PPPL- 5029

PPPL- 5029

Safety Culture And Best Practices At Japan's Fusion Research Facilities

Keith Rule, et. al.

MAY, 2014

Prepared for the U.S. Department of Energy under Contract DE-AC02-09CH11466.

Princeton Plasma Physics Laboratory
Report Disclaimers

Full Legal Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Trademark Disclaimer

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

PPPL Report Availability

Princeton Plasma Physics Laboratory:

http://www.pppl.gov/techreports.cfm

Office of Scientific and Technical Information (OSTI):

http://www.osti.gov/bridge

Related Links:

U.S. Department of Energy

Office of Scientific and Technical Information

Fusion Links

SAFETY CULTURE AND BEST PRACTICES AT JAPAN'S FUSION RESEARCH FACILITIES

K. Rule,[1] L. Cadwallader,[2] M. King,[3] Y. Takase,[4] Y. Oshima,[4] K. Nishimura,[5] A. Sukegawa[6]
1. Princeton Plasma Physics Laboratory, Princeton, New Jersey, USA
2. Idaho National Laboratory, Idaho Falls, Idaho, USA
3. General Atomics, San Diego, California, USA
4. University of Tokyo, Tokyo, Japan
5. National Institute for Fusion Science, Toki, Japan
6. Japan Atomic Energy Agency, Naka, Japan

Abstract. The Safety Monitor Joint Working Group (JWG) is one of the magnetic fusion research collaborations between the US Department of Energy and the government of Japan. Visits by occupational safety personnel are made to participating institutions on a biennial basis. In the 2013 JWG visit of US representatives to Japan, the JWG members noted a number of good safety practices in the safety walkthroughs. These good practices and safety culture topics are discussed in this paper. The JWG hopes that these practices for worker safety can be adopted at other facilities. It is a well-known, but unquantified, safety principle that well run, safe facilities are more productive and efficient than other facilities (Rule, 2009). Worker safety, worker productivity, and high quality in facility operation all complement each other (Mottel, 1995).

I. INTRODUCTION

Magnetic fusion experiment facilities have a large amount of support equipment that is similar to commercial industry equipment. The support equipment includes cooling water systems, electrical power distribution systems, compressed air systems, building heating, ventilation, and air conditioning systems, confinement isolation systems, and other systems used in industrial operations. Fusion also uses some systems that are more rare in industry, such as cryogenic liquid and gas handling systems, lasers, high vacuum pumping systems, and high power radiofrequency heating systems. Lastly, fusion has some unique systems: large, high-field magnets (either resistive or superconducting), large vacuum vessels, and specialized plasma diagnostic systems. Some occupational safety issues at fusion facilities are shared by most industries, and some issues are unique to fusion. The present generation of fusion experiments all use hands-on maintenance, although development of remote handling systems is in progress for future large scale devices.

Past experience has shown that most of the injuries at US fusion experiments tend to be among the technicians that work hands-on with the equipment in the experiment hall (Cadwallader, 2005). Injuries tend to be low severity; most are first aid cases and some are lost work time injuries. Fortunately, there have not been any fatalities in the operation of fusion facilities, and there have been only a few severe injury events over the decades of fusion research. Some of the most frequent hazards at fusion facilities are electrical short circuits, electrical arcs, electrical shock, small fires, falling objects striking personnel, personnel falling from height, exposure to harmful substances, gas leaks, and ionizing/non-ionizing radiation exposure (Cadwallader, 2005). Mitigations for several of these hazards – falling objects, gas leaks, ionizing and non-ionizing radiation exposure – are discussed here.

The safety culture and some good safety practices used in fusion facilities are also discussed in this paper.

II. SAFETY CULTURE AND GOOD SAFETY PRACTICES

The U.S. JWG (see http://www.pppl.gov/node/2136) met with our colleagues in Japan at three fusion research locations, the National Institute for Fusion Science (NIFS), University of Tokyo, and Japan Atomic Energy Agency (JAEA. The NIFS staff provided our team with an updated Safety Handbook written in English that was revised based upon the 2010 Japanese version of the handbook (NIFS, 2011). The second chapter of this handbook is titled "Safety Maintenance General Principles" which establishes the foundation for their safety culture and the required practices. These principles begin with their "safety first" priority which involves risk analysis while also stressing a neat and orderly work environment. The Japanese have a strong belief that a clean work environment is a much safer workspace. Work preparation is an essential component which normally involves procedures. This is followed by precautions such as personal protective equipment (PPE), checking safety equipment, and performing a "Tool Box Meeting" and KY (kiken yochi) which means "hazard prediction". The final principles stress proper response to abnormal or emergency conditions; paying close attention to signs and warning lights; and paying particular attention to proper procedures when working in radiation areas.

