shifts supports limiting the number of consecutive night shifts to allow time for recovery.

A recent study that used 2004 to 2008 U.S. National Health Interview Survey data found that performance decrements leading to increased occupational injury risk reportedly existed across multiple industries, even after controlling for a number of demographic factors (Table 4). Compared to work-related injury rates associated with nightly sleep periods of more than 7 hours, reported injury risk increased significantly in stepwise increments when nightly periods of sleep lasted less than seven hours.

Table 4: ***Estimated annualized injury rates/number of hours of sleep (adapted from Lombardi et al., 2010)***

	Estimated Annualized Injury Rates/100 Workers					
Hours of sleep	<5	5–5.9	6–6.9	7–7.9	8–8.9	9–9.9
Injury rates	7.89	5.21	3.62	2.27	2.50	2.22

The more days that individuals have worked since their last period of time off, also increases the risk of injury (Lamberg, 2004).

In the road safety field, required recovery of driver performance was studied under a sustained, daytime – 14 hours on/10 hours off schedule. Ten male commercial motor vehicle drivers operated a driving simulator in simulated long-haul runs for a period of 15 days, including occasional loading/unloading sessions and a relatively high frequency of simulated “crash-likely events”. Drivers returned to baseline reaction time performance and alertness within 24 hours after the end of a driving week, as shown by sleep latency, reaction time testing, and driver rating of subjective sleepiness. The study concluded that “in daytime driving schedules like this one, resuming work after 24 hours of rest would cause severe circadian disruption. Drivers ought to resume duty only after a minimum of 36 hours rest” (O'Neil, Kruegar, Van Hemel, & McGowan, 1999). Night shift workers would be expected to require more time.

It appears that shift time-of-day has a bearing on how much rest time is needed between shift cycles. In a summary of four of their own shift work studies, Folkard et al. (2005) conclude that the risk of, for example, workplace accidents or injuries is higher on the (8-hour) night shift, and to a lesser extent the afternoon shift, than on the morning shift (Folkard et al. 2005). Based on the pooled results from the studies, workplace accident risk increased (relative to the morning shift) by 18 per cent on the afternoon shift, and by 30 per cent on the night shift. The same authors also concluded that workplace accident risk increases over a sequence of 8-hour shifts, especially so if the shifts are worked at night. On average, risk increased by approximately six per cent on the second night, 17 per cent on the third night, and 36 per cent on the fourth night. Increases in risk over consecutive daytime shifts were also observed; however, the increase was substantially smaller than that observed over successive night shifts. It should be noted that another multi-year study by two of the three authors of Folkard et al. (2005) (Tucker, Folkard, & Macdonald, 2003) on the effects of rest breaks on occupational accident risk in automotive factory workers, found that there were significantly more accidents on the day shift (n=296) compared to the night shift (n=230; $p = 0.004$). However, Folkard et al. (2005) note that this may have been a result of any number of factors that were not controlled for, such as reduced supervision during the day, as opposed to during the night shift. Heslegrave et al. (2000), however, reported that driving risk was reduced on longer night shifts compared to shorter night shifts, so long as the longer night shift started and ended earlier (by 3:00 a.m.) so that the entire night was not dedicated to work (Heslegrave et al. 2000).

With respect to recovery time, a 1994 study done on behalf of Ontario Hydro assessed the alertness of shift workers after a rest period of 48 hours, as compared to 72 hours (Mallette, 1994). Alertness was measured using a psychophysical test, the “critical flicker fusion” test. Two representative shift crews worked three 12-hour night shifts followed by either a 48-hour or 72-hour rest period before resuming work on day shifts. Alertness after 72 hours’ rest was found to be significantly higher than alertness after only 48 hours’ rest. The difference in alertness levels was equivalent to the difference in a worker’s alertness at the start versus at the end of an 8-hour day. The major drawback of using this difference as a point-of-reference for the current considerations is that there is no information as to whether performance on the flicker fusion test varies according to circadian rhythm or if it declines monotonically with number of hours worked. If the former, it is possible the results of the Mallette study were a consequence of differences in participants’ positioning within their circadian cycle, as this factor was not controlled for in the research design. Interestingly, sleep (as measured using a wrist-worn monitor) on the second day of rest was only 7.5 hours when workers had only 48 hours off, compared to 8.7 hours when the workers had 72 hours off. It is probable that nightly sleep was shortened on the second night when the workers were required to get up for work earlier than they normally would on a day off.

Akerstedt et al. (2000) used the Karolinska Sleepiness Scale (KSS) to collect shift workers' and traditional day workers' subjective alertness ratings on days of work and rest (Akerstedt, Kecklund, Gillberg, Lowden, & Axelsson, 2000). The KSS is a reliable self-report sleepiness scale that has been validated against EEG parameters. The authors found that most “irregular” work schedules (i.e., those that involve night and early morning work) were associated with extreme sleepiness ratings that extended beyond the work week to the first day of recovery. The irregular shifts appeared to involve immediate recovery from severe sleepiness on the first full day off. Workers who worked 12-hour shifts seemed not to be any more affected by accumulated fatigue than were workers working 8-hour shifts, and so the authors recommend two days of recovery for both groups – the same amount recommended for the average, normal (9:00 a.m. to 5:00 p.m.) office worker. An extra day of recovery was recommended to allow workers to recover from a work schedule that involves a sequence of long (more than 8 hours) work hours where the circadian system adjusts to night work through special ambient light conditions (e.g., in the absence of natural daylight). The absence of natural day light (or an adequate artificial light substitute) in combination with a long period of night work seemed to create some of the greatest demands on recovery time.

Collectively, these results suggest that individuals working night shifts should be required to work fewer shifts in a sequence, and/or be provided with longer inter-shift recovery opportunities, than those workers working daytime shifts of the same duration.

3.2.1.2 BENCHMARKING

Nuclear/Petrochemical

The U.S. NRC’s review of their policy for nuclear plant operators (NRC 2001), which required a break of at least eight hours between work periods, indicated that this requirement was not consistent with scientific evidence, or with best practices in other industries at the time. Research had shown conclusively that, on average, most humans require about eight hours of sleep per night (Rosekind, Neri, & Dinges, 1997; Rosa 1991). The 8-hour guideline does not adhere to the year-2000 guidelines of the U.S. National Sleep Foundation, which instead recommended 12 hours of off-duty time. Twelve hours is also the length of time recommended by the NRC’s reliability experts in their 1983 report (Swain and Guttmann 1983), and one study even recommended

16 hours (Kecklund & Akerstedt, 1995). In 2001, the Insurance Institute for Highway Safety (IIHS) cited 12 to 14 hours off per day, citing a study by Wylie and colleagues (Wylie, Shultz, Miller, Mitler, & Mackie, 1996).

Generic required breaks (for any shift length) from the current NRC FFD programs (NRC, 2012) include the following:

- 10-hour break between successive work periods, or an 8-hour break between successive work periods when a break of less than 10 hours is necessary to accommodate a crew's scheduled transition between work schedules or shifts; and
- 34-hour rest break in any 9-day period.

The ANSI/API recommended practice for fatigue management for refining and petrochemical workers (ANSI/API 2010) indicates that, for extended (from 12-hour) shifts of 14 to 16 hours, a minimum recovery (time off) period of 8 hours shall be provided before the worker is required to return for the next shift. For extended shifts of greater than 16 hours, the employer shall provide a minimum of 10 hours off before returning for the next shift.

Aviation

Commercial aviation requirements stipulate a consecutive off-duty time of between about nine and 18 hours. The U.S. FAA requires a minimum of 10 hours' rest prior to beginning a flight duty period (FAA 2012). The FAA also recently proposed requiring continuous time off during a 7-day period to be extended to 30 hours (from 24 hours previously) with additional time off required for those individuals who are working during their circadian low (FAA 2012). Canadian requirements specify that a pilot must have a minimum rest period that allows for "an opportunity to obtain not less than eight consecutive hours sleep" (Transport Canada 2010).

The EASA (2012) proposes a minimum weekly recurrent rest period of at least 36 hours, which must include two local (to the flight departure city) nights. In addition, twice per month a pilot is required to have an extended rest period of 48 hours.

NAV Canada's collective agreement with CATCA specifies a minimum inter-shift rest period of at least 10 hours (NAV Canada 2012), and this period was also recommended previously by the tri-partite task force (Mein et al., 2001). However, the current NAV Canada – CATCA agreement provides for instances in which an employer is permitted to schedule a "short change" (where the period between the end of one shift and the beginning of the next is less than 10 hours) *for all operational staff in a unit or specialty* where the employer can provide at least 56 hours' notice. The employer is allowed to schedule a short change of *eight* hours no more than once during each employee's work week, and a short change of *nine* hours no more than twice during an employee's regular work week. Employees may elect to have short changes provided there are at least 72 hours between the start of a short-changed shift and the start of the subsequent short-changed shift. Of note is that, in the U.S., the most common shift has been a version of the short change schedule, where two evening shifts are followed by two day shifts and then a single night shift so that an air traffic controller would start on a Monday evening and end on a Friday morning for a 5-day shift, with short changes between evening and day shifts and between day and night shifts (Heslegrave, 2013).

Road Transport

Current U.S. Federal Motor Carrier Safety Administration regulations require that drivers have at least 10 continuous hours off duty per day. For drivers using an in-vehicle sleeper berth, at least eight consecutive hours in the sleeper berth, plus a separate two consecutive hours either in the sleeper berth, off duty, or any combination of the two, is required. For other drivers, 10 continuous hours off duty per day is required (FMCSA, 2012). This current requirement exists whereas, previously, the requirement had been only eight hours. This previous requirement was criticized by the U.S. NRC's panel of fatigue experts in 2001 because eight hours of off-duty time did not necessarily translate to eight hours of sleep (NRC 2001). Canadian hours of service regulations also require a minimum of 10 hours off duty, which includes eight consecutive hours plus two hours of other off duty time that is recorded in periods of no less than 30 minutes each. A driver is limited to 70 hours on-duty time in a 7-day period, followed by 36 consecutive hours off or 120 hours in a 14-day period, followed by 72 consecutive hours off (Transport Canada 2012). Finally, Australian heavy vehicle driver fatigue legislation requires a daily stationary rest time of seven continuous hours, and a weekly rest time of 24 continuous hours. There is also a requirement that drivers have at least two *night time* rest breaks taken on consecutive days (NTC 2008c).

Table 5: Summary of rest break recommendations and requirements across industries

Industry	Daily rest break	Weekly rest break	Reference
Nuclear (U.S. and international)	10 hours	34 hours (in 9 days)	NRC (2012)
Petrochemical	8 to 10 hours (depends on shift duration)		ANSI/API (2010)
Aviation (Canada)	at least 8 hours		Transport Canada (2010)
Aviation (U.S)	10 hours	30 hours	FAA (2012)
Aviation (EU)		36 hours (must include two local nights)	Transport Canada (2010)
Air traffic control	10 hours		NAV Canada (2012) Mein et al. (2001)
Road transport (Canada)	10 hours	36 hours after 7 days	Transport Canada (2012)
Road transport (Australia)	7 hours	24 hours	NTC (2008a-c)
Road transport (U.S.)	10 hours		FMCSA (2012)

3.2.1.3 FOR PERSONS WORKING 12-HOUR SHIFTS

With respect to consecutive 12-hour shifts, the 2005 criteria recommend:

(a) a maximum of 5 consecutive day shifts or 4 consecutive night shifts shall not be exceeded

The effects of different rostering schedules on sleep and subjective sleep quality were evaluated in a recent, multi-year study of Australian miners (Paech, Jay, Lamond, Roach, & Ferguson, 2010).

