

Health and Safety Considerations: Fukushima Nuclear Power Plant

Workers at Risk of Heat-Related Illness □ □ 健康と安全性への配慮—心臓にかかわる病気の危険に曝される福島原発作業員

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What more can be done to protect the workers—those on the front lines of protecting the nation—so they can continue their efforts to stabilize the Fukushima Nuclear Power Plant? The Japanese state and TEPCO should recognize the health and safety of front-line workers as a national priority

Concepts and best international practices presented in this document draw on current Japanese and international research and literature to provide information that may be of value in protecting the health of Fukushima workers and others who experience extreme heat and radiation.

The Great East Japan Earthquake and tsunami devastated the Fukushima Dai-ichi Nuclear Power Plant on March 11, 2011, causing three reactors to melt down and melt through the containment vessels. This crisis is of profound importance affecting the health of workers at Fukushima, the people of Japan's Northeast, and potentially people around the world. The buildings suffer from major structural damage, limiting cooling of the spent fuel pools and causing high levels of radiation and humidity.

Workers inside the reactor buildings are subject to excessive heat due to their protective gear. If workers continue to suffer from heat-related stress, impeding efforts to gain control of the plant, they may not be able to avert a disastrous chain of events. The primary purpose of this paper is to provide research-based information that could reduce the probability of death and disability from heat-related illness and facilitate their ability to work efficiently and safely.

Heat stress is of great concern, both from ambient temperatures and high temperatures generated by failing nuclear reactors. "Tsuyu-ake," the end

of the rainy season, was announced July 9 for the Kanto region (<http://www.yomiuri.co.jp/dy/features/science/T110711006037.htm>) around Tokyo. The temperatures in Northern Japan are increasing, impacting the health and safety of the workers who are already toiling in sweltering temperatures inside the buildings while burdened by several layers of protective gear. Research from the areas of sports and occupational medicine can provide valuable insight in developing further strategies to ameliorate the extreme conditions the workers face. Currently workers at Fukushima number in the thousands (<http://search.japantimes.co.jp/cgi-bin/nn20110618a1.html>), and the scope of their needs has yet to be fully determined under these unique conditions.



Medical workers gather around an ambulance

Tokyo Electric Power Company (TEPCO) has been criticized for reliance on contract workers for the dirtiest and most dangerous tasks, and for lack of concern and oversight for their health

care.

Reuters (<http://www.reuters.com/article/2011/06/24/us-japan-nuclear-idUSTRE75N18A20110624>) reported in June on a call by physicians to the Japanese government to provide a system of care that would ensure improved worker safety at Fukushima. The Japan Times (<http://search.japantimes.co.jp/cgi-bin/nn20110618a1.html>) reported TEPCO is making further provisions for medical care at the plant with government assistance. Under the guidance of the Nuclear and Industrial Safety Agency (NISA), a Japanese regulatory agency, TEPCO has taken several steps to improve the work environment. Their efforts include large-scale plant modifications, providing additional protective actions and resources, as well as medical and psychiatric (<http://www.tepco.co.jp/en/press/corp-com/release/11070804-e.html>) care.

Since May, TEPCO has been gradually taking corrective actions after one worker died and several workers began suffering from heat-related illness while working in their personal protective equipment (PPE). Excessive levels of humidity and heat near the reactors and in the microenvironment of the PPE have caused some workers to suffer from heat-related illness and cardiac arrest. Workers have only been able to tolerate 10-15 minutes (<http://www.japanprobe.com/2011/05/20/fukushima-workers-face-heat-stroke-danger/>) of

work in the contaminated buildings due to high levels of radiation, humidity and heat. If the levels of humidity and heat can be effectively reduced, workers will be safer and able to work more efficiently (<http://www.yomiuri.co.jp/dy/national/T110601005305.htm>) to remove contaminated water (<http://search.japantimes.co.jp/cgi-bin/nn20110618a1.html>), fix the water level gauge to help stabilize the reactor, and cool the spent fuel pools in the buildings. NISA required TEPCO to develop a plan to ensure worker safety in building #2 and to take extra measures to ensure the procedure was environmentally safe. On June 2, the Yomiuri Shimbun reported (<http://www.yomiuri.co.jp/dy/national/T110601005305.htm>) that the cooling system at reactor #2 was restored. TEPCO (<http://www.tepco.co.jp/en/press/corp-com/release/11060813-e.html>) has initiated a plan to vent reactor building #2, reducing the amount of radioactivity from .16 bq/cm³ and humidity from 99.9%. They began opening the double doors (Airlock (<http://www.tepco.co.jp/en/press/corp-com/release/11063004-e.html>)) slowly to reduce the high levels of radiation and humidity on June 19th, and installed an air filtration system a few days later.