II.A. Zero-Accident Total Participation Campaign in Japan

The Campaign is a culture-oriented activity that places a priority on occupational safety and health to create an interactive and lively workplace which is based on the fundamental concept that human life is to be respected and is irreplaceable. Further, to respect each co-worker, all managers and employees participate as a whole in industrial-accident prevention activities at their workplaces, striving to realize "zero accidents" as their ultimate goal through problem solving. All workers shall take steps in advance of activities to ensure no person is injured. This results in two main components, the philosphy or "spirit" of the Campaign along with actual physical actions to collectively prevent accident or injury.

There are three basic principles of the Campaign; 1) zero accidents, 2) preemptive action, and 3) participation. Zero Accidents requires the achievement of an accident free workplace while also meaning that no injuries or illness occur at work and in your daily life. This is achieved through preemptive action by identifying, understanding and solving potential problems. The third principle, participation, requires the involvement of personnel at all levels. Managers, supervisors, staff, and workers collectively detect, understand and solve potential or actual sources of harm. This principle requires effort and a strong commitment of all. The participation principle is also found in the US DOE voluntary protection program.

There are three pillars required to support the implementation of the Campaign: positive attitude of upper management; comprehensive management of the safety and health system by line managers and supervisors; and the promotion of voluntary activities in the workplace. The Campaign depends on the mutual relationships and integration of these pillars. The first two pillars are fundamental and commonplace however "voluntary activities" needs explanation. Human error is present in most accidents and workers must take responsibility for their actions, accountability. Therefore in order to result in zero accidents, workers must engage in small group activities to stress the importance of health and safety and the value of family, self, and co-worker.

Safety in the workplace will not be ensured unless every worker takes part in the practical activities with the positive attitude of "I will not get injured" and "My co-workers will never get injured."

II.B. Kiken-Yochi

Kiken Yochi (KY) means hazard prediction in English. In practice it could be considered similar to the combination of Job Safety Analysis (OSHA, 2002) and the "toolbox meeting" (OSHA, 2014) in the U.S. The practice of KY in Japan is considered to be a fundamental practice or tool in the Campaign. KY incorporates two of the previously mentioned basic principles, participation and preemptive action to achieve the third principle, zero accidents.

This begins with using illustrations of, or actual workplace conditions to demonstrate possible unsafe conditions or behavior. This should be done in small groups. Workers discuss, ponder, and then understand what could happen due to various factors and determine necessary actions.

The KY method increases the motivation of workers to practice in teams. It uses the techniques to sharpen awareness of unsafe issues and conditions. Workers share information on hazards and improve their problem solving capabilities.

II.C. Health and Safety at Universities

Research on risk perception by students who work in laboratories at Japanese Universities was conducted at the University of Tokyo Graduate School of Frontier Sciences (GSFS) (Oshima, 2013). The survey involved 406 science-major students at 7 Universities with the majority being chemistry and biology students. The research involved the use of questionnaires with four major focus areas: 1) Safety management of the laboratory, 2) Safety Training, 3) Accidents in the Laboratory, 4) Environment and Safety of the Laboratory. The responses required the student to provide a ranking on a Likert scale of 1 to 5, 1 being "strongly disagree" and 5 being "strongly agree". In response to the question; "Which information sources did you use to safely conduct your current study", the results indicated a significant dependence on "patrimonial education" through on-the-job training, i.e. learning from senior classmates and professors and a much lower reliance on actual literature, classroom training/lectures, and near-miss/past-accident analysis. One other interesting result was in regard to the use of safety glasses. There was a significant difference between senior students (2nd year of Master's program or beyond) and junior students. The senior students used safety glasses more often due to self motivation and experience.