Wrist actigraphy and sleep diaries were used to collect data from over 111 open pit miners for a full roster cycle, including days off. Four different rostering schedules that varied in the proportion of days off between successive day and night shifts were compared. Total sleep time was significantly longer on days off (mean = 7.0 h) compared to sleep on day (mean = 6.0 h) or night (mean = 6.2 h) shifts. Although other research had indicated that the number of successive days off would be significantly predictive of workers achieving adequate recovery sleep (Muller, Carter, & Williamson, 2008; Tucker, Smith, Macdonald, & Folkard, 1999), Paech et al.'s study did not find an impact of the number of consecutive shifts on sleep duration or subjective sleep quality.

Barton et al. (1995) focused on the number of consecutive night shifts worked on the health and wellbeing of permanent night versus rotating shift nurses (Barton, Spelten, Totterdell, Smith, & Folkard, 1995). The number of consecutive night shifts was found to be associated with increased sleep duration and sleep quality, both of which were correlated with improved measures of health and wellbeing. The strength of this relationship was stronger for permanent night nurses compared to rotating shift nurses. The authors speculated that, in permanent night shift nurses, increased exposure to night work may be associated with improved circadian adaptation, allowing those nurses to experience less disruption and ill effects. (However, it should be noted that only about 25% of the population are able to fully adapt to night work in terms of shifting circadian rhythm, and full adaptation takes 10 to 14 days, a period that is generally interrupted by time off, suggesting permanent night shifts are a less than desirable solution (Shapiro, Heslegrave, Beyers, and Picard, 1997) (p.65). These results suggest that it is important to consider the potential impact of individual employees' shift work history on fatigue and the potential for performance decrements on an individual (case by case) basis. However, the authors also note that, because their study was only able to explain a small amount of variance in the outcome measures, firm conclusions based on these data should not be drawn. Rather, the complexity of the relationship between sleep duration, quality, and health should be further explored in future research.

More recent research from South America has shown that, for workers on fixed shifts, 12-hour night workers' self-reported sleep quality and perceived alertness is worse than that of 12-hour day workers (Fischer 2004), and that day workers perceive worse sleep during their working days than during off days. These results were very dependent on individual differences, with the standard deviation of alertness scores increasing significantly from the 2nd to 10th hour, revealing a conspicuous difference among individuals who are able to cope with sleepiness as compared to others. These results highlight the need to consider individual workers on a case by case basis, and the significant potential of broader FRMS to more fully manage worker fatigue than simple limits on hours of work.

The maximum of four consecutive 12-hour night shifts proposed by the CNSC is consistent with guidelines issued by the Electric Power Research Institute (EPRI) (Baker, Campbell, Linder, & Moore-Ede, 1990) (cited in NRC 2001), which recommended that individuals work no more than four consecutive 12-hour shifts. There are differences, however, between night and day shifts, with most literature in agreement that night shifts pose more risk in terms of safety impacts than day shifts.

A study by Son et al. (2008) of auto workers on 12-hour shift systems with 5 to 7 consecutive shifts used questionnaires and sleep-wake diaries to assess severe sleepiness (Son and et al. 2008).

Night shifts and long working hours were the main risk factors for severe sleepiness, with working the night shift increasing the risk compared to day shifts by a factor of 4.7. Long working hours in combination with night shift work had a significant interactive effect. Night shift workers who worked for 12 hours or more a day had a risk of severe sleepiness that was 7.5 times greater than day shift workers who worked less than 11 hours.

Although they acknowledge that night shifts pose more significant safety concerns than do day shifts, the ANSI/API recommended practice (ANSI/API, 2010) recommends an upper limit of seven consecutive day *or night* 12-hour shifts. The authors suggest that, if an organisation has in place a comprehensive FRMS, which provides effective employee fatigue training that encourages the careful (employee-driven) design of their sleep schedules to mitigate any progressive performance impairment in blocks of consecutive shifts, this 7-day limit is supported by scientific research. (A block, sometimes called a "workset", is defined as a set of consecutive shifts with the same start and end times, that is followed by a minimum recovery period and a subsequent set of consecutive shifts.) We would contend, however, that seven days of 12-hour shifts, which would result in a total work duration of 84 hours in one week, is not supported by the scientific research; at least not the research that we reviewed.

Recommendation #10: Based on the scientific research reviewed and benchmarking to other safety relevant industries, for 12-hour shifts the recommended maximum of 5 consecutive day shifts or 4 consecutive night shifts is reasonable.

With respect to recovery periods, for 12-hour shifts, the 2005 criteria recommend:

- **(b) a minimum recovery period of 48 hours shall follow 3 or more consecutive day shifts, excluding shift turnover time**
- **(c) a minimum recovery period of 48 hours shall follow 2 consecutive night shifts, excluding shift turnover time**
- **(d) a minimum recovery period of 72 hours shall follow 3 or more consecutive night shifts, excluding shift turnover time**

As noted in an earlier section, a study of nuclear workers who worked three 12-hour night shifts found significantly higher alertness after a rest period of 72 hours as compared to 48 hours (Mallette, 1994). However, some methodological concerns are associated with this study.

A study by Smiley et al. (2004) reviewed literature related to recovery time requirements in trucking as well as in other industries (Smiley, Boivin, Heslegrave, & Davis, 2004). With respect to trucking, a field study of recovery, involving a small number of drivers, showed that after working four 13-hour shifts, based on sleep and lane tracking data, 60 hours off (2.5 days) were preferable to 36 hours, for both day and night drivers, but especially for the latter (Wylie, Shultz, Miller, Mitler, & Mackie, 1997).

Two laboratory studies examined recovery after daytime driving. The first found that, after a 5-day week of 14-hour shifts, a time-off period which allowed two night periods and one day period off, i.e., 36 hours, allowed full recovery from daytime driving (O'Neil et al. 1999). The second found significant and dose-dependent performance deterioration for groups restricted to seven hours in bed or less during the work period (Balkin, Thome, Sing, Thomas, Redmond, Wesensten, Williams, Hall, & Belenky, 2000). While it should be noted that this was nighttime sleep, the results clearly indicated that after 4 shifts, performance was reduced to 80% with 5 hours of nighttime sleep to 60% with 4 hours of nighttime sleep. Coupled with the finding that restricted sleep taken during the day after a nightshift is even less restful (Rogers et al, 2002), performance will be significantly impaired earlier. Both 8- and 12-hour shift workers have been shown to average less than seven hours per night (Pternitis 1977, Paech et al., 2010). During a four-day recovery period, there was minimal recovery for those who had been restricted to three hours in bed after each shift and incomplete recovery for the groups restricted to five or seven hours in bed, even after three nights of sleep.

Outside the trucking industry, Smiley et al. (2004) report a meta-analysis that showed, for most schedules, day or night, weekly or rapid rotation, regular or irregular, when recovery was assessed with respect to subjective sleepiness, one recovery day that included a full night's sleep was sufficient (Akerstedt et al. 2000). The Karolinska Sleepiness Scale (KSS) is a measure of subjective alertness that is scored on a scale of 1 to 9, where 9 = "very sleepy, fighting sleep, an effort to keep awake", 7 = "sleepy, but no effort to keep awake", 5 = "neither alert nor sleepy", 3 = "alert", and 1 = "very alert". The scale has been validated against EEG parameters of sleep and sleepiness. Akerstedt and colleagues looked at shift work and recovery needs in various industries, and found that, for most schedules—day or night, weekly or rapid rotation, 8-hour or 12-hour, regular or irregular—when recovery was assessed using the KSS, one recovery day that included a full night's sleep was sufficient for workers' subjective alertness levels to reach normal daytime values of less than 4 (Akerstedt et al. 2000). It is important to note that the study authors define "recovery day" as a day that "must be preceded by the opportunity of night rest between 2400 and 0800 hours. Thus, for example, the first recovery day after a night shift that ends in the morning does not start until the subsequent day" (p.253). Exceptions included construction workers working seven consecutive 12-hour day shifts who required three to four days off to reach normal sleepiness values, and oil platform workers working 14 consecutive 12-hour night shifts who were still not recovered after four to five days off. In a review of countermeasures against fatigue, Akerstedt et al. (2000) state that most shift workers reported that they needed at least two days with two normal sleep episodes to recover after three consecutive night shifts. This study also demonstrated that the need for recovery increased by one day when working a succession of seven consecutive shifts.

A study of a variety of schedules worked by nurses suggested that a number of measures such as alertness, sleep duration, mood and social satisfaction tended to be worst on the first rest day and at least two days of recovery was required, especially after shifts worked at night (Totterdell, Spelten, Smith, Barton, & Folkard, 1995). These findings suggest that longer periods of recovery should be required for those working blocks of consecutive night as compared to day shifts.

A study of the effect of chronic sleep restrictions looked at recovery after schedules when sleep is taken during the day. For ten days, subjects were assigned to diurnal sleep restriction which was followed by two recovery days with a ten hour nocturnal sleep period. This study showed the same amount of sleep restriction with respect to hours had a much stronger effect on performance when the sleep taken was during the day, as opposed to at night (Rogers, Van Dongen, Power IV, Carlin, Szuba, Maislin, & Dinges, 2002). This indicates that it is important to consider the timing of sleep as well as the duration of off-duty time. A sleep deprivation study by Price, Rogers, Fox, Szuba, Van Dongen and Dinges (2002) indicated that providing a longer opportunity to spend time in bed and to sleep results in quicker recovery from acute sleep deprivation than otherwise (Price, Rogers, Fox, Szuba, Van Dongen, & Dinges, 2002).

BENCHMARKING

Current U.S. NRC FFD programs (NRC 2012b) stipulate different required recovery periods depending on the work duties performed by an individual. Individuals whose role consists of maintenance activities working 12-hour shift schedules shall have at least 2 days off per week, averaged over the shift cycle. Individuals whose role consists of operations, health physics or chemistry, or involves being a member of the fire brigade working 12-hour shift schedules shall have at least 2.5 days off per week, averaged over the shift cycle. Finally, those individuals whose role is providing plant security working 12-hour shift schedules shall have at least 3 days off per week over the shift cycle. Alternatively, instead of a required minimum number of days off, licensees may choose to comply with requirements for maximum *average* work hours, which are calculated using an averaging period of up to six weeks (maximum weekly average of 54 hours, calculated using an averaging period of up to six weeks).

