INL/CON-06-11428
PREPRINT

Occupational Injury Rate Estimates in Magnetic Fusion Experiments

17th ANS Topical Meeting on the Technology of Fusion Energy

L. C. Cadwallader

November 2006

OCCUPATIONAL INJURY RATE ESTIMATES IN MAGNETIC FUSION EXPERIMENTS

L. C. Cadwallader

Idaho National Laboratory, PO Box 1625, Idaho Falls, ID 83415-3860, Lee.Cadwallader@inl.gov

In nuclear facilities, there are two primary aspects of occupational safety. The first aspect is radiological safety, which has rightly been treated in detail in nuclear facilities. Radiological exposure data have been collected from the existing tokamaks to serve as forecasts for ITER radiation safety. The second aspect of occupational safety, "traditional" industrial safety, must also be considered for a complete occupational safety program. Industrial safety data on occupational injury rates from the JET and TFTR tokamaks, three accelerators, and U.S. nuclear fission plants have been collected to set industrial safety goals for the ITER operations staff. The results of this occupational safety data collection and analysis activity are presented here. The data show that an annual lost workday case rate of 0.3 incidents per 100 workers is a conceivable goal for ITER operations.

I. INTRODUCTION

At present, the safety assessment for the International Thermonuclear Experimental Reactor (ITER) is one of the necessary items to provide to the French DGSNR Nuclear Safety Agency before they will grant a license to construct the facility. In addition to public safety, the ITER International Team is concerned about occupational safety, especially because ITER is a much larger experiment with more power demand, larger inventories, a higher megawatt thermal power, high duty factor, and more complex equipment than existing facilities. The ITER International Team has begun to address industrial safety in the Generic Site Safety Report;[1] personnel safety will also be addressed in the ITER safety assessment. To assess worker occupational radiation exposure, data were collected and analyzed from the Joint European Torus (JET) and the Princeton Plasma Physics Laboratory (PPPL).[2,3] In the same way, data have been collected to examine occupational injury rates at tokamaks and similar facilities.

In the U.S., fusion experiments are operated for the U.S. Department of Energy (DOE). Institutions that operate fusion experiments for DOE must abide by the DOE standard on fusion safety, which states that facility workers and staff will be protected from routine hazards to a level commensurate with that of comparable industrial facilities.[4] The ITER International Team has also adopted such a rule for worker protection.[1] This paper presents the occupational injury rates for PPPL (which has operated several U.S. large plasma devices), JET, and several of the large U.S. particle accelerator facilities that are comparable to fusion facilities. The accelerator facilities are an appropriate comparison because they are research facilities with large staffs and operating schedules similar to the planned ITER schedule.

II. DATA COLLECTION AND ANALYSIS

Occupational injury data were collected from DOE's Computerized Accident/Incident Reporting System.[5] This DOE database records information for major DOE sites; only PPPL data were readily available in the database. PPPL and several major particle accelerators, the Fermi National Accelerator Laboratory (FNAL), the electron beam accelerator at Jefferson Lab (Jlab), and the Stanford Linear Accelerator Center (SLAC), were examined for injury rate information.[6] The results are presented in Table I. Table II gives similar lost work values for JET.[7] None of the staff at these facilities experienced any fatalities or major injuries during the time period reported.

There are several established ways to measure injuries and illnesses. Total Recordable Cases are those injuries and illnesses that resulted in days away from work. These data are mandatory to report to the U.S. Occupational Safety and Health Administration (OSHA). The Total Recordable Case rate is the number of work-related injuries or illnesses in a year per 100 workers (using 200,000 labor hours in a year). The Lost Workday Case (LWC) rate is also per 100 workers; it is the rate of injury or illness cases (that is, incidents) that cause days away from work (for medical treatment, hospital stay, healing time, etc.) or days of restricted work activity, or both. The Lost Work Days rate is the count of work days lost, whether consecutive or not, beyond the day of the injury or illness, in which the employee was away from work or on restricted work.

