

## A Study on Fatigue Measurement of Operators for Human Error Prevention in NPPs

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### 1. The Need for a Fatigue Measurement and Management for Human Error Prevention

The identification and the analysis of individual factor of operators, which is one of the various causes of adverse effects in human performance, is not easy in NPPs. There are work types (including shift), environment, personality, qualification, training, education, cognition, fatigue, job stress, workload, etc in individual factors for the operators.

Research at the Finnish Institute of Occupational Health (FIOH) reported that a 'burn out (extreme fatigue)' is related to alcohol-dependent habits and must be dealt with using a stress management program. USNRC (U.S. Nuclear Regulatory Commission) developed FFD (Fitness for Duty) for improving the task efficiency and preventing human errors. 'Managing Fatigue' of 10CFR26 presented as requirements to control operator fatigue in NPPs. The committee explained that excessive fatigue is due to stressful work environments, working hours, shifts, sleep disorders, and unstable circadian rhythms. In addition, an International Labor Organization (ILO) developed and suggested a checklist to manage fatigue and job stress. In domestic, a systematic evaluation way is presented by the Final Safety Analysis Report (FSAR) chapter 18, Human Factors, in the licensing process. However, it almost focused on the interface design such as HMI (Human Machine Interface), not individual factors. In particular, because our country is in a process of the exporting the NPP to UAE, the development and setting of fatigue management technique is important and urgent to present the technical standard and FFD criteria to UAE. And also, it is anticipated that the domestic regulatory body applies the FFD program as the regulation requirement so that a preparation for that situation is required.

In this paper, advanced researches are investigated to find the fatigue measurement and evaluation methods of operators in a high reliability industry. Also, this study tries to review the NRC report and discuss the causal factors and management.

## 2. A Approach to Fatigue Management

### 2.1 The Definition of Fatigue

The dictionary definition of fatigue is as follows:

- The worse situation for task performance by hard work
- The worker has less energy by repetitive contraction of muscles

- A loss strength and insufficient ability to respond to stimuli because of excessive activity
- The physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness and physical activity that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety related duties.

It is difficult to obviously find out the causes of fatigue because the fatigue is related to the characteristics of living and working environments as well as pathologic, psychological and nutritional factors. Recently, several researches have attempted to identify fatigue levels and related factors which have a negative effect on the fatigue. The fatigue has various characteristics in accordance with private properties of workers (gender, ages, marital status, personality, education level, etc) and job (work type, working hours, continuous service year, etc) characteristics.

### 2.2 The Methodology

Fatigue can be classified as the mental and the physical fatigue and is measured and evaluated in different ways. There are the subjective and the objective measurement as a representative way in evaluation fatigue. In the case of the subjective measurement, questionnaires that depend on the observers or workers subjective judgment are mainly used. The objective measurement can obtain more accurate and comprehensive data through experiments. MFS (Multidimensional Fatigue Scale), FAI (Fatigue Assessment Inventory), CFSI (Cumulative Fatigue Syndrome Index), FIS (Fatigue Index Score), NASA-TLX (NASA Task Load Index), SOFI (Swedish Occupational Fatigue Inventory), etc are subjective measurement as shown in table 1. The subjective measurement is relatively easy to measure and does not interfere with the task performance and mostly chronic fatigue measure is intended to assess. In general, it is recommended to carry out the objective measurements in company with the subjective measurements because the latter has a limitation in obtaining high reliability data. The objective measurements have a limitation to apply to the real field, and can only be executed by the lab experiment with Electroencephalogram (EEG), Electrocardiogram (ECG), Electrooculogram (EOG), Electromyogram (EMG), Eye tracking and so on (table 2).

Table 1. The subjective techniques of a fatigue analysis

Method	Items	Evaluation items	Criteria/Results
MFS	19	mental state, fatigue levels, soreness	Measurement scale : 7 Fatigue level : MFS total score
FAI	29	severity, evasiveness, associated consequences, sleep	Measurement scale : 7 Fatigue level : FAI total score
CFSI	81	depressive, fatigue, irritability reflecting conditions of excessive workload, weakened work morale and vitality, chronic, physical breakdown	Measurement scale: the positive number of answer 1-10: mild 11-20: moderate 21-30: severe
FIS	22	sleep hours/day before the casualty, total number of fatigue symptoms, total work hours	Fatigue : FIS > 50 point
NASA-TLX	6	mental, physical, temporal demand, effort, performance, frustration	Measurement scale: 0-100 TLX rating scale
SOFI	25	lack of energy, physical exertion, physical discomfort, lack of motivation, sleepiness	Fatigue level : lack of energy

