EMERGENCY PLANNING LESSONS LEARNED FROM A REVIEW OF PAST MAJOR RADIOLOGICAL ACCIDENTS

J. G. Stephan, J. M. Selby, J. B. Martin
Pacific Northwest Laboratory
Richland, Washington U.S.A.

D. W. Moeller
Harvard Medical School
Boston, Massachusetts U.S.A.

E. J. Vallario
Office of Nuclear Safety
U.S. Department of Energy
Washington, DC U.S.A.

In examining a range of nuclear accidents from the 1950s to the present that were reported in the literature, the authors have identified a number of contributing factors which affected human judgment during these events. One common thread found in a large number of accidents is the time of occurrence; a second is the adequacy of emergency training.

The data show that events, whether severe accidents or operational incidents, appear to occur more frequently during off-normal hours such as the early morning shift, weekends, or holidays. Accidents seldom occur during the day shift when the full management team and senior operations personnel are present. As a result, those facility employees most expert in coping with the situation may not be available, and the normal chain of command may be disrupted. At several nuclear power plants, it was also observed that new or less experienced technicians are often assigned to night shifts. The lack of experienced human resources and the pressure of an accident situation can have an adverse impact on individuals who are faced with making important decisions.

An in-depth review of the literature conducted for the U.S. Nuclear Regulatory Commission (NRC) by staff members at the Pacific Northwest Laboratory (PNL) [1] determined that human errors generally increase at night, and the chance for error is significantly greater if the worker has already been working four or more hours before midnight. The highest error rates were reported to occur between 3 and 6 a.m. The most efficient work is typically performed during the day. When a person is required to work at night and sleep during the day, both work performance and sleep were found to be degraded.

During a recent annual meeting of the Academy of Behavioral Medicine Research, members of the Harvard Medical School research staff observed that three of the recent major disasters--Three Mile Island, Bhopal, and Chernobyl--all occurred at night. The concern expressed by behavioral scientists was not only that lowered alertness might cause accidents at nuclear facilities during off-hours, but that the concurrent human ability to detect and correct the problem in a timely manner might also be reduced [2].

Dr. C. A. Czeisler of the Harvard Medical School, Department of Medicine, has conducted extensive studies of the effects of rotating shift work schedules [3]. Dr. Czeisler observed that workers on night or rotating shifts experience adverse consequences because their circadian rhythm and physiological functions, such as body temperature, hormone secretions, cell division, and antibody formation, vary over a 24-hour period. Whenever a worker's normal wake/sleep schedule is interrupted, a mismatch occurs between the body's ability and the demands placed upon it in the workplace. Stress, gastrointestinal disorders, low morale, high rates of accidents and illness, as well as low productivity, result from this mismatch. Sleep-deprived shift workers often experience involuntary lapses of wakefulness; while they appear to be awake, they may actually be drifting in and out of sleep. Because of these lapses, the ability to respond to warning signals or lights may be impaired [4,5]. Czeisler reported in field studies of 1500 workers at a number of industrial facilities, that over 55% of the workers admitted to "nodding off" or falling asleep on the job during any given week. At the Fast Flux Test Facility at the Hanford Site in Washington, PNL researchers are currently evaluating the effects of a 12-hour-a-day rotating shift. The shift was adopted to help reduce the attrition of operators.

Another common thread is that, no matter how well emergency scenarios are developed and emergency planning exercises are conducted, no scenario can adequately simulate an actual emergency [6]. During an emergency, there is little time to consult the emergency operating plan to decide on a response. Response performance will reflect the quality of the training imparted to emergency response personnel from plan-and-procedure implementation, as well as from periodic drills and exercises.

How individuals respond to an actual emergency is another uncertainty. In Japan, analysis of safety evaluations performed at commercial nuclear installations revealed that an appropriate response of operators to an accident could not be expected for at least 10 minutes after they became aware of the emergency situation [7]. Part of this delay is due to the time required to effectively analyze the situation. Another part of the delay may be due to the reluctance of the operators to acknowledge that they have an emergency. Irrespective of the number of emergency drills and exercises conducted, the real situation may reveal flaws in the emergency plan and response. Therefore, everything that borders on an emergency at a facility should be treated as an emergency.