TABLE I. Occupational Injury Rates at Several U.S. DOE Research Facilities

Calendar year	Institution	Number of Employees	Total Recordable Case Rate	Lost Workday Case Rate	Lost Work Days Rate
1993	PPPL	1,087	2.5	1.2	10.1
	FNAL	2,387	4.2	2.5	55.3
	Jlab	578	5.1	2.2	5.6
	SLAC	1,504	6.3	3.4	75.1
1994	PPPL	1,001	1.9	1.6	94.2
	FNAL	2,166	3.8	2.0	44.0
	Jlab	586	3.1	1.4	33.8
	SLAC	1,530	3.9	2.1	66.9
1995	PPPL	955	1.3	1.1	15.8
	FNAL	2,200	3.5	1.9	27.6
	Jlab	649	4.1	1.3	6.2
	SLAC	1,562	5.5	3.1	68.7
1996	PPPL	633	1.3	1.2	11.2
	FNAL	2,161	4.4	2.6	41.7
	Jlab	630	3.0	1.2	11.2
	SLAC	1,481	3.8	1.9	79.0
1997	PPPL	563	1.9	1.4	44.8
	FNAL	1,824	3.2	1.7	18.0
	Jlab	583	3.1	1.0	12.0
	SLAC	1,419	1.9	1.2	42.6
1998	PPPL	475	1.5	1.1	24.2
	FNAL	1,907	3.7	1.4	15.5
	Jlab	560	2.0	0.9	3.9
	SLAC	1,511	1.7	1.1	25.7
1999	PPPL	526	3.0	2.1	75.1
	FNAL	1,972	3.2	0.9	9.4
	Jlab	500	1.8	1.2	9.0
	SLAC	1,536	2.5	1.8	53.5
2000	PPPL	591	3.7	1.9	62.9
	FNAL	2,023	2.9	1.0	21.2
	Jlab	549	1.8	0.7	4.2
	SLAC	1,571	2.0	1.0	36.9
2001	PPPL	630	5.1	4.3	164.8
	FNAL	1,981	2.8	1.0	20.7
	Jlab	593	2.7	1.5	12.7
	SLAC	1,636	1.3	1.0	14.5
2002	PPPL	601	2.7	1.5	46.2
	FNAL	2,087	2.1	1.1	21.2
	Jlab	573	1.7	0.9	48.3
	SLAC	1,4551	0.8	0.5	45.6
2003	PPPL	527	0.9	0.8	12.7
	FNAL	2,547	1.0	0.3	5.9
	Jlab	591	1.9	1.2	17.8
	SLAC	1,548	1.7	1.0	71.9
2004	PPPL	470	1.7	1.1	62.6
	FNAL	2,486	0.9	0.4	20.1
	Jlab	646	1.2	0.2	2.0
	SLAC	1,502	1.4	0.7	57.0
2005	PPPL	470	1.7	1.1	62.6
	FNAL	2,173	1.0	0.1	7.2
	Jlab	667	0.7	0.3	0.3
	SLAC	1,599	0.6	0.4	21.8

TABLE II. Summary of Injury Absences at JET

Calendar Year	Absence More than 1 Day but Not More than 3 Days		Absence More than 3 Consecutive Days		Number of Workers	
	Staff	Contractors	Staff	Contractors	Staff	Contractors
1997	0	1	0	0	≈ 175	≈ 428
1998	1	1	0	2	≈ 175	≈ 428
1999	0	2	0	3	≈ 175	≈ 428
2000	0	0	0	1	155	375
2001	0	0	0	0	175	435
2002	0	0	0	1	165	405
2003	1	0	0	1	180	435
2004	0	0	0	2	180	460
2005	0	0	1	1	195	455

The U.S. data in Table I include only direct employees of the project or institution, not the service providers such as construction companies and other subcontractors. At JET, the staff members are direct employees of the project. Contractors include hired staff embedded within the JET line management structure and the main contractors who work under the JET safety management system. Service providers and any other workers who perform under another set of safety management rules are not included in Table II. Thus, the worker counts are comparable between PPPL and JET. The Table II data had no major injuries or fatalities.

