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## **Fatigue, sleep disorders, and excessive sleepiness: important factors for nuclear power shift workers**

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In current urban societies, it is estimated that approximately 20% of the population does not work traditional working hours, and this percentage is tending to increase due to economic, demographic, and technological changes that have occurred in the last decades (Presser, 1999; Rajaratnam, 2001).

From the middle of last century, researchers have reported (Bjerner, 1948; Andersen, 1970; Akerstedt, 1981) that working in shifts affects the health of workers; even then, it was shown that shift workers complained about fatigue and sleepiness. Around 81% of the workers complained about night shifts in contrast to only 4% for afternoon shifts (Bjerner, 1948).

Production and distribution of electrical power from nuclear stations requires 24 h operation. Therefore, as in other sectors, the security of the whole operational system depends on the efficiency and the ability of the worker to execute tasks with remarkable accuracy and attention. However, because this type of energy is government-controlled, access to research in this area is mostly difficult; therefore, there is a scarcity of scientific publications related to the health of these shift workers.

The objective of this chapter is to describe aspects related to sleepiness, particularly excessive day sleepiness, with respect to its origins and consequences as well as the forms of minimization and preventive strategies that can be adopted by companies that use shifts and night work. Such practices may reduce the number of accidents related to fatigue and sleepiness that occur inside and outside the work environment.

### **1. Sleep and shift work**

Although sleep functions are not completely known yet, it was assumed for several decades that brain activity was widely reduced or absent during sleep (Saper, 2005; Tufik et al. 2009). However it is important to emphasize that even during sleep, the brain is 80% active, such

that sleep is an active process of neuronal reorganization rather than just a process of diminishing wakefulness (Hobson, 2007).

Currently, it is accepted that the wakefulness-sleep cycle in human beings is coordinated by two processes that interact among themselves: the homeostatic process (process S) and the circadian process (process C) (Borbely, 1982; Borbely, 1999). The homeostatic process reflects the duration of wakefulness and can be monitored by slow-wave activity (Dijk, 1990), while the circadian process occurs during a 24-hour time frame and sets the rhythms of several physiological activities. Both processes interact to consolidate sleep (Czeisler, 1980).

The first systematic classification of sleep stages was described in the Standard Manual organized by Rechtschaffen and Kales (1968), where sleep was divided into NREM sleep (stages 1, 2, 3, and 4) and REM sleep. REM sleep alternates with NREM in intervals of 70 to 110 minutes that are repeated 4 to 6 times a night, depending on the total time slept (Silva, 1996). The duration of REM sleep episodes in humans progressively increases over a sleeping period, with longer episodes occurring closer to the awakening time (Siegel, 2007).

Shift or night work, characterized as being performed outside regular working hours, i.e., from 8 or 9 am to 5 or 6 pm (Fischer, 2003), is part of the professional experience of an increasing number of workers around the world (Smith et al., 2005).

According to research by the European Union (2000), only 24% of the population works within regular working hours. Countries like the United States of America (USA) estimate that approximately 20 to 25% of their workers are engaged in some type of shift work (U.S. Congress, 1991).

Consequently there is an increasing number of people constantly changing their sleep times. This means that they never sleep in a fixed period, resulting in adaptation problems and an inability to sleep for a long or sufficient period (Rutenfranz et al., 1989). Moreover, due to sleep time irregularity, other problems can also occur, such as decreased professional performance, social and marital conflicts, mood changes, serious traffic or work accidents, increased cardiovascular disease/systemic high blood pressure, and even serious psychiatric diseases and disorders (Moore Ede, 1993; Presser, 1999; Smith et al., 2005).

The adverse effects of shift work can individually vary according to age and gender as well as to the performed activities. Younger people can better tolerate shift work than older people, principally due to the sleep architecture and pattern change (Akerstedt, 2003).

Sleepiness is a biological function defined by an increased probability to sleep (Bittencourt, 2005), and excessive sleepiness (ES), or hypersomnia, refers to an increased propensity to sleep with a subjective compulsion to sleep, i.e., to take involuntary naps and have sleep attacks, when inappropriate (Bassetti, 2000).