The authors of this paper have examined over fifty accidents and derived the most important lessons learned from each accident. Indeed, a review of nuclear facility accidents since the 1950s revealed that human error contributed to a majority of the incidents. Most of these accidents began during night shifts, on weekends, or holidays. This suggests the possibility that fatigue and/or the absence of experienced personnel could have been among the causes of the incidents. Human error during off-normal hours was clearly involved in the following representative cases:

- Windscale Works of British Nuclear Fuels Accident - 7:25 p.m., Monday, 10-7-57
- SL-1 U.S. Army Reactor Accident - 9:01 p.m., Monday, 1-3-61
- Recuplex Nuclear Criticality - 10:59 a.m., Saturday, 4-7-62
- Wood River Junction Criticality - 6:00 p.m., Friday 7-24-64
- Browns Ferry Nuclear Power Plant Fire - 12:20 p.m., Saturday, 3-22-75
- Three Mile Island Unit 2 Nuclear Power Plant Accident - 4:00 a.m., Wednesday, 3-28-79
- Chernobyl Nuclear Reactor Accident - 1:23 a.m., Saturday, 4-26-86

Contributing factors to the earlier incidents were perhaps deficiencies in the design of facilities or equipment involving this new technology. Later accidents, however, involved facilities and equipment that had become "safer" as a result of many redundancies built into the operating systems to safeguard the facility and human health. The more recent accidents appear to be the result of errors on the part of humans trying to respond to unusual events involving this increasingly complex technology. Compounding this problem was the fact that many of these accidents may have occurred when the most qualified and best trained personnel were not on duty.

Several lessons have been learned from an analysis of these accidents:

- Nuclear accidents can have worldwide impact on the public, governmental agencies, and the nuclear industry.

- Rotating of operating personnel to work during off-normal hours requires careful planning, taking into consideration the body's natural rhythm, to maximize performance.

- The response of an individual to an emergency cannot always be predicted. Also, operating personnel require some time to respond to an emergency. Ultimately, the major response will be based on the quality of the training imparted to emergency response personnel.

- Emergency preparedness instrumentation capable of assessing high radiation fields is required. This equipment must be operable in a wide range of environments.

- Remotely-operated retrieval and surveillance equipment is essential during emergencies. Control rooms should be designed with optimum consideration for human factors.

- Potential accidents must be anticipated through formal safety studies. Exercise scenarios should focus on higher probability accidents as well as worst-case accidents.

- Regularly scheduled, rigorous emergency preparedness exercises are needed. These exercises must include objective, post-exercise critiques and a commitment from facility management to correct any deficiencies identified.

- Improved emergency response training and retraining is needed for plant personnel.

- Emergency responses require well-directed coordination.

- Rigid administrative control of fissile materials is essential.

- Nuclear facilities should be sited where population density is low.

ACKNOWLEDGMENTS

This work was performed for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

REFERENCES

1. Lewis, P. M. 1985. Shift Scheduling and Overtime: A Critical Review of the Literature. PNL-5391, Pacific Northwest Laboratory, Richland, Washington.

2. Squires, S. June 15, 1986. "Researchers: Nighttime is the Right Time for Work Accidents." Reno Gazette Journal, pp. 1E-3E.

3. U.S. Congress, Subcommittee of Investigation and Oversight of the Committee on Science and Technology, House of Representatives. 1983. Hearings. 89th Cong., 1st sess. (March 23-24, 1983, Testimony by C. A. Czeisler, Harvard Medical School.) Biological Clocks and Shift Work Scheduling. U.S Government Printing Office, Washington, D.C.

4. Czeisler, C. A., E. D. Weitzman, M. C. Moore-Ede, J. C. Zimmerman, and R. S. Knauer. 1980. "Human Sleep: Its Duration and Organization Depend on Its Circadian Phase." Science. 210:1264-1267.

5. Rafferty, J. F. 1983. "Watching the Biological Clock." Harvard Magazine, March-April 1983, pp. 26-29.

6. Vallario, E. J., and J. M. Selby. 1981. "Use of Accident Experience in Developing Criteria for Teleoperator Equipment." Paper presented at Harvard School of Public Health, June 8-12, 1981, Boston, Massachusetts.

7. Matsuda, Y., K. Suehiro, and S. Taniguchi. 1984. "The Japanese Approach to Nuclear Power Safety." Nuclear Safety. 25(4):451-471.