The LWC rate was the most readily compared data point between the two recording systems in Tables I and II. The JET counts of absence data in Table II were summed to an LWC rate per 100 workers and are presented with PPPL LWC data in Table III. Note that the numbers of employees at the two facilities are very similar, within 20% of each other and usually within 10%. The ages of the workforces at the two facilities are thought to be highly comparable, and are not believed to be a factor in the lost workday counts.

Next, the PPPL and JET values were compared to U.S. industry averages. On the U.S. Bureau of Labor Statistics web site,[8] the U.S. national average LWC rate for private industry in the 21st century is in the 1.4–1.5 range. An LWC rate less than 1.5 is above average performance , and less than 1.0 is considered a very positive sign. Many U.S. industries are in the 0.5–1.5 range each year; very few U.S. industries achieve an annual LWC rate below 0.1. Using these performance ranges, we see a few high-value years in the Table III data, but PPPL shows good performance overall and JET shows very good performance, well below US private industry values. Note that the LWC rate is consistently higher at PPPL than at JET. The LWC rate values compare within factors of 3 to 10 over most of the given calendar years, except 2001 where JET had an LWC of 0.

TABLE III. Comparison of PPPL and JET values

Calendar Year	PPPL Values		JET Values	
	Number of Workers	LWC Rate	Number of Workers	LWC Rate
1997	563	1.4	≈ 603 avg	≈ 0.2
1998	475	1.1	≈ 603 avg	≈ 0.7
1999	526	2.1	≈ 603 avg	≈ 0.8
2000	591	1.9	530	0.2
2001	630	4.3	610	0.0
2002	601	1.5	570	0.2
2003	527	0.8	615	0.3
2004	470	1.1	640	0.3
2005	470	1.1	650	0.3
9-year average	539	1.7	603	0.3

There are several reasons for the variances in the Table III data. First and foremost, there is no standardization between the U.S. and UK reporting rules. U.S. employers report basically all events of interest to OSHA and then decompose the data as needed; therefore, many very minor injuries are logged together with major injuries. The UK uses three databases to track occupational accidents and diseases or illnesses. The UK Reporting of Injuries, Diseases and Dangerous Occurrences (RIDDOR) rules record fatalities, major injuries, and the moderate to minor injuries of more than 3 days away from work as separate categories.[9]

Another fact to note in the comparison is that historically, U.S. overall private industry occupational fatality and injury rates have been higher than those in the UK.[10,11] Comparing a few recent data points from the U.S. and UK statistics web sites for 2003 and 2004 (Refs.

8 and 12), country-wide injury rates per 100 workers show the U.S. had 4.7 and 4.5 injuries, respectively, while the UK had 0.62 and 0.63 injuries, respectively. The U.S. injury rate values were higher than those of the UK by a factor of about 7.5. Most of the PPPL data in Table III are within a factor of 7.5 of the UK data, so in most cases the overall U.S.-UK trend of a variance of 7.5 between the LWC rates is preserved in these two tokamak data sets.

Another potential reason for the data discrepancies is the associated work activities during the given time frame. PPPL was placing the Tokamak Fusion Test Reactor (TFTR) into safe shutdown after its final campaign with tritium fuel in April 1997. After safe shutdown in 1997–1999, the TFTR underwent decontamination and decommissioning (D&D) and was dismantled from 1999–2002, which was a major activity at the site. While subcontractors were employed for that work, PPPL staff also supported this activity and supervised subcontract workers. PPPL also had a small effort to construct the National Spherical Torus Experiment from 1997 to 1999. JET workers ran the Deuterium-Tritium Experiment in 1997 and the Trace Tritium Experiment in 2003, and had significant downtime for machine refitting and maintenance between these campaigns. In 1998–1999, a new divertor was remotely installed and other, directly-hands-on improvements were made. Injury rates typically increase when labor-intensive activities are under way at a facility, as is the case here: the 1999–2001 time frame gave the highest values at PPPL and 1998–1999 gave the highest values at JET. JET is scheduled to operate for years to come and will not undertake D&D work very quickly.