ES is also referred to in terms of a decreased capacity for physical and/or mental work as well as incomplete rest after insufficient sleep, and is generally associated with sleep disorders (Bakshi, 2003).

The first laboratory studies that simulated work conditions and tried to use EEG and EOG to identify the moment when workers began to doze off and sometimes even sleep were from the 1960s and focused, among other things, on telephone switchboard operators, nurses (Folkard, 1978), truck drivers, and airplane pilots (Lille, 1982).

To investigate ES, some procedures, such as clinical evaluation, sleep diaries, subjective and objective measures (scales, specific questionnaires and polysomnography, Sleep Multiple Latencies Test and the Wakefulness Maintenance Test, respectively) can be used. Other methods of accident risk evaluation are also specifically recommended for accident

prevention. These include the FAID "Fatigue Audit InterDyne" (Roach, 2004), the CAS "Circadian Alertness Simulator" (Moore-Ede, 2004), and the "Risk Index" (Folkard, 2004).

## 2. Shift workers and sleepiness

The most important consequences of sleepiness for shift workers are related to quality of life, decreased production, and increased potential risk of accidents and injuries during working hours (Dinges, 1995).

According to Akerstedt (2001), women present a lower peak of sleepiness than men in the night shift. According to this study, the risk of being involved in an accident provoked by sleepiness during night work is doubled for men compared to women.

Fischer et al. observed a reduction in the total sleep time after a night shift that resulted in lower sleep efficiency. In the evaluated workers, this reduction in sleep could have contributed to a reduction in alertness after the sixth to tenth continuous hours of work. Thus, a decrease of the sleep period can lead to sleepiness during the day or the night, jeopardizing efficiency during working hours.

Several studies showed an increase in the frequency of complaints related to sleep disorders in shift workers, including insomnia, excessive sleepiness, breathing and movement disorders; all of these could contribute in a substantial way to decreased life quality of the workers (Mello et al., 2000; Ohayon et al., 2002; Sallinen et al., 2003; Akerstedt, 2003; Howard et al., 2004; Menezes et al., 2004; Pandi-Perumal et al., 2006; Akerstedt, 2007).

Mathias et al. (2004) verified a significant reduction of the sleep latency (SL) in resident anesthesiologists on duty after 24 or 30 hours without sleeping. In this study, values of SL below 5 min (considered pathological) were observed, reflecting the extreme fatigue that these professionals are submitted to. These data obtained are important for determining the total working time and break times between shifts.

Carvalho & Vieira (2002) reviewed the literature to analyze medical errors. Although barely mentioned in the scientific literature, the statistics indicate that many incidences of medical errors are due to fatigue and sleepiness; this rate increases according to the level of complexity and frequency of the procedure. Most incidents occur during the night shift and are related to cognitive aspects, although environmental (noise, heat), psychological (depression, anxiety, stress), and physiological factors (fatigue, sleep) also contribute to the occurrence of errors. The authors verified that after working 24 h without sleeping, the psychomotor performance of a health professional is similar to one subject legally intoxicated.

A Brazilian study interviewed 400 professional interstate bus drivers from 20 transportation companies, aiming to evaluate the more common complaints of sleep among this type of worker. Important data were obtained related to sleepiness, as it was verified that 16% of the surveyed drivers had dozed off when driving, with an average of 8 such events per trip (Mello et al., 2000). Another Brazilian study of professional drivers diagnosed 38% of these workers with Sleep Apnea and Hypopnea Syndrome (Santos et al., 2004).

Moreno et al. (2004) analyzed the risk of sleep apnea in 10,101 drivers and verified that 26% of them met the criteria for high risk for SA. However, scientific publications related to worker health in nuclear power plants are scarce. Smith and Folkard (1993) used questionnaires to study the impact of shift work on the general aspects of health, sleep, and social problems for shift workers of nuclear stations. In general, it was demonstrated that

with night shifts, alertness and the duration and quality of sleep decrease, generating problems related to health and influencing social and family dynamics.