The ANSI/API recommended practice (ANSI/API 2010) permits two consecutive nights of sleep following a block of day shifts by requiring 36 hours off and, following blocks of four or more consecutive night shifts, by requiring 48 hours off. A work set could theoretically comprise up to seven consecutive nighttime, 12-hour shifts. Further, a minimum of 48 hours off after a total of 84 hours worked should be provided, regardless of whether the employee has worked night or day shifts. The authors point out that, if an employee has worked a set of night shifts, and is coming back to night shifts, the 48-hour minimum effectively becomes a minimum of 60 hours, allowing two complete days off, and the opportunity for three daytime sleep episodes. Although this schedule theoretically allows for this many sleep episodes, it is important to remember that daytime sleep, especially when taken in workers who are not fully adapted to a night shift schedule, will not be as restorative as sleep taken at night, during most individuals' periods of circadian low. Furthermore, workers are unlikely to maintain a daytime sleep schedule on their days off.

The scientific and benchmarking evidence for recommended recovery period length after 12-, 10-, and 8-hour shift blocks is summarised in Table 6.

Table 6. Evidence supporting recovery periods following blocks of 12-hr., 10-hr., and 8-hr. shifts

Shift length and type	Block size (number of consecutive shifts)	Minimum recovery period	Scientific evidence and benchmarking for recommendation
13-hour day	4	60 hours	Wylie et al. (1997)
14-hour day	4	36 hours	O'Neill et al. (1999)
12-hour day	3-4	48-72 hours***	NRC (2012b)
	7	72-96 hours	Akerstedt et al. (2000)
	7	36 hours	ANSI/API (2010)

Shift length and type	Block size (number of consecutive shifts)	Minimum recovery period	Scientific evidence and benchmarking for recommendation
12-hour night	3	72 hours	Malette (1997)
	3	48 hours	Akerstedt et al. (2000)
	4	48 hours	ANSI/API (2010)
	3-4	48-72 hours***	NRC (2012b)
13-hour night	4	60 hours	Wylie et al. (1997)
11-hour night	4	48 hours	Totterdell et al. (1995)
10-hour day*	9	36 hours	ANSI/API (2010)
10-hour night*	3	48 hours	Akerstedt et al. (2000)
	3	48 hours	Totterdell et al. (1995)
	up to 5	48 hours	NRC (2012b)
	4	72 hours	Wylie et al. (1997)
	4 to 9	48 hours	ANSI/API (2010)
8-hour day or evening	5 or 6	36 hours	NAV Canada (2012)** NRC (2012b)
8-hour night	4	36 hours	NAV Canada (2012)**
	5	48 hours	NAV Canada (2012)**
	5	48 hours	Lille (1967)

**There is currently no available scientific evidence to differentiate between 12- and 10-hour shifts with respect to number of consecutive shifts that should be allowed.*
***In the event that an employee agrees to work their full yearly allowance of 65 days of overtime*
****Depends on worker's work duties*

Recommendation #10: Based on the scientific research reviewed and benchmarking to other safety relevant industries, the recovery periods for 12-hour shifts stipulated in the 2005 criteria following 5 consecutive day shifts and 3 consecutive night shifts are reasonable. There are no studies that directly support the requirement for 48 hours off after a block of 3 or 4 day shifts, or after a block of 2 night shifts. Thus for 12-hour shifts, the following is instead proposed:

1. A minimum recovery period of 48 hours shall follow a block of 5 consecutive day shifts, excluding shift turnover time;
2. A minimum recovery period of 72 hours shall follow blocks of either 3 or 4 consecutive night shifts, excluding shift turnover time.

It should be noted that the rolling 7-day limit of 60 hours also applies.

3.2.1.4 For persons working 10-hour shifts

The 2005 criteria make no recommendations regarding 10-hour shifts.

There is no available scientific evidence to directly differentiate between 12- and 10-hour shifts with respect to the number of consecutive shifts that should be allowed, nor to the amount or duration of recovery periods following blocks of consecutive shifts. There is, however, a study showing that, compared to 8-hour shifts, 10-hour shifts were associated with a 13 per cent increase in risk of work-related accidents or injuries, while 12-hour shifts were associated with a 27 per cent increase, implying that 12-hour shifts are more fatiguing than 10-hour shift (Folkard et al. 2005).

Current U.S. NRC FFD programs (NRC, 2012) require that individuals working 10-hour shift schedules shall have at least 2 days off per week. Alternatively, as noted above, instead of a required minimum number of days off, licensees may choose to comply with requirements for maximum *average* work hours, which are calculated using an averaging period of up to six weeks (maximum weekly average of 54 hours, calculated using an averaging period of up to six weeks).

The ANSI/API (2010) recommended practice stipulates that, for workers working 10-hour shifts, work sets should not exceed nine consecutive day or night shifts. The document also recommends that 36 hours “off” should be provided following a work set, or 48 hours after a work set containing four or more night shifts. For shifts that are scheduled to last for 10 hours, “holdover periods” should not exceed two hours’ duration. Finally, no more than one extended (from 10 hours) shift longer than 14 hours is allowed per work set, and no more than two extended (from 10 hours) shifts of 12 hours are allowed per work set. If three or more 12-hour shifts are worked in a work set (by an individual who usually works 10-hour shifts), then the organisation is required to follow the guidelines for 12-hour shifts (see above).

Recommendation #11: Based on the scientific research reviewed and benchmarking to other safety relevant industries in relation to 12-hour shifts, the recommended maximum of 5 consecutive day shifts or 4 consecutive night shifts for 10-hour shifts is reasonable.

With respect to recovery periods, for 10-hour shifts, we recommend:

(a) a minimum recovery period of 48 hours shall follow 5 consecutive day shifts, excluding shift turnover time;

(b) a minimum recovery period of 72 hours shall follow 3 or 4 consecutive night shifts, excluding shift turnover time;

It should be noted that the rolling limit of 60 hours in a 7-day period also applies.

3.2.1.5 For persons working 8-hour shifts

The 2005 criteria make no recommendations regarding 8-hour shifts.

Recommendation #12: With respect to consecutive 8-hour shifts, we recommend:

(a) a maximum of 6 consecutive day or evening shifts, or 5 consecutive night shifts, shall not be exceeded.

The ANSI/API (2010) recommended practice stipulates that work sets for those individuals working 8-hour shifts should not exceed 10 consecutive day, evening, or night shifts. The authors justify this recommendation on the basis that "working under the umbrella of an FRMS enables the limits to be extended without increasing risk because employees receive training to help them mitigate sleep deficits" (p.37). Unless the CNSC develops and is able to adequately enforce clearly defined FRMS requirements, we do not recommend a maximum of 10 8-hour shifts, especially if they are worked at night. ANSI/API (2010) recommends that, for those who normally work 8-hour shifts, no more than two non-consecutive extended (from 8 hours) shifts greater or equal to 14 hours be allowed per work set, and that no more than two extended (from 8 hours) 12-hour shifts be permitted in a work set (these 12-hour shifts can be consecutive). As for those normally working 10-hour shifts, if a worker is required to work three or more extended (from 8 hours) 12-hour shifts in a work set, then an employer must follow the guidelines for 12-hour shifts.

The proposed six-day maximum number of shifts is in line with the criteria of the collective agreement between NAV Canada and CATCA, which applies to employees working a normal shift duration of 8.5 hours. ATC operational employees are permitted to work one of two shift cycles: a 17/11 cycle (17 work days in each 4-week period) or a 34/22 cycle (34 work days in each 8-week period). Employees are entitled to choose among the two shift cycles, depending on their seniority with the organisation. The maximum number of consecutive days of work for the 17/11 schedule is six, while the maximum number of consecutive days of work for the 34/22 cycle is five. There is no mention in the agreement for the maximum number of night shifts worked; therefore, we can assume that it is the same regardless of whether a shift is worked during the day or the night. It should be noted that the collective agreement further specifies that, *except in an emergency*, no operating employee shall work more than nine consecutive days.

Recommendation #12: With respect to recovery periods, for 8-hour shifts, we recommend:

(b) a minimum recovery period of 36 hours shall follow 5 or 6 consecutive day or evening shifts, excluding shift turnover time.

The minimum recovery period specified in the NAV Canada agreement with CATCA (NAV Canada 2012) is three days (72 hours), regardless of the number of consecutive shifts worked prior. This applies to workers on both the 17/11 and the 34/22 cycles. However, there is the possibility for employers, in cases where there is a "reduced staffing requirement on weekends in a unit or specialty", to schedule only two days off following four consecutive work shifts. It should also be noted that the agreement allows for less than two consecutive days of rest in the event that an employee agrees to work their full yearly allowance of 65 days of overtime (Section 16.02[f]). The 2000 NAV Canada/TC/CATCA tri-partite task force had recommended that at least two consecutive calendar days off be provided after five or more consecutive days worked and, where "circumstances did not permit such rest periods to be taken", NAV Canada was urged to implement "appropriate fatigue countermeasures" (Mein et al., 2001). It should be noted that many believe there should be fewer day shifts if start times are early (e.g., 6:00 a.m.) as sleep prior to the day shift is truncated (Heslegrave, 2013).

Recommendation #12: With respect to recovery periods, for 8-hour shifts, we recommend:

(c) a minimum recovery period of 48 hours shall follow blocks of either 4 or 5 consecutive night shifts, excluding shift turnover time.

A seminal study by Lille (1967), involving EEG measures, showed that shift workers slept an average of 1 ½ hours less after night shifts as compared to after day shifts. After a series of five 8-hour night shifts, experienced shift-workers slept 10-12 hours per night on days off, with the longer sleep occurring on the second night, suggesting that a single night off was insufficient to recover from a week of night shifts.

Current U.S. NRC FFD programs (NRC 2012b) stipulate that individuals working 8-hour shift schedules shall have at least 1 day off per week. However, this is likely insufficient for those working night shifts. Alternatively as above, instead of a required minimum number of days off, licensees may choose to comply with requirements for maximum *average* work hours, which are calculated using an averaging period of up to six weeks (maximum weekly average of 54 hours, calculated using an averaging period of up to six weeks). Under this option, the requirement for a 34-hour rest break in any 9-day period (see Section 3.2.1.2) would still apply.

Direction of Shift Rotation

In their review of the shift work literature up until 2006, Driscoll et al. (2007) determine that forward rotating shift systems (that apply to 8-hour shifts), which require the worker to wake later with each change in shift, were associated with better sleep quality, increased sleep length, less fatigue, and fewer attention lapses than backwards rotating systems (Driscoll et al. 2007). These effects were constrained, however, mostly to night shifts, rather than to morning or afternoon shifts. The authors point out that the problems associated with backwards rotating systems in the reviewed studies are consistent with what it known regarding the expected effects of early rising and reduced recovery time between shifts, and therefore recommend the use of forward-rotating shift systems, at least in cases where 8–hour shifts are concerned.

In a survey study of American continuous operations petrochemical workers, sleep quality, physical well-being, and time for family and personal pursuits were all rated more poorly by those workers who were working an 8-hour backward shift schedule, compared to workers on an 8-hour day shift, or those on a 12-hour shift work schedule (Jaffe, Smolensky, & Wun, 1996). This study further exemplifies why a forward-rotating shift schedule is preferred to a backward-rotating schedule. Interestingly, the reason the workers were on a backward rotating schedule in the first place was because the union requested it so that workers could have a 4.5 day off time between shift rotations.

The ANSI/API (2010) recommended practice stipulates that a forward direction of shift rotation should be used for those individuals working 8-hour shifts. This recommendation was based on ample evidence showing that forward-rotating schedules are associated with better sleep quality and less family-work conflict.