Table 2. The objective methods for a fatigue measurement

Method	Item	Evaluation items	Criteria/Results
EEG	4	Beta, Alpha, Theta, Delta wave	Specific wave rate Frequency form
ECG	10	RR interval	RR interval time
EOG	4	Eye blinking, Eye move	Eye blinking
EMG	22	Frequency power spectrum, Frequency analysis	RMS, MPF, Peak frequency
Eye tracking	6	Animated representations of a point on the interface, Static representations of the saccade path, Heat maps, Blind zones maps	Eye blinking, Pupil size, Gaze tracking, Somnolence

### 3. A Previous Studies for Fatigue Analysis

#### 3.1 Regulatory Guide 5.73 in USNRC

The regulations promulgated by the NRC under the title of "Fitness for Duty Programs" which is the code in the Federal Regulations 10 CFR Part 26 established requirements for ensuring that the personnel are fit to their works and can perform their duties safely and competently. The subpart I, "Managing Fatigue", provides the requirements to manage the personnel fatigue at NPPs. And also, it provides a comprehensive and integrated approach to fatigue management considering multiple causes and effects of workers' fatigue. USNRC has recognized that the potential of excessive fatigue is not solely based on extensive work hours but can result from other factors such as stressful working conditions, sleep disorders, accumulation of sleep debt, and the disruptions of circadian rhythms associated with shift work. The requirements of subpart I of 10CFR26 are organized into six sections as follows: applicability, general provisions, work hours, waivers and exceptions, self-declaration, and fatigue assessment. General provisions include the requirements for a fatigue management policy, procedures, training and examinations, recordkeeping, reporting, and audits of the program. In the section of Work hours, minimum days off (MDO) and the calculation and review of work hours and rest-break periods are described. In the section of Waivers and exceptions, under the specific conditions and circumstances licensee can be permitted not to apply the work-our and rest-break requirements. Operators have to express whether they can control the tasks themselves based on their fatigue situations.

Fatigue assessments include specific provisions regarding the scope of the assessments and the associated documentation requirements placed on the licensees.

#### 3.2 The Case Studies

We are interested in analysis and management fatigue because worker fatigue causes adverse effects of the job performance in high-reliability industries. Several previous studies were performed to measure and analyze fatigue (table 3). The researchers insist that there is a high correlation between workers fatigue and work efficiency. In addition, many researchers studied in fatigue factor analyses, the physiological reasons, correlation between work environment and fatigue, and preventive measures of fatigue according to the work types. The Federal Aviation Administration developed a fatigue risk management system (air traffic controllers shift work, sleep, relax time, etc) to find the hazard factors and also correct and analyze data related to the fatigue.

Table 3. The case studies on fatigue

Title	Method	Results	Field
A study on pilot fatigue relating to safety operations	research	Previous studies	aviation
A study on the C.F.S of Korean pilots	chronic fatigue questionnaire	Pilots' chronic fatigue level.	aviation
Factors affecting fatigue in male railroad workers	PWI-SF, MFS	fatigue level and influence factor	railroad
A study on upper extremity muscle fatigue changes of train driver	EMG	Muscle fatigue	railroad
A Study on the Effects of Marine Accidents by Navigation Officers' Fatigue	questionnaire ISM(Interpretive Structural Modeling)	Sleep time and stress impact on fatigue.	marine
A study on the fatigue factor as a cause of human error	questionnaire	The need of sleep study	marine

#### 4. Discussions

Workers in NPPs have followed the task procedures thoroughly and the tasks directly related to safety. So the responsibilities and privileges of them are high. Accordingly, fatigue and stress of the workers in NPPs are higher than in other industries, especially under abnormal situations like an over-haul. In FSAR, chapter 18, a systematic evaluation is presented but only deals with the human factor technology related to the interfaces, and not individual factors. Some of regulatory organizations recognized the need for fatigue evaluation and management program to prevent human error in NPPs. To evaluate and manage the fatigue of the NPP workers, USNRC suggested a FFD program which is focused on the shift work, health conditions, and behaviors of workers and started regulation applying it. To apply the USNRC FFD program guideline to the domestic, the criteria of the standards and individual factors which affect workers fatigue should first be re-defined and developed.

#### REFERENCES

[1] USNRC Regulatory commission, "Regulatory Guide 5.73; Fatigue management for nuclear power plant personnel", 2009