Continuing this study, Smith and collaborators (1995) investigated the level of alertness, the cognitive performance and the work load of shift workers in nuclear stations. Sleep duration and quality were analyzed for 35 days and the work load was kept stable during that period. The authors confirmed that night shift workers presented sleep of lower duration and quality as well as a significant decrease in alertness and performance levels, especially during the first hours of the day.

Takahashi et al. (2005) investigated the adaptation to shift work among Japanese nuclear station workers in relation to several variables, including sleep. In comparison to workers considered to be little-adapted to shift and night work, those classified as adapted had day sleep (before the night shift) of better quality and also took some naps during the night work. In continuation of this study, the same group (Smith et al., 2005) demonstrated that factors related to sleep and fatigue directly influence the tolerance to shift work: workers who present a higher flexibility for sleep at different times, as required for shift workers, report less complaints related to sleepiness and fatigue.

However, except for the studies of Smith's and Takahashi's groups, little is known about the complaints and possible sleep disorders in nuclear power plant shift workers.

### 3. Sleepiness and Nuclear Power Plant shift workers

Paim et al. (2008) study described the sleep complaints and polysomnographic results for shift workers in nuclear stations using the Unifesp Sleep Questionnaire (Pires et al., 2007) and polysomnography, respectively.

According to the criteria established by Pires et al. (2007), 113 (35%) of workers presented subjective complaints of insomnia, excessive sleepiness, snoring and leg movements. The frequency of insomnia was less than that found by Pires et al. (2007) in 1995 in the city of São Paulo. In the survey, 13.1% of the male population reported difficulties in initiating sleep (versus 8.8% among night shift workers), 24.6% presented difficulties in maintaining sleep (versus 17.1% of shift workers), and 11.3% complained about early morning awakening (versus 8.2% in the Paim et al. study).

The data found are closer for the frequency of complaints related to excessive sleepiness at 3.9% and 3.3% for Pires et al. (2007) and Paim et al. (2008), respectively. Similar figures were also found for the two studies with regard to snoring frequency or wakening with a suffocating sensation at 26.3% and 23.5%, respectively.

Even though it was expected, based on the literature (Mello et al., 2000, Akerstedt, 2003; Menezes et al., 2004; Santos et al., 2004), that the rate of sleep complaints would be higher among shift workers compared to the general population, that expectation was not confirmed.

As this specific population does not present a wide diversity with respect to social, cultural, and educational aspects and because it has good access to medical care, it was considered important to identify the factors involved in sleep complaints.

Some studies show that aging is associated with a more fragmented and superficial sleep that results in subjective complaints related to sleep (Young et al., 1993; Dijk et al., 1999; Buysse et al., 2005). Paim and colleagues (2008) found that workers with subjective sleep complaints were older, supporting with the aforementioned studies.



Polysomnographic recording of the nuclear power plant shift workers (Paim et al., 2008) characterized the frequency and the severity of the breathing events and periodic limb movement. Of the ninety workers that presented polysomnographic alterations, 18 (20%) met the criteria for periodic limb movement, 30 (33%) had sleep apnea, and 42 (47%) had both conditions; however, the disorders were observed to be mild in the great majority of the workers. Because the combination of sleep disorders can be a consequence of a respiratory disorder that secondarily generates leg movements, the task force of 2006 (WASM-2006) suggested that apnea treatment should be offered first, after which the presence of periodic leg movement should be verified. Considering that the great majority of workers presented a light degree of sleep disorder, the use of measures such as physical activity, appropriate eating habits, and sleep hygiene could help to reduce the consequences of these disorders, their worsening and decreasing the risk of accidents (De Mello et al., 2000).

In reference to the study of Paim and colleagues (2008), the limitations we can identify include the inability to correlate the collected and presented data with work schedules or workdays, as all data were collected in the work environment and during shifts. However, it is important to highlight that the objective of this study was to verify and describe the presence of sleep disorders in this specific population. Thus, the identified limitations did not affect the analysis; even though a circadian variation could affect the observation of the frequency of some sleep disorders, this would be identified with any type of methodology used.