TEPCO provided an updated “road map” July second (<http://www.tepco.co.jp/en/press/corp-com/re>

lease/11070209-e.html) and eighth (<http://www.tepco.co.jp/en/press/corp-com/release/11070804-e.html>), with plant diagrams showing progress on multiple rest spots provided with coolers and drinking stations throughout the plant. They also purchased hundreds of “cool vests” and masks with blower motors. TEPCO has procured three types of cool vests: paraffin phase change vests, icepack cool vests and lighter duty vests containing chloride. The Occupational Health and Safety Administration (OSHA (http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html)), an American regulatory agency, provides guidelines to protect workers from injury. They report “water-cooled garments” and forced air personal cooling systems provide optimal cooling under encapsulated suits, but they are expensive. TEPCO is under no obligation to follow American guidelines, but they may be useful in this extreme situation. Unfortunately, as of July 19th another worker has succumbed to severe heat stroke (http://news.xinhuanet.com/english2010/indep/2011-07/21/c_131000601.htm), bringing the total number to 33.

Professionals in Occupational Health can provide valuable direction for safely combating the extreme conditions at Fukushima. Assessment of workers’ medical history, medications, health conditions, substance abuse, and normal weight can provide valuable baseline information for

understanding levels of tolerance of excessive heat. Providing a proper nutrition and hydration program is essential. Measuring and understanding actual working conditions and workload can give an indication of the heat stresses workers experience and the work-to-rest ratio required for safety. Portable heat stress meters are used to calculate the wet bulb globe temperature (WBGT) index. OSHA OTM Section III Chapter IV (http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html) provides a method to estimate the tolerable work-to-rest ratio using the WBGT index. The WBGT index reflects variables of ambient temperature, solar radiation, and humidity to indicate the levels of heat stress on humans (Howe, 2007).

Training the workers to monitor dehydration, assess symptoms, and treat heat-related illness is essential. The situation is quite complex and requires a well thought-out plan that includes worker training and access to basic healthcare for heat-related illness. Once all options are understood by experts in the field, appropriate modifications can be made that will allow workers to maximize energy conservation.

Many factors, both physical and environmental, impact an individual's response to heat stress. Physical factors include: age, weight, workload, metabolism, level of acclimatization and fitness, medications, current level of hydration, and consumption of alcohol and caffeine. Prior

history of a heat-related injury predisposes a person to further heat illness. Medical conditions such as diabetes, cardiovascular disease, and hypertension are also contributory. Medical clearance would be advisable for all workers at Fukushima. Administrative controls can alleviate the heat stress workers are exposed to by reducing their work-to-rest ratio and limiting work in the heat of the day. Environmental factors include: ambient temperature, relative humidity, solar radiation, conduction, convection, wind speed and evaporative cooling. Providing proper PPE, equipment and tools to increase efficiency would markedly reduce heat stress.

Workers are subject to very high heat stress risk at moderate ambient temperatures, when factors for the high levels of humidity in the buildings and PPE suits are considered. The body generates metabolic heat when working that is normally dissipated through the skin and respiration. Evaporation is critical in maintaining thermal homeostasis (Howe and Borden, 2007), but it is markedly restricted by the microenvironment of the PPE. The standard adjustment factor for a fully encapsulated suit is 11°C of WBGT stress (Bernard & ACGIH, 2006). Looking at a heat stress index at a temperature of about 30°C (85°F) with a 90% relative humidity, we find a heat stress of 38.7°C (101.6°F). Using the heat stress index as an estimate of actual WBGT in the reactor buildings, and a rough correction factor

for the PPE of 10°C, we get an exceptionally high heat stress of 49°C (120°F). However, under these conditions the adjustments for PPE may not be enough and the actual temperatures may be even higher than 49°C (120°F), according to Thomas Bernard (<http://personal.health.usf.edu/tbernard/thermal/>), an expert in the field of occupational heat exposure from the University of Southern Florida.