Recommendation #12: Based on the scientific research reviewed and benchmarking, a forward direction of shift rotation should be used for those individuals working 8-hour shifts.

3.3 Potential for Exceptions to Hours of Work Limits

This section addresses Research Question #4: Is there any basis for granting exceptions to the hours of work limits or rest periods for short durations at times of peak demand? (If yes, recommend evidence-based, permissible exceptions to the hours of work limits or rest periods and the duration of these exceptions.)

It is our understanding that this research question is not about emergencies or unforeseen circumstances. Instead, it is about times that a licensee would like certain workers to work in excess of the limits, such as during a forced outage or planned outage or during a short term period of maintenance.

The U.S. NRC reviewed its own policy for nuclear power plant operators in 2001. This review activity included evaluating sections of the NRC's "Policy on factors causing fatigue of operating personnel at nuclear reactors" that concerned the pre-conditions required for a guideline deviation in periods of increased demand to be authorized. At the time, the NRC specified the following requirements to be adopted during periods of planned outages and increased demand:

> *In the event that unforeseen problems require substantial amounts of overtime to be used, or during extended periods of shutdown for refuelling, major maintenance or major plant modification, on a temporary basis, the following limits shall be followed:*
>
> - *An individual should not be permitted to work more than 16 hours straight (excluding shift turnover time) and an individual should not be permitted to work more than 16 hours in any 24-hour period;*
> - *An individual should not be permitted to work more than 24 hours in any 48-hour period;*
> - *An individual should not be permitted to work more than 72 hours in any 7-day period;*
> - *A break of at least 8 hours should be allowed between work periods;*
> - *Except during extended shutdown periods, the use of overtime should be considered on an individual basis and not for the entire staff on a shift.*

The review (NRC 2001) found a number of limitations with these requirements, and was generally quite critical, claiming that scientific studies of work scheduling, fatigue, and human performance indicate that the above scheduling requirements during outages can result in degraded human performance from work-related fatigue. They also criticized these requirements as not being responsive to variations in plant risk that can occur during a shutdown, and to the heightened challenges to human performance that are present in these working conditions. The review also recommended that the NRC consider limitations for periods of time that are longer than seven days.

Finally, the review made it clear that the nomenclature and definitions that are used throughout regulations stipulating maximum hours of work and minimum periods of rest must be clearly defined in order to avoid misinterpretations, and this is especially relevant to periods during outages. For example, what constitutes a "temporary" basis? "Unforeseen problems"? What about "substantial" amounts of overtime? Other concepts that may be equally difficult to clearly define include, for example, a role involving the performance of "safety-related" tasks or work on "safety-related" systems. It is interesting to note that in some industries (e.g., the Australian aviation industry) a "safety sensitive aviation activity", or SSAA, is linked to both the safe operation of aircraft and the safety of individuals in and around aircraft. SSAAs include, but are not limited to the specific roles of: flight crew, cabin crew (flight attendants), flight instructors, aircraft dispatchers, aircraft maintenance and aircraft production workers, air traffic controllers, aviation security activities (including activities involving screening), baggage and ground handlers, and refuellers (CASA, 2012).

The U.S. NRC's current FFD programs include hours of work and rest requirements for periods during unit outages, planned and unplanned security system outages, and "increased threat conditions" that are significantly less restrictive than those in place during normal work periods. During the first 60 days of a planned outage, licensees are required to ensure that those individuals whose role consists of maintenance activities working 12-hour shift schedules shall have at least one day off per 7-day period. Individuals whose role consists of operations, health physics or chemistry, or involves being a member of the fire brigade working 12-hour shift schedules shall have at least three days off per (non-rolling) 15-day period. Finally, those individuals whose role is providing plant security working 12-hour shift schedules shall have at least four days off in each successive (non-rolling) 15-day period.

For periods during the first 60 days of an *unplanned* security system outage or increased threat condition, licensees are not required to meet even the above reduced requirements for those individual employees whose role consists of providing plant security.

Finally, the 60-day period may be extended in 7-day increments for each non-overlapping 7-day period an individual has worked not more than 48 hours during the outage.

The ANSI/API (2010) recommended practice specifies that, during outages, hours of service limits for those individuals working 12-hour shifts include that work sets not exceed 14 consecutive day or night shifts, that a minimum of 36 hours "off" be provided after a work set, that holdover periods should not exceed two hours and, where appropriate, should occur at the end of the day shift. The document makes note that "the start-up and shut-down of a process is a critical time in operations and due consideration should be provided so safety critical personnel are well rested and fit for duty" (p.5).

During outages, the ANSI/API (2010) recommended practice specifies that hours of service limits for individuals working 10-hour shifts include the following limits: work sets not exceed 14 consecutive calendar days, there shall be a minimum of 36 hours off after a work set, and any holdover periods should not exceed two hours (and, where possible, occur at the end of the day shift).

For those working 8-hour shifts, the ANSI/API (2010) document states that, during outages, hours of service limits include that work sets not exceed 19 consecutive calendar days, that there shall be a minimum of 36 hours "off" after a work set, and that holdover periods not exceed two hours (and, where possible, occur at the end of a day shift).

The NAV Canada collective agreement with CATCA specifies that the usual limit of nine consecutive shifts in a row can be exceeded in cases of "emergency"; however, "emergency" is not defined in the agreement (NAV Canada 2012).

Recommendation #13: In sections 3.1.1 to 3.1.8, the scientific evidence underpinning the recommended hours of work restrictions was presented. To our knowledge there are no studies that provide a basis for granting exceptions to the hours of work limits or rest periods for short durations at times of peak demand. Indeed, if anything, work at times of peak demand would be expected to be more stressful than during normal working hours. Permitted hours suggested above are already long, considerably more than the standard 40-hour work week, with its 68-hour recovery period, and involve shift work, circadian disruption and compromised sleep when working night shifts. Without decreasing safety, there is no scientific basis for allowing exceptions to the hours of work limits or rest periods. For the same reason, workers trading shifts or working overtime should not be exempted from the regulations. It is also recommended that, for planned shutdown periods, appropriate scheduling be implemented based on the earlier recommendations for work and recovery schedules for normal procedures.

3.4 Other Recommendations (Recommendation #14)

The literature review revealed a number of studies and review articles that made recommendations regarding how to augment the effectiveness of hours of work and rest requirements by enacting countermeasures. The most commonly cited countermeasures were the implementation of fatigue risk management systems (FRMSs), the use of naps, and employee training in fatigue management.

3.4.1 Fatigue Risk Management Systems (FRMS)

The ACOEM Presidential Task Force on fatigue risk management concluded that it is important for an organisation to enact a comprehensive FRMS (Lerman et al. 2012) in addition to following hours of work and rest requirements or guidelines. These authors cite concepts put forth by Moore-Ede as representing the essential elements of a successful FRMS (Moore-Ede, 2009):

1. Science-based (supported by established peer-reviewed science);
2. Data driven (decisions are based on the collection and objective analysis of data);
3. Cooperative (the FRMS is designed by all stakeholders together);
4. Fully-implemented (there is system-wide use of the FRMS' tools, systems, policies, and procedures);
5. Integrated (the FRMS is built into the corporate safety and health management systems);
6. Continuously improved (the FRMS progressively reduces risk using feedback, evaluation, and modification);
7. Budgeted (the FRMS is justified by an accurate return-on-investment business case); and
8. Owned (the responsibility for the FRMS is accepted by senior corporate leadership).

These elements underpin key attributes of an effective FRMS, which include: the understanding that both employee and employer share the responsibility for preventing fatigue, that an organisation is responsible for the systematic support of operator alertness, and that, given adequate time away from work, employees are responsible for making arrangements to get enough sleep. It is also important that a FRMS provide defences against the risk of fatigue. According to Moore-Ede (2009), there are five such defences:

1. Workload-staffing balance (providing sufficient staffing levels limit opportunities for unexpected employee absences requiring overtime by other employees);
2. Shift scheduling (assigning shifts requiring the performance of safety sensitive tasks during periods of circadian "highs"; allowing maximum sleep opportunities between shifts; limiting shift duration and overtime);
3. Employee fatigue training and sleep disorder management with periodic re-training (employees can then be responsible for their own sleep management; training of family members can also improve the effectiveness of fatigue training; sleep disorder screening and treatment can be applied to manage these common causes of workplace fatigue);
4. Workplace environmental design (designing the workplace so that it is conducive to alertness – e.g., light, temperature, humidity, noise, and ergonomics; providing spaces that adequately accommodate work breaks and/or naps, if relevant); and
5. Fatigue monitoring (ensuring supervisors and co-workers are able to identify the acute signs of fatigue as well as repeated bouts of chronic fatigue, supporting supervisors to apply fatigue mitigation strategies—for example, require that a break be taken, refer an employee for medical evaluation of a sleep disorder).

Kogi (2001), in a review of earlier shift work research, concludes that, in addition to a reliance on flexible work schedules and teamwork, there is a need for industry to implement what he calls "participatory planning" and "multi-area improvements" (Kogi, 2001). While not explicitly defined as FRMS, the tenets put forth are certainly in line with this approach to fatigue and shift work management. According to Kogi, it is only when a broader approach to shift work management is adopted that healthy shift workers and healthy shift work become compatible. In Kogi's opinion, the conditions required to allow this compatibility include: a) comprehensive measures to improve work schedules and job life, b) strict risk management that includes ergonomics and social supports, and c) locally adjusted steps to enable continuous improvement.

The U.S. NRC concluded in 2001 that there was an adequate technical basis and relevant experience to develop new requirements that were technically sound and practical in nuclear plant settings. These requirements were recommended to include fatigue management principles. In fact, the authors specifically identified the "fatigue management" approach that was, at that time, being pursued by some industries in the U.S. and abroad, as a countermeasure that addresses not only limits on hours of work and rest, but other, multiple contributory factors that underlie fatigue. Unlike pure requirements for hours of work and rest, fatigue management approaches also include prevention aspects such as training and health screening, as well as detection, monitoring, mitigation, and evaluation of employees' fatigue. Fatigue management training and evaluation (through employee examination) are now included in the current NRC fitness for duty programs (NRC 2012b).

The ANSI recommendation made by the American Petroleum Institute (ANSI/API 2010) recommends that fatigue among refineries, petrochemical and chemical operations, natural gas liquefaction plans, and other facilities be mitigated through a comprehensive FRMS that is integrated with other safety management systems. The recommended practice relies on the recent general acceptance of FRMS as “the standard for managing and mitigating employee fatigue risk” (Circadian, 2010), and represents movement from the “old and familiar” hours of service rules to a process that requires active management while at the same time allowing increased flexibility. It is recommended that the CNSC consider developing guidelines or recommendations regarding how licensees can best develop and implement FRMS in the Canadian nuclear context.