Paim and colleagues (2008) verified that among 327 shift workers, 35% reported some kind of subjective sleep complaint, 12% sought out a physician for sleep problems, and 12% confirmed that had already taken sleeping pills. Ninety workers presented polysomnographic alterations, where 18 (20%) had MPP, 30 (33%) had SA, and 42 (47%) had both alterations. Although the results obtained represent a preliminary evaluation, they are expected to contribute to a better comprehension of the sleeping patterns of shift workers and of the factors that influence such patterns, with the aim of establishing corrective and preventive measures to promote worker health.

#### **4. Sleep deprivation and its costs**

Several studies point to a higher number of accidents during the night compared to the day period (Akerstedt, 2004; Costa, 1996; Ingre, 2004; Knutsson, 2004). A possible explanation might be that night shift workers have other jobs or other activities during the day, resulting in a double workday, with insufficient time for sleep (Rosa, 1993). Another explanation might be that the night shift has an increased risk for accidents (Costa, 1996) or that the risk of workers being involved in accidents is related to an increase in continuous working time, as many of these workers have long working periods, performing the same work without breaks (Akerstedt, 2001; Santos et al. 2002; Folkard, 2004). Therefore, this risk would increase after about around 9 hours of work; after 12 hours it would double, and after 14 hours the risk would triple.

Pinho et al. (2006), studied a sample of 300 professional drivers and observed that 46% presented excessive sleepiness associated, in the case of younger drivers, with snoring and working periods of more than 10 consecutive hours, often without breaks. This excessive sleepiness was also associated with reports of accidents for long working periods.

Another factor that contributes to increased accident rates is the presence of sleep disorders. People with sleep disorders have a higher risk of being involved in accidents. The main sleep disorder, apnea syndrome and obstructive sleep hypopnea (ASOSH), which generally occurs in obese and sedentary individuals, increases the possibility of being involved in car accidents by two- or three-fold in comparison to the population without this syndrome (Folkard, 2004).

Epidemiologic studies carried out in the city of São Paulo by the Department of Psychobiology of the Paulista Medicine School showed variations in the sleep complaints of the general population. In 1987, Del Giglio demonstrated that 76% of the population presented some complaint related to sleep; in 1997, Palma (1997) found that this proportion increased to around 82%. In a more recent study by Bittencourt et al. (2009), 63% of the population presented at least one subjective sleep complaint.

The number of road accidents involving commercial and private vehicles is increasing annually, and is it concern for authorities and respective agencies in the entire world. Studies relating these accidents to sleepiness have been garnering special attention in recent years (Hakkanen, 2000).

According to Caldwell (2001), problems related to fatigue cost the USA approximately US \$18 billion a year in terms of productivity. Sleepiness on the roads provokes/causes more than 1,500 deaths, 100,000 automobile crashes and 76,000 injuries a year.

Statistics show that from 26 to 32% of the automobile accidents are caused by sleepiness and fatigue when driving. Studies carried out in other countries, such as France, also revealed that around 31% of fatal car accidents can be due to sleepiness or dozing when driving. The same study found that sleep deprivation, long working periods, and (mainly) sleep disorders were the factors that contributed the most to these fatal accidents, as they directly affect psychomotor function and alertness. These factors were also attributed to work schedules that, in several cases, were inappropriate for the drivers' wakefulness/sleep pattern.

According to data obtained from the Denatran Yearbook (National Traffic Department) in Brazil, a total of 394,596 and 337,190 traffic accidents occurred in 2001 and 2002, respectively, distributed as shown in Table 1 (DENATRAN 2005).