Exploratory factor analysis was conducted and provided four latent factor groups which make up safety awareness: 1) Education on Safety, 2) Operational Procedure, 3) Self Protection, and 4) Sense of Fulfillment. These results indicated that education on safety and operational procedures were the main factor groups leading toward a strong sense of safety consciousness of the lab and university albeit the source of the education is largely through the aforementioned “patrimonial education”.

The second phase of the research was expanded to include research students in the field of bioscience at University of Tokyo GSFS and Massachusetts Institute of Technology (MIT) in the U.S. The same questionnaire was used with 97 responding at UT and 99 from MIT. The results were compared to each grouping, Japanese Universities as a whole, GSFS, and MIT. When evaluating the same question of “Which information sources did you use to safely conduct your current study” the MIT students gave a more balanced use of sources, including their environment, safety & health (ES&H) staff, while the GSFS was still “patrimonial education” because it did not have departmental ES&H staff. In regard to the use of safety glasses the comparisons revealed that it was more likely based on the field of study, although the MIT students use them more often. In the field of biosciences, the use was much lower than that of chemistry students.

The results of this research identified a clear need for improved safety education at Japanese universities and as you would expect there is a clear difference between industry and university practices and program. The reliance on patrimonial education is counterproductive in the long term. In July 2007, the Research for Environment, Health and Safety Education (REHSE) program was established to develop a new safety educational program which enables the researchers in universities to learn ES&H through both “Facility” and “Knowledge of Operations” approaches. This is a collaborative program between research institutes, universities and industry. There are four guiding principles of REHSE: 1) to aid in problem solving in labs, 2) propose reasonable guidelines, 3) develop human resources, and 4) create new academic fields. The goal of the new “University Safety and Health Management System” is to create a more balanced approach through management, education, and safety research which results in a greater self-initiated safety behavior for research students. The overall program could than yield collective improvement to all.

- Students -Concentrate on research in safe workplace environment
- Professor -Increased research productivity and more involved with facilitating activities
- Facility Manager –more effective laboratory facility design & operation
- Administrator -Cost effective management, improves the university’s social responsibility
- Enterprise –Expectation of ES&H educated students starting up an emerging business
- Government - science and technology is a foundation of the nation, improved ES&H standards by Japan

III. SPECIFIC GOOD PRACTICES AT FUSION FACILITIES IN JAPAN

III.A. Universal Symbol Safety Sign Usage in Japan

A general good practice for fusion facilities is the use of internationally recognized pictograms or symbols to alert all personnel, both permanent staff and visitors, of dangers. The ISO standard 7010 (ISO, 2011) gives many examples of universal symbol signage. These signs have no language barrier, making them perfect for facilities that have many visiting researchers who may not fully understand the language of the host country. A few examples are shown in Figure 1. The example signs in the figure depict a tripping hazard, a sign to prevent pacemaker wearers from entering a magnetic field area, and a personnel exclusion area sign. Use of these signs has increased in the last twenty years and have great benefit when used in facilities where there can be a language barrier.

Figure 1. Universal symbol safety signs used in Japanese facilities.

III.B. Design to Prevent Objects Striking Workers

The large tokamaks and other fusion machines tend to be multi-level experiments, with a pit or well below the machine, then the operating floor or deck, and mezzanine walkways above the machine. There may be scaffolding or walkways to access the top of the tokamak or fusion machine. There is a continual safety concern for objects being dropped from height that could strike a person working below. Industrial helmets (i.e., hard hats) are always specified for work around fusion machines. Researchers at the Large Helical Device (LHD) chose to mount clear Plexiglas panels on the sides of the elevated walkways that access the machine deck. Figure 2 is a photograph of these Plexiglas panels. The walkways have toeboards to prevent small objects such as hand tools, bolts, etc., from falling off the walkway and down to the lower levels. A hand tool, such as a 0.3 kg wrench, falling several meters can produce a serious injury to an unprotected worker. The LHD personnel continue the practice of wearing hard hats despite their engineered barriers.

Figure 2. Protective panels on walkways near the LHD machine.