Whereas previous European flight crew requirements did not specify fatigue management training for aviation personnel, current recommendations (EASA 2012) include mandatory fatigue management training requirements for all operators. Under this new requirement, all aviation operators would be required to provide fatigue management training to their employees, especially those who perform safety sensitive duties. The EASA cites a report by Gundel, which provides the scientific basis for this recommendation (Gundel, 2011). Other recent scientific opinion and research (Dawson et al. 2011; Kogi 2001) also strongly supports FRM training. If implemented using clearly defined concepts and minimum training requirements (e.g., instructor-led, small group size, “refresher” courses, identification of sleep disorders, training for family members, additional training for supervisors; see Lerner et al. 2012), fatigue management training is expected to increase overall safety levels across a broad range of occupations over and above that which can be obtained using hours of work and rest requirements alone. Unfortunately, however, apart from the trucking study mentioned below, there has been little, if any, research to-date looking at safety outcomes as a consequence of the implementation of fatigue training. This is obviously an area in which future research is needed.

In the ATC domain, the collective agreement between NAV Canada and CATCA (NAV Canada 2012) does not specify criteria for FRMS; however, the agreement does contain wording which is indicative of a FRMS approach. For instance, there is a letter of understanding between the parties that, in order to introduce opportunities to waive the “10-hour rule” (the requirement to have a period of at least 10 hours between work shifts), which was requested by the Union, employees have a responsibility to report to work “rested and prepared to perform their duties” (Letter of Understanding 2005-1). As well, the employer is required to closely monitor the use of the waiver, keeping in mind that “the principles of fatigue management will be adhered to at all times”. A separate letter of understanding relating to fatigue management was introduced in 2011 that specified the creation of a joint (NAV Canada/CATCA) Hours of Work committee, which reviews shift scheduling options while keeping the interests of both parties in mind. Further, in the agreement, NAV Canada agrees to keep any overtime work to a minimum.

NAV Canada has developed its own FRMS, which is integrated into its safety management system (SMS). The FRMS includes a number of components including education, preventative and operational strategies, scheduling practices, and the concept of shared (employer/employee) responsibility. All operational controllers receive information on fatigue management during their basic and recurrent training. The goal of the training is to encourage employees to use operational and preventative strategies to help manage the risk of fatigue and related performance decrements. Preventative strategies are used before shifts to properly manage sleep-wake patterns and to reduce the likelihood of fatigue. Operational strategies are used during a shift to maintain alertness and performance levels. These strategies include consuming caffeine, changing the environmental conditions of the workplace, and taking short physical activity and napping breaks.

The heavy vehicle industry in Australia was one of the first to introduce and trial a FRMS-based approach to road safety. In 2008, the National Transport Commission (NTC) introduced heavy vehicle driver fatigue legislation that, rather than stipulating prescriptive hours-of-work requirements, directs operators to manage their own employees' fatigue through the application of occupational health and safety legislation. The legislation also establishes a "chain of responsibility", or CoR, which extends the responsibility for drivers' fatigue beyond the sole responsibility of the driver and his or her company. Indirect members of the CoR include, for example, the schedulers, prime contractors or clients (who may demand that their cargo arrive in unrealistic timeframes), and scheduling and loading managers. Further, the legislation allows three different levels of fatigue management requirements (standard hours, basic fatigue management, and advanced fatigue management), depending on whether and the extent to which organisations can demonstrate that they manage driver fatigue using more "sophisticated" methods than hours of work and rest requirements alone (NTC, 2010). This kind of outcome-based (e.g., fatigue management) approach could be adopted by the CNSC to decide whether a licensee would be permitted to allow exceptions to the hours of work and rest criteria.

FRMS have been evaluated in terms of their ability to impact heavy vehicle drivers' sleep-wake behaviour and performance. In 2007, FRMS were implemented at three North American trucking companies. All drivers participating in the study, as well as a number of managers, trainers and dispatchers, received education on fatigue and sleep disorders. All drivers were screened for sleep disordered breathing, and treated if appropriate. Before-after measures showed that the FRMS programs had a positive impact on drivers' sleep-wake behaviour and performance on a fatigue sensitive psychomotor vigilance task. In addition, the study demonstrated a beneficial effect of education on corporate health and safety measures of absenteeism and crash rate (Smiley, Smahel, Boivin, Boudreau, Remmers, Turner, Rosekind, & Gregory, 2009).

Based on developments in various work settings discussed above, it is clear that fatigue management principles should be seriously considered for inclusion in any effective fatigue management approach. It should be noted that FRMS ought to be more easily implemented in the nuclear industry as compared to aviation or trucking given the nuclear industry's relatively stable and consistent work hours and fixed work location.

3.4.2 Naps

In recent years, the use of structured naps to decrease the performance-impairing effects of fatigue has received increasing support among industry groups (Lerman et al. 2012). Strategic, controlled (i.e., shorter than 45 minutes' duration) naps have been shown to reduce or delay expected fatigue-related performance decrements and to improve subjective ratings of fatigue. The limit of 45 minutes is stipulated in order to maximize the restorative functions of deep sleep attained during early sleep phases, while minimising the likelihood for negative consequences of naps, such as sleep inertia, that are likely to be encountered with longer periods of sleep.

The dangers of exceeding recommended time limits on naps, especially among certain industries, were revealed in 2011, when a pilot of a passenger plane flying over the Atlantic Ocean was allowed to sleep for 70 minutes. He awoke from his nap[1] and mistook the planet Venus for the lights of an approaching aircraft. The pilot then reacted to the perceived imminent collision by pushing forward on the control column, which caused the aircraft to suddenly pitch forward. Fourteen people seated towards the rear of the aircraft were injured (TSB, 2012).

Folkard et al. (2005), in their review of earlier shift work studies, note that, while fatigue-related injury risk increases in an approximately exponential fashion across time on shift, it appears that this risk decreases after the fifth hour on task (Folkard et al. 2005). These authors suggest that it is the influence of breaks during a duty period that may be contributing to this reversal of risk rate occurring after the fifth hour of work. Indeed, in a seminal study on the effects of rest breaks on work-related accident risk in automotive factory workers, rest breaks successfully counteracted the accumulation of risk noted over 2-hour periods of continuous, repetitive, and largely machine-paced work (Tucker et al. 2003). Risk immediately after a break was reduced to a rate close to that recorded at the start of the preceding period of work. However, the authors note that the restorative effects of breaks were short lived. It is probable that rest breaks that allowed for the accumulation of restorative sleep (i.e., naps) would bring about even more significant risk-offsetting effects.

Driscoll et al. (2007), in their systematic review of the experimental shift work literature, identified only two methodologically sound empirical studies relating to the effect of naps during night shifts on performance and alertness (Purnell, Feyer, & Herbison, 2002; Sallinen, Harma, Akerstedt, Rosa, & Lilliqvist, 1998). The review authors concluded that the two studies, which showed some benefits of short (i.e., 20 – 50 minutes) naps on vigilance and lapses across the work shift but lack of findings on other measures (such as reaction time and subjective sleepiness ratings), were inconclusive in terms of supporting the use of naps as a fatigue intervention strategy. However a study by Smiley and Davis (2006), which also reviewed the literature, provided specific “lessons” as to when napping was effective (e.g., after partial sleep restriction) and when it was not (e.g. after the operator had been awake all night) (Smiley and Davis 2006).

The U.S. NRC’s current FFD programs (NRC 2012b) recognize the potential benefits of a nap during a shift, but only if it is of sufficient duration and taken in surroundings that are conducive to restorative sleep. The FFD programs (Section 26.205[2]) allow licensees to exclude from the calculation of work hours, that portion of a break or rest period “during which there is a reasonable opportunity and accommodations for restorative sleep (e.g., a nap)”.

Whereas previous EU commercial pilot requirements did not include any allowances for naps, the EASA (2012) now recommends that pilots be allowed a duty extension “due to in-flight rest”, citing research extolling the benefits of in-flight naps (Moebus Aviation 2008; Simon & Spencer, 2007). The proposed extension is based on the average ratio of in-flight rest in a certain in-flight rest facility (which is recommended *not* to be an economy passenger seat) and the actual in-flight sleep, and credits two hours of additional wakefulness for each hour of sleep. This formula is said to preserve the principle that any crew members should amass a total sleep opportunity of eight

[1] Air Canada Flight Operations Manual, Section 2.9.10 — Alertness Management, describes “controlled rest” as an operational fatigue countermeasure that improves on-the-job performance and alertness when compared to non-countermeasure conditions. Controlled rest uses strategic napping on the flight deck to improve crew alertness during critical phases of flight. The rest periods are a maximum of 40 minutes in length (periods to be reviewed prior to resting) and must be completed 30 minutes prior to the top of aircraft descent.

hours in a 24-hour period. Based on these calculations, longer extensions to the flight duty period would only be achievable if high quality in-flight napping facilities were provided.

In 2001, NAV Canada began to develop a FRMS for ATC operational staff with the assistance of international fatigue experts. This FRMS is now integrated within NAV Canada's SMS (Lindeis, 2008). Since 1999, they have double-staffed night shifts in order to allow employees to take strategic (controlled) naps of between 20 and 45 minutes during their breaks. NAV Canada also provides education programs for its 2,200 controllers about the science of sleep, and the role of circadian rhythms, good nutrition and "sleep hygiene" (Mertl, 2011).

3.4.3 The role of education

In the nuclear industry, education on fatigue could address such issues as the appropriate use of napping to extend performance (Smiley and Davis 2006), the value of forward rather than backward rotating shifts (Driscoll et al. 2007; Jaffe et al. 1996; Luna, 1997), the impact of shift change time on sleep and performance (Tucker et al. 1999), and strategic use of caffeine (Reyner & Horne, 1997). Lerman et al. (2012) emphasize the importance of training for family members, too. To be successful however, worker education must be part of a larger FRMS. A study of railroad workers by Popkin and Coplen showed that although these workers had a positive response to fatigue education, there was no change in their behaviour, likely because their working environment had not changed (Popkin & Coplen, 1995). Unless there is some accommodation for applying fatigue management strategies (e.g., a quiet area to nap or avoiding tasks that are particularly demanding at the end of a series of night shifts), knowledge that one is fatigued without the opportunity to mitigate it is not helpful.

3.4.4 Key additional requirements for managing fatigue-related risks

Based on the scientific literature and benchmarking, fatigue countermeasures which should be considered by CNSC include the implementation of fatigue risk management systems (FRMSs), the use of naps, and employee training in fatigue management as part of a FRMS.

4 CONCLUSIONS

The highlights of the literature review are summarized below.

With respect to a maximum regular shift limit of 12 hours, a systematic review of experimental shift work research literature up until 2006 found that 12-hour shifts were neither significantly better, nor worse, than 8-hour shifts in terms of sleep indices or measures of alertness (Driscoll et al. 2007). However, a study on the effects of over 20 years of rotating 12-hour shifts in Canadian petroleum refinery workers found numerous drawbacks of 12-hour shifts including chronic fatigue, impaired recovery, and sleep disorders (Bourdouxhe et al. 1999). A study of nurses found that inadequate inter-shift sleep duration on 12’s may underpin increased (from shorter duration shifts) work-related accidents and injuries and errors (Geiger-Brown et al. 2012). This study demonstrates the importance of improving the quantity and quality of intershift sleep. The relative risk of having an occupational accident was found to increase dramatically after nine consecutive hours on the job (Hanecke et al. 1998; Colquhoun et al. 1996), and performance declines were found after 12 hours on a task (Folkard 1997; Dawson and Reid 1997; Rosa 1991). Finally, a meta-analysis of shift work studies found that 10-hour shifts were associated with a 13 per cent increase (over 8-hour shifts) and 12-hour shifts with a 27 per cent increase in risk of accidents or injuries (Folkard et al. 2005).