Overall, LWC rates for both PPPL and JET are low, which indicates that few industrial injuries occurring at these tokamaks are resulting in lost work days and therefore the injuries are not very consequential in nature. The PPPL injuries categorized in Ref. 6 show that the most frequently logged injuries are lacerations/abrasions (26%), strains (17%), and fractures (8%). Some of the PPPL injuries reported would be classified as major injuries under the UK RIDDOR rules.

While LWC rates for PPPL and JET are both low, the 9-year average in Table III for the two facilities differs by a factor of 5.7. To further analyze the data, the LWC rates for FNAL, Jlab, and SLAC were collected as well as the LWC rate for the U.S. nuclear power plant (NPP) industry.[6,7,14] These data are shown in Table IV. The NPP industrial accident rate is same as the LWC rate.

The comparison results from Table IV are surprising. NPPs tend to have high levels of hazards: high temperature and pressure cooling systems, usage of a wide variety of chemicals, work at heights, high levels of vehicle traffic on site, compressed gas systems, numerous mechanical and electrical systems, work performed with systems on-line, short maintenance time periods, and other hazards,[13] all of which are generally proportionally higher hazards than those found in fusion experiments or accelerators, which have more modest energy use and longer downtimes. One explanation for the low NPP accident rate is that the fission NPP industry has strived to improve plant safety and efficiency during the 1980s and 1990s. (Ref. 15) It is a well-known safety principle that well-run facilities are safer, cleaner, more productive, and more efficient than facilities with little interest in safety,[16] and the U.S. NPPs have sought safety and efficiency. The NPPs have reduced their LWC rate from greater than the U.S. national average to below it in 20 years (a reduction by a factor of about 9.5). The U.S. NPP LWC rates are presently a factor of 5 below national averages for U.S. private industry.

TABLE IV. U.S. NPP and Experiment LWC Rates

Calendar Year	NPP Industrial Accident Rate	LWC Rate				
		JET	PPPL	FNAL	Jlab	SLAC
1980	2.1	—	—	—	—	—
1985	1.1	—	—	—	—	—
1990	1.03	—	—	—	—	—
1995	0.55	—	1.1	1.9	1.3	3.1
1998	0.29	≈0.7	1.1	1.4	0.9	1.1
1999	0.34	≈0.8	2.1	0.9	1.2	1.8
2000	0.26	0.2	1.9	1.0	0.7	1.0
2001	0.24	0.0	4.3	1.0	1.5	1.0
2002	0.22	0.2	1.5	1.1	0.9	0.5
2003	0.25	0.3	0.8	0.3	1.2	1.0
2004	0.25	0.3	1.1	0.4	0.2	0.7
2005	0.24	0.3	1.1	0.1	0.3	0.4
8 year average (1998–2005)	0.3	0.3	1.8	0.8	0.9	0.9

Another possible explanation of the low NPP rate is that NPPs tend to be better staffed, with adequate numbers of trained workers to perform all of the routine tasks, while other types of power plants have fewer staff available. There are approximately 100 large, central station NPPs in the U.S. These plants provide about 20% of the country's electrical power needs and employ about 40% of all U.S. utility workers.[6] There are 704 medium to large fossil-fueled power plants, 1,080 small hydroelectric dams, and 485 gas turbine facilities in the

U.S.[17] All of these non-nuclear power plants have smaller staffs than the nuclear power plants.

From the data presented in Table IV, we can determine a reasonable LWC rate goal for ITER. Because JET, as the largest tokamak in operation, can meet the U.S. NPP LWC rate, and the U.S. high technology facilities are within a factor of 6 (which is within the U.S.-UK variance of 7.5) of JET data, it is conceivable that ITER can reach an annual LWC rate of 0.3. This goal should be compared to the Tore Supra industrial safety values because that tokamak has operated under the same safety management rules that will apply to the ITER facility. Comparison to CERN LWCs may also be useful.