<b>Comparison of traffic accidents in the years 2001 and 2002</b>				
	<b>Accidents with victims</b>	<b>Fatalities</b>	<b>Non-fatal injuries</b>	<b>TOTAL NUMBER OF VICTIMS</b>
<b>2001</b>	307,287	20,039	374,557	394,596
<b>2002</b>	251,876	18,877	318,313	337,190

Table 1. Comparative data of traffic accidents in the years 2001 and 2002

A reduction in the total number of victims and accidents may have been a result of the great number of traffic education campaigns that the government is promoting; however, a study carried out by the IPEA (Economic Researches Institute -2003), demonstrated that the costs related to traffic accidents in Brazil are still very high and distributed as follows:

- Average cost of a traffic accident: US \$4,878
- Average cost of a traffic accident with injury: US \$19,520
- Average cost of a traffic accident with fatality: US \$80,080

In a simple analysis, it was observed that the financial cost of accidents with fatalities (not considering other types of accidents and victims) was approximately US \$3,116,371,660 in

2001-2002. This represents a very high cost for any country; a strategy to minimize the costs of accidents and deaths that involves educational and preventive projects could reduce both this cost and the number of fatalities.

## 5. Minimizing the problem of sleepiness

Knauth (1996) mentioned Guidelines (see Table 2) for planning working hours in accordance with psycho-physiological criteria; such guidelines could improve or minimize the negative effects of night/shift work and reduce the incidence of work accidents.

An epidemiologic survey on physical activity and sleep complaints carried out by Mello et al. in 2000 in the city of São Paulo, Brazil demonstrated that physically active people presented less complaints related to sleep and excessive sleepiness during the day, suggesting that physical activity was a favorable factor for the sleep quality. This study suggested that the psychosocial factors, lifestyle, sleep location, and the living conditions of the individual directly influenced the quality of life and physical performance. Therefore, the implementation of physical activity for that population is highly important for consolidation and improvement of sleep efficiency.

Guidelines	Effect
1. Quick rotation shift systems	• Less interference in circadian rhythms
2. Clockwise rotation	• Allow longer resting periods
3. Avoid early morning shifts	• Reduce sleep fragmentation
4. Avoid long journeys (9-12 h), or adjust the breaks	• Minimize fatigue
5. Regular shift systems	• Guaranteed free weekend; make the most of leisure; minimize social impact
6. Scheduled night work only for special situations	

Table 2. Guidelines for the planning of work hours (Knauth, 1996).

## 6. Brazilian Legislation

Recently, the National Traffic Council (CONTRAN) (de Mello et al., 2009) approved the inclusion of clinical evaluation of sleep disturbances for Brazilian drivers who will be submitted for the first evaluation to obtain, renew, or alter the category (to categories C, D, and E) of their driver's license. This new approach and evaluation for professional drivers in Brazil could also be applied to shift workers and nuclear energy station workers, as evaluation of sleep disturbance is essential for minimizing the risks of fatigue and accidents.

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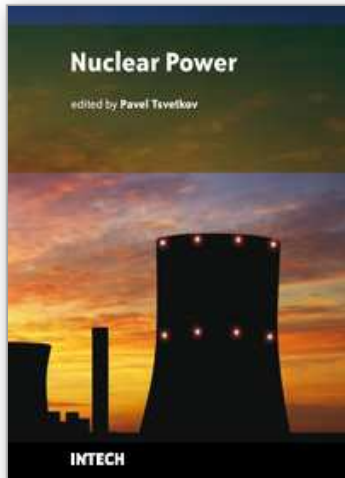
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## **Nuclear Power**

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The world of the twenty first century is an energy consuming society. Due to increasing population and living standards, each year the world requires more energy and new efficient systems for delivering it. Furthermore, the new systems must be inherently safe and environmentally benign. These realities of today's world are among the reasons that lead to serious interest in deploying nuclear power as a sustainable energy source. Today's nuclear reactors are safe and highly efficient energy systems that offer electricity and a multitude of co-generation energy products ranging from potable water to heat for industrial applications. The goal of the book is to show the current state-of-the-art in the covered technical areas as well as to demonstrate how general engineering principles and methods can be applied to nuclear power systems.

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