With respect to allowing a longer day than night shift, there are numerous studies indicating that night shifts were associated with more negative effects of various kinds than were day shifts including less sleep (e.g. Pternitis 1977; Grandjean 1982) and severe sleepiness especially following long hours (Son and et al. 2008, Geiger-Brown et al. 2012).

The limiting of weekly work to 60 hours was supported by two studies of injury risk (Vegso et al. 2007, Lombardi et al. 2010).

With respect to allowing a maximum of 26 hours in a 48-hour period, 260 hours for a 5-week cycle, and 2400 hours in a year, studies were not found that dealt specifically with these time periods. Instead a combination of scientific evidence and benchmarking supported by scientific opinion was the basis for the recommendations.

With respect to the purpose of determining compliance with the limits, a review of the literature found evidence that naps are restorative if taken under appropriate conditions (e.g. after partial, but not full, sleep restriction) (Smiley and Davis 2006). Thus, it was recommended to exclude time spent napping from the calculation of working time.

The current recommendations consider time frames of maximum shift length, hours in 24 hours, in 48 hours, in 7 days, in 5 weeks and in 1 year. It was concluded that no limits for time frames other than those mentioned above are required.

Individuals who perform construction work on safety relevant facilities should be covered under CNSC hours of work regulations. Construction workers face both mental and physical fatigue, both of which contribute to potential impaired performance. They report more injuries, more overtime, and are more likely to work more than one job, compared to other employee groups (Dong 2005).

For 12-hour shifts, the recommended maximum is 5 consecutive day shifts or 4 consecutive night shifts; for 10-hour shifts, the same; and for 8-hour shifts, 6 consecutive day and 5 consecutive night shifts. The shorter number of allowed consecutive night versus day shifts is supported by a study (one of many) showing that night workers' self-reported sleep quality and perceived alertness are worse than day workers' (Fischer 2004).

With respect to direction of rotation, in their review of the shift work literature up until 2006, Driscoll et al. (2007) determine that forward rotating shift systems (that apply to 8-hour shifts) were associated with better sleep quality, increased sleep length, less fatigue, and fewer attention lapses than backwards rotating systems (Driscoll et al. 2007).

With respect to recovery periods, a study found that, following four 13-hour shifts, 60 hours off was preferable to 36 hours, for both day and night (truck) drivers, but especially for the latter (Wylie et al. 1997). Another study found that, after a 5-day week of 14-hour shifts, a time-off period which allowed two night periods and one day period off (i.e., 36 hours) allowed full recovery from daytime truck driving (O'Neil et al. 1999). A review of several studies by Akerstedt and colleagues, which looked at shift work and recovery needs in various industries, found that, for most schedules – day or night, weekly or rapid rotation, 8-hour or 12-hour, regular or irregular – one recovery day that allowed for two nights of sleep was sufficient for workers' subjective alertness levels to reach normal daytime values (Akerstedt et al. 2000). An exception to the "one recovery day" finding, however, was for construction workers working seven 12-hour shifts who needed between 4 to 5 days off to reach normal daytime levels of alertness. Two full days of recovery was also recommended to allow workers to recover from a work schedule that involves working a sequence of long (more than 8 hours) work hours.

It should be noted that working at the limits for hours of work and rest is not sustainable and may lead to chronic sleep debt (ANSI/API, 2010).

Fatigue risk management systems (FRMS) are being promoted in a number of organizations (Lerman et al. 2012). Moore-Ede (2009) describes five components of FRMS: 1) Workload-staffing balance; 2) Shift scheduling; 3) Employee fatigue training and sleep disorder management with periodic re-training; 4) Workplace environmental design; and 5) Fatigue monitoring. FRMS programs have been shown to have a positive impact on sleep-wake behaviour and performance (Smiley et al. 2009).

The EASA (2012) recommends making fatigue management training mandatory for European aviation operators. The U.S. NRC's fitness for duty programs (NRC, 2012b) comprise some elements of a FRMS; for example, training of employees to identify potential adverse effects of fatigue. ANSI/API (2010) and NAV Canada (Lindeis, 2008) also support the promotion of FRMS; for instance, educating employees to recognize the signs of fatigue and the appropriate use of fatigue countermeasures. Scientific support for FRMS is provided by Dawson et al. (2011) and Kogi (2001).

The use of structured naps to decrease the performance-impairing effects of fatigue has received increasing support among industry groups (Lerman et al. 2012). A review by Driscoll et al. (2007)

indicates inconclusive findings with respect to the value of naps on the night shift. However, a review by Smiley and Davis (2006) provides specific examples of when naps are effective.

A beneficial effect of fatigue education (as part of a FRMS) on measures of absenteeism and crash rate was found (Smiley et al. 2009).

5 SUMMARY OF RECOMMENDATIONS

A summary of hours of work recommendations supported by the scientific literature and by benchmarking are given below. Where changes from the proposed 2005 CNSC regulations are recommended, the original recommendation is noted.

1. The regular shift limit should be a maximum of 12 hours.

2. The maximum night shift (i.e. a shift including the period between midnight and 5:00 a.m.) should be 12 hours; otherwise, a day shift could be extended to 16 hours in a 24-hour period. (Original limit allowed 16 hours in 24 hours on rare occasions with no restriction to day shifts.)

3. The maximum number of hours that should be worked in a 48-hour period is 26. (Original limit was 28 hours.)

4. Work hours should have a rolling limit of 60 hours in a 7-day period. (Original limit was not a rolling limit.)

5. Work hours should be limited to 260 hours for a 5-week cycle. (Original limit was 268 hours for a 5-week cycle.)

6. Yearly hours should be limited to 2400.

7. For the purpose of determining compliance with the limits, all time should be included from the time that the worker reports to work until the time that the worker is relieved from all responsibility for work, including unpaid lunch or rest breaks, with the exception of restorative naps. (Original limit was not to make an exception of naps.)

8. At this time, there is no scientific evidence to suggest that limits for time frames other than those mentioned above are required.

9. Individuals who perform construction work on safety relevant facilities should be covered under the same CNSC hours of work regulations as power plant operators or others with safety sensitive roles.

10. For 12-hour shifts, the recommended maximum is 5 consecutive day shifts or 4 consecutive night shifts.
    a. A minimum recovery period of 48 hours shall follow a block of 5 consecutive day shifts, excluding shift turnover time. (Original rest periods required 48 hours off following a block of 3 or more consecutive day shifts.)
    b. A minimum recovery period of 72 hours shall follow a block of 3 or 4 consecutive night shifts, excluding shift turnover time. (Original rest periods required 48 hours off following a block of 2 or more consecutive night shifts.)

11. For 10-hour shifts, the recommended maximum is 5 consecutive day shifts or 4 consecutive night shifts. (Original limits did not include mandatory rest periods following a block of 10-hour shifts.)
    a. A minimum recovery period of 48 hours shall follow a block of 5 consecutive day shifts, excluding shift turnover time;
    b. A minimum recovery period of 72 hours shall follow a block of 3 or 4 consecutive night shifts, excluding shift turnover time.

12. For 8-hour shifts, the recommended maximum is 6 consecutive day or evening shifts, or 5 consecutive night shifts. (Original limits did not include mandatory rest periods following a block of 8-hour shifts.)
    a. A minimum recovery period of 36 hours should follow a block of 5 or 6 consecutive day or evening shifts, excluding shift turnover time;
    b. A minimum recovery period of 48 hours should follow a block of 4 or 5 consecutive night shifts, excluding shift turnover time;
    c. A forward direction of shift rotation should be used for those individuals working 8-hour shifts.

13. It should be noted that working at the limits for hours of work and rest is not sustainable and may lead to chronic sleep debt. Without decreasing safety, there is no scientific basis for allowing exceptions to the hours of work limits or rest periods.

14. Further fatigue countermeasures which should be considered by CNSC include the implementation of fatigue risk management systems (FRMSs), the use of naps, and employee training in fatigue management as part of a FRMS.

6 AREAS OF FUTURE RESEARCH

In carrying out this literature review, there were numerous scientific studies found concerning the effects of working long hours within a 24-hour period, and within a one-week period (based on averaging annual hours). However, no studies were found that specifically considered issues of the effects of working long hours over periods longer than a week on safety impacts. This makes it difficult to make recommendations that are empirically based. It is important, therefore, that future research consider time periods longer than one week. Further, no studies were found directly comparing recovery requirements for 10-hour as compared to 12-hour shifts. The lack of carefully conducted research in this area makes it difficult to make firm conclusions on the effects of 10-hour shifts, and recommendations regarding their application. Research in this area is needed.

Similarly, there was a paucity of research found that related to issues related to overtime work. Overtime issues which need exploration include the relevance of time of day to when the overtime is worked; the importance of rest breaks and their potential for allowing extensions to the work day; and the influence of the type of work and amount of overtime on the nature of errors and any other relevant behavioural changes (Spurgeon et al. 1997).

Finally, throughout the literature review, the importance of FRMS was particularly noteworthy. While FRMS were, and continue to be, recommended by a number of authors, few studies have been carried out to determine if they are as effective and as cost-beneficial as predicted. One exception is a study in the trucking industry showing positive effects on sleep and on some aspects of performance. More studies of this nature are critically needed in other fatigue-sensitive industries. As is noted by EASA (2012): “Once a rule is in place it is crucial to monitor if the objectives are indeed achieved in an effective and efficient manner.” (p.23). FRMS are intended to reduce fatigue and resulting incidents. If they become required, it is vital that they be evaluated and fine-tuned to ensure that the goal is being met.

7 REFERENCES

ACGME. *Accreditation Council for Graduate Medical Education*. Available at: www.acgme.org/acgmeweb/tabid/271/GraduateMedicalEducation/DutyHours.aspx. 2011.

Adamus, D. and Booth, J. *Report of the Canadian Aviation Regulation Advisory Council (CARAC) flight crew fatigue management working group - June 27*. Available at: http://www.h-a-c.ca/RDIMS-7640094-v2-FLIGHT_CREW_FATIGUE_MANAGEMENT_WORKING_GROUP_DRAFT_REPORT.pdf. 2012.

Akerstedt, T., Kecklund, G., Gillberg, M., Lowden, A., and Axelsson, J. Sleepiness and days of recovery. *Traffic Psychology and Behaviour*, *3*, 251-261. 2000.

ANSI/API . *Fatigue risk management systems for personnel in the refining and petrochemical industries*. ANSI/API recommended practice 755. Available at: http://publications.api.org. 2010.

Baker, T.L., Campbell, S.C., Linder, K.D., and Moore-Ede, M. *Control-room operator alertness and performance in nuclear power plants*. Electric Power Research Institute Report NP-674, Palo Alto, CA. 1990.

Balkin, T., Thome, D., Sing, H., Thomas, M., Redmond, D., Wesensten, N., Williams, J., Hall, S., and Belenky, G. *Effects of sleep schedules on commercial motor vehicle driver performance*. Federal Motor Carrier Safety Administration, U.S. Department of Transportation. 2000.