Another issue of safety concern around fusion machines is the clearance for personnel to gain access to equipment such as diagnostics and sensors. Often the workspace near the tokamak is very restrictive; workers have had injuries of striking against equipment and structural members. We should note that the LHD machine areas were designed with improved space for workers. This is a new function of machine design that should be incorporated in future tokamaks. Certainly helmets protect from serious head injury but striking an object with another body part can also result in injury. In one stairwell location, LHD researchers chose to mount not only the expected black and yellow safety tape as a warning, but also dangling plastic safety chains that are easily audible when touching a helmet, or easily felt when touching a person's back. This is a simple but effective warning to workers who are moving to stand up from close quarters that there is an overhead hazard nearby. Figure 3 is a photograph of these plastic safety chains.

Figure 3. Plastic chains warn workers of the overhead hazard.

III.C. Prevention of First Aid Injuries

The US fusion technician injuries show reasonably high percentages of finger (18%) and hand (8%) injuries per year (Cadwallader, 2005). This result is similar to many industries; hands and fingers are often the most frequently injured body part. Some industries have up to 50% of annual injuries being to fingers and hands (Baistrocchi, 2011). The technicians and construction workers at the JT-60 and LHD machines were all using (as standard practice) appropriate reinforced-cloth work gloves along with other personal protective equipment, including industrial helmets, knee pads, hearing protection, eye protection, and anti-contamination coveralls when needed.

III.D. Oxygen-Deficient Atmospheres and Confined Space Entry

Gas leaks can occur due to the large number of gases and gas distribution systems in use at fusion facilities. (e.g., helium, nitrogen, argon). Other gases can pose combustion hazards (e.g., hydrogen, deuterium, decaborane, diborane) in release events. Gas cylinder storage areas inside buildings always use oxygen monitors to track the volume percentage of oxygen in the air so if a gas is leaking in the area and this gas displaces air then the monitor will alarm that condition.

Liquid helium is used in fusion experiments for magnet and other coolant, and liquid nitrogen is used for some radiation instrument coolant. Cryogen leaks also pose asphyxiation concerns. Oxygen monitors are used in cryogenic areas similar to those used in gas storage and distribution areas.

Confined spaces are defined as areas that have limited or restricted means for entry or exit, are not designed for continuous occupancy, and have the potential to contain a hazardous atmosphere. An example of a confined space in fusion research is entry into the tokamak. While the future fusion devices will likely be too radioactive for personnel entry, most of the existing machines use manned entry for wall tile changeouts, heating antenna maintenance and repair, diagnostic window cleaning, and other tasks. Good practices include enforcing environmental controls, atmospheric sampling, and using a check list before entry. Figure 4 shows a portable oxygen monitor for use when entering a tokamak pit, and a good example of gas cylinder safe practices.

Figure 4a. An oxygen monitor hanging at the entryway to the TST-2 tokamak pit.

Figure 4b. Good gas cylinder safety practices at the University of Tokyo.

III.E. Ionizing Radiation Exposure

Analyses of exposures at tokamaks that have used tritium fuel have shown that while the largest percentage of ionizing radiation exposure is incurred by the maintenance staff in outages, there has been 15 to 20% of annual radiation doses incurred by non-maintenance workers during tokamak operating periods (Natalizio, 2005; Natalizio, 2005a). Very little of these doses were obtained from direct radiation exposure in plasma operations because shielding and exclusion areas are used when a tokamak is in operation (see Figure 5). The main exposure has come from neutron-activated materials that create radiation fields and brief entries between plasma shots to perform manipulations of equipment. The technicians retreat to safe areas before the next plasma pulse.

Figure 5. A radiation shielding door at entry to the JT-60 torus hall.

Radiation safety plans address several issues, including external radiation from radiation sources, internal radiation from inhalation or ingestion of radioactive materials, and radioactive contamination on equipment and surfaces in and around the tokamak. Prudent precautions are taken to protect personnel, including access control to radiation areas, training for work with radioactive materials, use of dosimetry, and work planning. The fundamental radiation safety tenets of reducing time spent in radiation areas, keeping as much distance from radiation sources as possible, and use of radiation shielding are employed. The workers use anti-contamination clothing and shoes, wash hands after radiation work, and use a hand and foot frisker (radiation monitor) to detect if any contamination remains on their skin from the work performed in the radiation area.