It is notable that the overall trend in Table IV is a reduction in the LWC rates. Taking good industrial work practices from the tokamaks and the fission NPP industry, ITER can formulate good industrial safety approaches—management commitment to safety, use of adequately staffed work teams, generating appropriate procedures and work requests, prudent work planning, comprehensive worker training on unique systems and equipment, providing proper tools and equipment for worker use, and other worker safety principles from operational plants.

III. CONCLUSIONS

The occupational safety data presented here on high-technology facilities and nuclear fission power plants shows that all of these facilities are performing well, with a downward trend in lost workday case rates per 100 workers. A surprising result was that the U.S. fission plants give the most enviable lost workday case rates. The JET facility also shows a very good level of safety performance, surpassing U.S. high technology facilities. It is conceivable that ITER operations staff can also reach a goal LWC rate of 0.3 when operations begin. This suggested goal should be compared to the Tore Supra, and perhaps CERN, industrial safety values.

ACKNOWLEDGMENTS

The author wishes to thank Mr. D. P. Williams of the JET staff for providing occupational safety data. This work was prepared for the U. S. Department of Energy, Office of Fusion Energy Sciences, under the DOE Idaho Field Office contract number DE-AC07-05ID14517.

REFERENCES

1. INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR INTERNATIONAL TEAM, *Generic Site Safety Report*, Volume VI, "Occupational Safety," G 84 RI 5 01-07-12 R 1.0 (2001).
2. A. NATALIZIO, T. PINNA, and J. D. LEVINE, "TFTR Occupational Radiation Exposure Data Collection and Analysis," *Fus. Eng. Des.,* **75-79**, 1187 (2005).
3. A. NATALIZIO, M. T. PORFIRI, and B. PATEL, "Collection and Analysis of Occupational Radiation Exposure Data from the JET Tokamak," *Fus. Eng. Des.,* **75-79**, 1193 (2005).
4. DOE, *Safety of Magnetic Fusion Facilities: Requirements*, STD-6002-96, May (1996).
5. DOE, "Computerized Accident Incident Reporting System," http://www.eh.doe.gov/cairs/ , Last update October 13 (2006).
6. L. C. CADWALLADER, *Occupational Safety Review of High Technology Facilities*, INEEL/EXT-05-02616, Idaho National Engineering and Environmental Laboratory (2005).
7. D. P. WILLIAMS, JET facility, private communication, to L. C. Cadwallader, Idaho National Laboratory, February 13 (2006).
8. U.S. DEPARTMENT OF LABOR, "Bureau of Labor Statistics," http://www.bls.gov/ , Last update October 27 (2006).
9. NATIONAL BRITANNIA LTD., "Incident Contact Centre Website," http://www.riddor.gov.uk/, last visited October 30 (2006).
10. M. CONCHA-BARRIENTOS, D. I. NELSON, M. FINGERHUT, T. DRISCOLL and J. LEIGH, "The Global Burden Due to Occupational Injury," *Am. J. Ind. Med.*, **48**, 470 (2005).
11. P. HÄMÄLÄINEN, J. TAKALA, K. L. SAARELA, "Global Estimates of Occupational Accidents," *Safety Sci.,* **44**, 137 (2006).
12. OFFICE FOR NATIONAL STATISTICS, "National Statistics," http://www.statistics.gov.uk/ , Last visited October 30 (2006).
13. D. LOOMIS, W. DUFORT, R. C. KLECKNER, and D. A. SAVITZ, "Fatal Occupational Injuries Among Electric Power Company Workers," *Am. J. Ind. Med.*, **35,** 302 (1999).
14. NUCLEAR ENERGY INSTITUTE, "Up Front," http://www.nei.org , Last visited October 30 (2006).
15. NUCLEAR NEWS, "Performance Indicators Show That Nuclear Power Industry Keeps on Improving," *Nucl. News*, **46,** *8*, 29 (2003).
16. W. J. MOTTEL, J. F. LONG, D. E. MORRISON, *Industrial Safety is Good Business, the DuPont Story*, John Wiley & Sons, Inc., New York (1995).
17. DOE, *Inventory of Electric Utility Power Plants in the United States 2000*, DOE/EIA-0095(2000), Washington, D.C. (2002).