Barton, J., Spelten, E., Totterdell, P., Smith, L., and Folkard, S. Is there an optimum number of night shifts? Relationship between sleep, health and well-being. *Work & Stress*, *9*(2-3), 109-123. 1995.

Bourdouxhe, M.A., Quéinnec, Y., Granger, D., Baril, R.H., Guertin, S.C., Massicotte, P.R., Levy, M., and Lemay, F.L. Aging and shiftwork: The effects of 20 years of rotating 12-hour shifts among petroleum refinery operators. *Experimental Aging Research*, *25*(4), 323-329. 1999.

CASA. *What is an SSAA*. CASA web site. Accessed December 12, 2012. Available at: http://www.casa.gov.au/scripts/nc.dll?WCMS:Standard::pc=PC_100004. 2012.

Circadian. *Technical support document for ANSI/API RP 755, Fatigue risk management systems for personnel in the refining and petrochemical industries*. Circadian, p.5. API Technical Report 755-1, April. 2010.

Colquhoun, W.P., Costa, G., Folkard, S., and Knauth, P. *Shiftwork - problems and solutions*. Peter Lang GmbH: Frankfurt am Main, Germany. 1996.

Dawson, D., Noy, Y.I., Härmä, M., Akerstedt, T., and Belenky, G. Modelling fatigue and the use of fatigue models in work settings. *Accident Analysis & Prevention*, *43*, 549-564. 2011.

Dawson, D. and Reid, J.G. Fatigue, alcohol and performance impairment. *Nature, 388*, 235. 1997.

Dinges, D.F. *Sleep and circadian rhythms*. Presentation made at the NTSB Academy "Investigating for Fatigue" course, November 16 & 16. 2012.

Dong, X. Long work hours, work scheduling and work-related injuries among construction workers in the U.S. *Scandinavian Journal of Work and Environmental Health*, *31*(5), 329-335. 2005.

Driscoll, T.R., Grunstein, R.R., and Rogers, N.L. A systematic review of the neurobehavioural and physiological effects of shiftwork systems. *Sleep Medicine Reviews*, *11*(3), 179-194. 2007.

EASA. *Subpart 1 - Flight and duty time limitations and rest requirements of Annex III of Commission Regulation (EC) No. 859/2008 of 20 August amending Council Regulation (EEC) No. 3922/91 as regards common technical requirements and administrative procedures applicable to commercial transportation by aeroplane*. European Aviation Safety Agency. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:254:0001:0238:EN:PDF. 2008.

EASA. *Appendix 1 to Opinion 04/2012 - Regulatory impact assessment to RMT.0440 (POS.055) - (Flight Time Limitations)*. European Aviation Safety Agency. Available at: http://www.easa.europa.eu/agency-measures/docs/opinions/2012/04/Appendix%201%20to%20Opinion%2004-2012%20(RIA).pdf. 2012.

European Community. *Directive 2003/88/EC of the European Parliament and of the Council of 4 November 2003 concerning certain aspects of the organization of working time*. Available at: http://ec.europa.eu/social/main.jsp?catId=706&langId=en&intPageId=205. 2003.

FAA. *Fact sheet: Pilot fatigue rule comparison*. Federal Aviation Administration. Available at: www.faa/gov/news/fact_sheets/news_story.cfm?newsId=13272. 2011.

FAA. *U.S. DOT flightcrew member duty and rest requirements*. Federal Aviation Administration. Available at: http://www.faa.gov/regulations_policies/rulemarking/recently_published/media/2120-AJ58-FinalRule.pdf. 2012.

Fischer, F.M. What do petrochemical workers, healthcare workers, and truck drivers have in common. *Cad Saude Publica*, *20*(6), 1732-1738. 2004.

FMCSA. *FMCSA 395*. Federal Motor Carrier Safety Administration. Available at: http://www.fmcsa.dot.gov/rules-regulations/administrationfmcsr/fmcsrguidedetails.aspx?menukey=395. 2012.

Folkard, S. Black times: Temporal determinants of transport safety. *Accident Analysis & Prevention*, *29*(4), 417-430. 1997.

Folkard, S., & Akerstedt, T. Trends in the risk of accidents and injuries and their implications for models of fatigue and performance. *Aviation, Space, and Environmental Medicine*, *75(suppl 1)*, A161-A167. 2004.

Folkard, S., & Lombardi, D.A. Designing safer shift systems. In: Aspekte der Arbeitpsychologie au Wissenschaft und Praxis. Eds P. Nickel, K. Hanecke, M. Schutte, & H. Grzech-Sukalo. Pabst Science Publishers: Lengerich. Pp.151-166. 2004.

Folkard, S., & Tucker, P. Shiftwork, safety and productivity. *Occupational Medicine, 53*, 95-101. 2003.

Folkard, S., Lombardi, D.A., and Tucker, P. Shiftwork: Safety, sleepiness and sleep. *Industrial Health*, *43*(1), 20. 2005.

Geiger-Brown, J., Rogers, V.E., Trinkoff, A.M., Kane, R.L., Bausell, R.B., and Scharf, S.M. Sleep, sleepiness, fatigue, and performance of 12-hour-shift nurses. *Chronobiology International*, *29*(2), 211-219. 2012.

Gold, D.R., Rogacz, S., Bock, N., Tosteson, T.D., Baum, T.M., Speizer, F.E., and Czeisler, C.A. Rotating shift work, sleep, and accidents related to sleepiness in hospital nurses. *American Journal of Public Health*, *82*(7), 1011-1014. 1992.

Grandjean, E. *Fitting the Task to the Man: An Ergonomic Approach*. Taylor and Francis Ltd.: London. 1982.

Gundel, A. *Provision of scientific expertise to submit an assessment of the Notice of Proposed Amendment (NPA) on flight time limitations (FTL) and to provide guidance and advice to the FTL Review Group*. Final report. Available at: http://east.europa.eu/rulemaking/docs/crd/2011/CRD%202010-14/CRD%202010-14.pdf. 2011.

Hanecke, K., Tiedemann, S., Nachreiner, F., and Grzech-Sukalo, H. Accident risk as a function of time on task and time of day. Abstracts from the XII International Symposium on Night and Shiftwork: New Challenges for the Organisation. Majvik, Finland. *Shiftwork International Newsletter*, *14*(1) 1998.

Heslegrave, R. *Subjective and objective changes in performance and sleep in air traffic controllers as a function of shift type, shift length, and age*. Proceedings of the European Symposium of Ergonomics on Working Time: Changes in Work and New Challenges, Troia, Portugal, pp. 10.1.1-10.1.12, June. 1998.

Heslegrave, R., Reinish, L., Beyers, J., Picard, L., Horbul, B., Huterer, N., Jovanovic, D., Sabanadzovic, S., Kayumov, L., Chung, S., Flint, A., Hall, G., and Shapiro, C. *The short-term impact of changing shift duration from 8 to 10.5 hours*. Proceedings of the XIV International Symposium on Night and Shiftwork: Shiftwork in the 21st Century, Wiesensteig, Germany, September. 1999.

Heslegrave, R., Reinish, L., Beyers, J., Picard, L., Horbul, B., Huterer, N., Jovanovic, D., Sabanadzovic, S., Kayumov, L., Chung, S., Flint, A., Hall, G. and Shapiro, C. *The differential impact of extended 10-hour shifts on day and night shifts.* In: Hornberger, S., Knauth, P., Costa, G., and Folkard, S. (eds.), *Shiftwork in the 21st Century*. Frankfurt am Main: Peter Lang GmbH, p. 67-72. 2000.

Heslegrave, R. Personal communication. 2013.

Jaffe, M.P., Smolensky, M.H., and Wun, C.C. Sleep quality and physical and social well-being in North American petrochemical shift workers. *South Medical Journal*, *89*(3), 305-312. 1996.

Kecklund, G. and Akerstedt, T. Effects of timing of shifts on sleepiness and sleep duration. *Journal of Sleep Research*, *4*(S2), 47-50. 1995.

Kogi, K. Healthy shiftwork, healthy shiftworks. *Journal of Human Ergology, Tokyo (1-2)*, 3-8. 2001.

Kulp, K. *Development of a regulatory monitoring program for shiftwork systms at Canadian nuclear power plants*. RSP-0096. 1999.

Lamberg, L. Impact of long working hours explored. *Journal of the American Medical Association*, *292.1*, 25-26. 2004.

Lerman, S.E., Eskin, E., Flower, D.J., George, E.C., Gerson, B., Hartenbaum, N., Hursh, S.R., and Moore-Ede, M. Fatigue risk management in the workplace. *Journal of Environmental Medicine*, *54*(2), 231-258. 2012.

Lewis, P.M. *Shift scheduling and overtime: A critical review of the literature*. Prepared for the Nuclear Regulatory Commission under Contract DE-AC06-76-RLO. 1985.

Lille, F. Le sommeil de jour d'un groupe de travailleurs de nuit. *Travail Humain*, *30*, 85-97. 1967.

Lindeis, A. *NAV Canada's fatigue management program*. Presented at the FAA Fatigue Management Symposium: Partnerships for Solutions, Vienna, VA, June 17 - 19. 2008.

Lombardi, D.A., Folkard, S., Willetts, J.L., and Smith, G.S. Daily sleep, weekly working hours, and risk of work-related injury: US National Health Interview Survey (2004-2008). *Chronobiology International*, *27*, 1013-1030. 2010.

Luna, T.D. Air traffic controller shiftwork: What are the implications for aviation safety. *Aviation, Space & Environmental Medicine*, *68*(1), 69-79. 1997.

Mallette, R. *Shift study and assessment of 48 and 72-hour rest breaks*. Ontario Hydro HRP and Development. 1994.

Mein, D., Heslegrave, R., David, J., Dooling, M., Fox, K., and Labrosse, B. *Report of the Tripartite Steering Committee on ATC Fatigue*. Transport Canada Report No. TP-13742E, Ottawa, Canada. 2001.

Mertl, S. *Why sleeping on the job makes Canada's skies safer*. Yahoo! Canada news. Available at: http://ca.news.yahoo.com/why-sleeping-on-the-job-makes-canada-s-skies-safer.html. 2011.

Moebus Aviation. *Scientific and medical evaluation of flight time limitations*. Moebus study, final report. EASA: Cologne, 30 September. Available at: http://www.easa.europa.eu/rulemaking/docs/research/FTL%20Study20Final%20Report.pdf. 2008.

Moore-Ede, M. *Evolution of fatigue risk management system: the "tipping point" of employee fatigue mitigation*. Circadian White Papers. Available at: www.circadian.com/pages/157_white_papers.cfm. 2009.

Muller, R., Carter, A., and Williamson, A.M. Epidemiological diagnosis of occupational fatigue in a fly-in- fly-out operation of the mineral industry. *Annals of Occupational Hygiene, 52*(1), 63-72. 2008.

NAV Canada. *Collective agreement between NAV Canada and the Canadian Air Traffic Control Association, CAW Local 5454*. 2012.

NRC. *Attachment 1 - Assessment of the NRC's "Policy on factors causing fatigue of operating personnel at nuclear reactors"*. Nuclear Regulatory Commission. 2001.

NRC. *NRC 10 CFR*. Available at: http://www.nrc.gov/reading-rm/doc-collections/cfr/part026/. 2012a.