III.F. Magnetic Field Exposure

Fusion experiments generate high magnetic fields and can also generate electric fields. These fields can pose safety concerns for persons who have medical implants and pacemakers. A good practice is to mark the areas of magnetic field strength on the floor near magnets so that persons approaching the magnet understand the increasing magnetic field as they walk near the magnet cryostat. Figure 6 shows a 200 Gauss magnetic field strength radius marked on the floor as measured from the magnet, a safety fence, warning sign on the fence door, and a red strobe light that operates when the magnet is energized. These engineered barriers and warnings control access to the high Gauss areas.

Figure 6. Good safety precautions near magnetic fields.

IV. CONCLUSIONS

The 2013 JWG visit to Japan has shown that national rules for occupational safety can vary from country to country. The safety culture in place at Japanese fusion facilities functions very well. The visit also showed a number of good safety practices in use in the Japanese facilities. Some of those notable practices were discussed in this paper. The JWG hopes that all fusion device operators will adopt these and other good practices to enhance safety for their staff. Setting good safety precedents now helps to keep occupational safety provisions included in future designs, such as the design of the demonstration reactor.

Acknowledgments

The authors thank the governments of Japan and the United States for creating the bi-lateral collaboration that allows these safety visits between countries. The US authors thank the Japanese researchers for opening their facilities to the JWG team.

This work was funded by the US DOE Office of Fusion Energy Science under the DOE Chicago Area Office contract DE-AC02-09CH11466 with the Princeton Plasma Physics Laboratory and under the DOE Idaho Field Office contract DE-AC07-05ID14517 with the Idaho National Laboratory.

References

Rule, 2009. K. RULE, L. CADWALLADER, Y. TAKASE, T. NORIMATSU, O. KANEKO, M. SATO, and R. SAVERCOOL, “Elements of Successful and Safe Fusion Experiment Operations,” *Proceedings of the 23rd IEEE/NPSS Symposium on Fusion Engineering*, San Diego, CA, May 31-June 5, 2009.

Mottel, 1995. W. J. MOTTEL, J. F. LONG, and D. E. MORRISON, *Industrial Safety is Good Business, the duPont Story*, John Wiley & Sons, Inc., New York, 1995.

Cadwallader, 2005. L. C. CADWALLADER, *Occupational Safety Review of High Technology Facilities*, INEEL/EXT-05-02616, January 2005.

NIFS, 2011. *Safety Handbook*, 2011 edition, National Institute for Fusion Science, 2011. Available at http://safety.nifs.ac.jp/.

OSHA, 2002. *Job Hazard Analysis*, OSHA-3071, US Department of Labor, 2002. Available at: https://www.osha.gov/Publications/osha3071.pdf.

OSHA, 2014. Toolbox Talks for Construction Focus Four Training are available at: https://www.osha.gov/dte/outreach/construction/focus_four/, accessed March 14, 2014.

Oshima, 2013. Y. OSHIMA, "A New Approach of EHS Education in Japanese Universities," presentation to the Safety Monitor Joint Working Group, University of Tokyo, July 31, 2013. For more information, see www.rehse2007.com.

ISO, 2011. Graphical symbols – *Safety colours and safety signs – Registered safety signs*, second edition, International Organization for Standardization, Geneva, Switzerland, 2011.

Natalizio, 2005. A. NATALIZIO, T. PINNA, J. D. LEVINE, "TFTR occupational radiation exposure data collection and analysis," *Fusion Engineering and Design*, **75-79** (2005) 1187-1191.

Natalizio, 2005a. A. NATALIZIO, M. T. PORFIRI, B. PATEL, "Collection and analysis of occupational radiation exposure data from the JET tokamak," *Fusion Engineering and Design*, **75-79** (2005) 1193-1197.

Baistrocchi, 2011. M. BAISTROCCHI, "Lend a Hand to Save a Hand: An Innovative Communication Campaign to Reduce Hand and Finger Injuries," *Proceedings of the SPE European Health, Safety and Environmental Conference in Oil and Gas Exploration and Production*, Vienna, Austria, 22-24 February 2011, paper SPE 140867.

The Princeton Plasma Physics Laboratory is operated
by Princeton University under contract
with the U.S. Department of Energy.

Information Services
Princeton Plasma Physics Laboratory
P.O. Box 451
Princeton, NJ 08543

Phone: 609-243-2245
Fax: 609-243-2751
e-mail: pppl_info@pppl.gov
Internet Address: http://www.pppl.gov