NRC. *Part 26: Fitness for duty programs, Subpart 26.205 "work hours"*. National Research Council. 2012b.

NTC. *Advanced Fatigue Management explained*. Heavy vehicle driver fatigue reform information bulletin. National Transport Commission. Available at: www.ntc.gov.au. 2008a.

NTC. *Basic Fatigue Management explained*. Heavy vehicle driver fatigue reform information bulletin. National Transport Commission. Available at: www.ntc.gov.au. 2008b.

NTC. *Standard Hours explained*. Heavy vehicle driver fatigue reform information bulletin. National Transport Commission. Available at: www.ntc.gov.au. 2008c.

NTC. *Advanced fatigue management explained*. National Transport Commission. Available at: http://www.ntc.gov.au/viewpage.aspx?documentid=1500. 2010.

NTC. *Safety and compliance: Heavy vehicle driver fatigue (June)*. National Transport Commission. Available at: http://www.ntc.gov.au/viewpage.aspx?AreaId=35&DocumentId=1409. 2011.

O'Neil, T.R., Kruegar, G.P., Van Hemel, S.B., and McGowan, A.L. *Effects of operating practices on commercial driver alertness*. Rep. No. FHWA-MC-99-140, Office of Motor Carrier and Highway Safety, Federal Highway Administration, Washington, D.C. 1999.

Paech, G.M., Jay, S.M., Lamond, N., Roach, G.D., and Ferguson, S.A. The effects of different roster schedules on sleep in miners. *Applied Ergonomics, 41*(4), 600-606. 2010.

Popkin, M. and Coplen, M.K. Effects of an educational program for shiftworkers and their spouses. *Shiftwork International Newsletter*, *12*(1), 50. 1995.

Price, N.J., Rogers, N.L., Fox, C.G., Szuba, M.P., Van Dongen, H.P., and Dinges, D.F. Sleep physiology following 88h total sleep deprivation: Effects of recovery sleep duration. *Sleep*, *25*(Abstract Supplement 2000), A92-A93. 2002.

Pternitis, C. *Etudes electrophysiologiques au cours du sommeil chez l'ouvrier poste*. In Ergonomie du travail de nuit et des horaires alternants, P. Andlauer and collab. (Ed.) Editions Cujas, Paris. 1977.

Purnell, M.T., Feyer, A., and Herbison, G.P. The impact of a nap opportunity during the night shift on the performance and alertness of 12-h shift workers. *Journal of Sleep Research*, *11*(3), 219-227. 2002.

Reyner, L.A. and Horne, J.A. Suppression of sleepiness in drivers: Combination of caffeine with a short nap. *Psychophysiology*, *34*, 721-725. 1997.

Rogers, N.L., Van Dongen, H.P., Power IV, J.W., Carlin, M.M., Szuba, M.P., Maislin, G., and Dinges, D.F. Neurobehavioural functioning during chronic sleep restriction at an adverse circadian phase. *Sleep*, *25*(Abstract Supplement 2000), A126-A127. 2002.

Rosa, R. Performance, alertness and sleep after 3.5 years of 12 h night shifts: A follow-up study. *Work & Stress*, *5*, 107-116. 1991.

Rosekind, M., Neri, D.F., and Dinges, D.F. *From laboratory to flightdeck: Promoting operational alertness*. In: *Fatigue and Duty Time Limitations - An International Review*. Proceeding of the Aeronautical Society. 1997.

Sallinen, M., Harma, M., Akerstedt, T., Rosa, R., and Lilliqvist, O. Promoting alertness with a short nap during a night shift. *Journal of Sleep Research*, *7*, 240-247. 1998.

Shapiro, C.M., Heslegrave, R.J., Beyers, J., and Picard, L. *Working the Shift: A Self-Help Guide.* JoliJoco Publications. 1997.

Simon, M.J. and Spencer, M.B. *Extension of flying duty period by in-flight relief, TNO Defence, Security, Safety; September*. 2007.

Smiley, A., Boivin, D.B., Heslegrave, R., and Davis, D. *Investigation of commercial motor vehicle driver cumulative fatigue recovery periods: Phase II*. Report No. TP14245E. Transportation Development Centre, Transport Canada. 2004.

Smiley, A. and Davis, D. *Investigation of commercial motor vehicle driver cumulative fatigue recovery periods: Napping literature review*. Report No. TP14614E prepared for the Transportation Development Centre, Transport Canada, Ottawa, Canada. 2006.

Smiley, A. and Moray, N. *Review of 12-hour shifts at nuclear generating stations*. Final report: INFO-0318. 1989.

Smiley, A., Smahel, T., Boivin, D.B., Boudreau, P., Remmers, J.E., Turner, M., Rosekind, M., and Gregory, K.B. *Summary Report: Effects of a fatigue management program on fatigue in the commercial motor carrier industry*. Report No. TP 14921E. Transportation Research Centre of Transport Canada, Ottawa, Canada. 2009.

Son, M.I.A. and et al. Effects of long working hours and the night shift ln severe sleepiness among workers with 12-hour shift systems for 5 to 7 consecutive days in the auotmobile facatories of Korea. *Journal of Sleep Research, 17*(4), 385-394. 2008.

Spurgeon, A., Harrington, J.M., and Cooper, C.L. Health and safety problems associated with long working hours: A review of the current position. *Occupational and Environmental Medicine, 54*(6), 367-375. 1997.

Steele, M.T. and et al. The occupational risk of motor vehicle collisions for emergency medicine residents. *Academic Emergency Medicine*, *6*, 1050-1053. 1999.

Swain, A.D. and Guttmann, H.E. *Handbook of human reliability analysis with emhasis on nuclear power plant applications*. NUREG/CR-1278. Washington, DC. 1983.

Totterdell, P., Spelten, E., Smith, L., Barton, J., and Folkard, S. Recovery from work shifts: How long does it take? *Journal of Applied Psychology*, *80*, 43-57. 1995.

Transport Canada. *Flight and duty times*. Available at: http://www.tc.gc.ca/eng/civilaviation/standards/general-flttrain-integrated-guidance-flight-2021.htm. 2010.

Transport Canada. *Commercial vehicle drivers hours of service regulations SOR/2005-313, current to December 10, 2012*. Available at: http://www.tc.gc.ca/eng/roadsafety/safedrivers-CommercialDrivers-HoursofService-index-110.htm. 2012.

TSB. *Aviation Investigation Report A11F0012. Pitch excusion, Air Canada, Boeing 767-333, C-GHLQ, North Atlantic Ocean, 55º00'N 029º00'W*. Transportation Safety Board. Available at: http://www.tsb.gc.ca/eng/rapports-reports/aviation/2011/a11f0012/a11f0012.pdf. 2012.

Tucker, P., Folkard, S., and Macdonald, I. Rest breaks and accident risk. *The Lancet*, *361*, 680. 2003.

Tucker, P., Smith, L., Macdonald, I., and Folkard, S. Distribution of rest days in 12-hour shift systems: Impacts on health, wellbeing, and on shift alertness. *Occupational and Environmental Medicine*, *56*, 206-214. 1999.

Vegso, S., Cantley, L., Slade, M., Taiwo, O., Sircar, K., Rabinowitz, P., Fiellin, M., Russi, M.B., and Cullen, M.R. Extended work hours and risk of acute occupational injury: A case-crossover study of workers in manufacturing. *American Journal of Industrial Medicine*, *50*, 597-603. 2007.

Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M., and Mackie, R.R. *Commercial motor vehicle driver fatigue and alertness study*. Rep. No. TP 12875E, Transportation Development Centre, Safety and Security, Transport Canada, Montreal, Quebec. 1996.

Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M., and Mackie, R.R. *Commercial motor vehicle driver rest periods and recovery of performance*. Rep. No. TP 12850E, Transportation Development Centre, Transport Canada. 1997.

APPENDIX

2005 HOURS OF WORK LIMITS AND MANDATORY REST PERIODS

Objective 1: Hours of work are limited to minimize the adverse impact of fatigue upon performance.

Criterion 1.1: A normal scheduled work shift must not exceed 12 hours plus shift turnover. Shift turnover is not normally longer than 30 minutes.
Criterion 1.2: The number of hours worked in a 24-hour period does not exceed 16 hours, including shift turnover, and only extends to 16 hours on rare occasions when all other alternatives are exhausted.
Criterion 1.3: Overtime is in the form of an additional shift added to a series of consecutive shifts. Overtime is only added to an existing shift when all other alternatives are exhausted.
Criterion 1.4: The number of hours worked in a 48-hour period does not exceed 28 hours, including shift turnover.
Criterion 1.5: The maximum number of hours worked in a week is 62.5 hours including overtime and shift turnover. (NPPs must also ensure they are in compliance with provincial limits on hours of work.)
Criterion 1.6: There is a limit on time worked during a shift cycle. The adequacy of the limit for a shift cycle will be evaluated against a limit of 268 hours (excluding shift turnover time) in a 5-week cycle.
Criterion 1.7: Overtime hours for each individual worker must not exceed 400 in a one year period, with an upper yearly limit of 2400 hours per year that includes regular working time, overtime and shift turnover.
Criterion 1.8: Staffing levels are sufficient to ensure that training activities, sickness or vacation do not lead to hours of work violations.

NOTES: Unpaid lunch or rest breaks during the shift are included in the limits in Criterion 2.1, 2.2, 2.4, 2.5, 2.6, and 2.7. Overtime means time actually worked rather than time paid.

Objective 2: The number of consecutive shifts is limited and adequate provision for recovery is made to reduce the risk of fatigue adversely impacting upon human performance.

Criterion 2.1: A maximum of 5 consecutive day shifts or 4 consecutive night shifts is not exceeded.
Criterion 2.2: A minimum recovery period of 47.5 hours follows 3 or more consecutive day shifts including shift turnover time.
Criterion 2.3: A minimum recovery period of 47.5 hours follows 2 consecutive night shifts including shift turnover time.
Criterion 2.4: A minimum recovery period of 71.5 hours follows 3 or more consecutive night shifts including shift turnover time.

GLOSSARY OF TERMS

ACGME	Accreditation Council for Graduate Medical Education
ACOEM	American College of Occupational and Environmental Medicine
AECB	Atomic Energy Control Board (Canada)
ANSI	American National Standards Institute
API	American Petroleum Institute
ATC	Air Traffic Control
CASA	Civil Aviation Safety Authority (Australia)
CATCA	Canadian Air Traffic Control Association
CNSC	Canadian Nuclear Safety Commission
CoR	Chain of Responsibility
EASA	European Aviation Safety Agency
EEG	Electroencephalogram
EPRI	Electric Power Research Institute
EU	European Union
FAA	Federal Aviation Administration (U.S.)
FFD	Fitness-for-duty
FMCSA	Federal Motor Carrier Safety Administration (U.S.)
FRMS	Fatigue Risk Management Systems
HFN	Human Factors North Inc.
KSS	Karolinska Sleepiness Scale
NRC	Nuclear Regulatory Commission (U.S.)
NTC	National Transport Commission (Australia)
NTSB	National Transportation Safety Board (U.S.)
NUREG	Nuclear Regulatory Commission (U.S.)
SMS	Safety Management System
TSB	Transportation Safety Board (Canada)