Workers at Fukushima should wear respirators and their fully encapsulated PPE (assumed to be Tyvek 1422A or 1427 with cotton anti-C base layers underneath). Thomas Bernard asserted that under conditions at the plant where water is present, the coated Tychem QC suits would be preferable to the Tyvek suits currently in use. Tyvek and Tychem suits are relatively impervious to moisture and thus inhibit evaporative cooling. One can infer that there is very high relative humidity inside the suit and that a thin layer of wicking material may reduce conduction of heat. One worker reported that wearing the PPE was like wearing “a sauna suit (<http://mdn.mainichi.jp/features/archive/news/2011/05/20110514p2a00m0na012000c.html>);” after a short time the facemask fogs and fills up with sweat several cm deep.

A releasing agent on the glass has micro-pores, which tend to collect water droplets that cause fog in the facemasks. To address this problem, divers typically use toothpaste, spit or a drop of

baby shampoo rubbed inside the mask to reduce fogging.

Watersorb (http://watersorb.com/polymer_cool_neck_bands.htm) beads may be useful for absorbing the excess moisture in the facemasks and can tolerate microwaving to dry them out. The cooling scarves TEPCO has purchased contain polymer substances that absorb water like Watersorb. The cooling bandana may not provide enough surface area to be very effective in cooling but may be effective in absorbing excess moisture if placed along the inner rim of the mask. Perhaps ERGODYNE Chill-Its® (http://www.labsafety.com/ERGODYNE-Chill-Its-Evaporative-Cooling-Towel_s_148783/Hydration---Heat-Stress_24538416/?isredirect=true) Evaporative Cooling Towel would be worth a try. TEPCO has plans to purchase 1,300 masks with blowers (three types) that can be used in high dose radiation.

When workers are in their PPE, there may be better alternatives to wick the moisture away from the body than usual under-garments. Under-layers of tech-wear might be preferable to cotton.

DragonFur (http://www.truenorthgear.com/news_article.php?article=19) base layers are specialized clothing for high heat conditions. OEL Structure Wear Base Layer (<http://www.licensedelectrician.com/Store/OEL/StructureWear.htm>) Clothing with Outlast

Thermocouple technology developed for NASA is the only base layer that absorbs, stores and releases body heat, balancing body temperature and reducing sweat. In conditions of exceptionally high heat more advanced cooling vests with circulating water, reflective layers, thicker layers of polyester or wool can provide an extra thermal barrier from radiant heat.

American Conference of Governmental Industrial Hygienists (ACGIH) provides guidelines for heat exposure limits for nuclear power plant workers and threshold limit value. Under the extreme conditions and potentially high metabolic workload at Fukushima it is very difficult to know what the actual levels of heat stress are inside the workers' suits and at the plant, so tools that can monitor physiological conditions while working may be valuable in determining what workers can tolerate.

In 2010 researchers from the University of Occupational and Environmental Health (UOEH) conducted a small study attempting to measure core body temperature with a thermocouple device in an earplug, attaining accurate core body temperature readings while individuals worked in a high heat situation. Heat flux transducers

(<http://cnx.org/content/col10530/latest/>) can be worn by workers to assess the true level of heat stress on the body.

TEPCO

(<http://www.tepco.co.jp/en/press/corp-com/release/11070209-e.html>) Administration assigned a Heat Stroke Manager as of July 1. They will develop an action plan based on the WBGT (Wet Bulb Globe Temperature (http://en.wikipedia.org/wiki/Wet_Bulb_Globe_Temperature)) heat stress index and a heat stress management plan. For workers not acclimatized to the heat, the work-to-rest ratio will be adjusted. OSHA provides guidelines for acclimatization to heat; it takes about one week and can be achieved by gradually increasing workload with minimal exposure on day one and increasing exposure at 20% increments per day. TEPCO will also prohibit work between 2-5 PM in July and August to reduce workers' exposure from solar radiation. Other administrative actions include provisions for educating managers and workers on the signs and symptoms of heat illness and basic first aid, physiological monitoring, an acclimatization program. Provisions should also provide access to emergency whole body cooling treatment and a comprehensive hydration program.

In a hot environment, the primary way to dissipate heat is through evaporation of sweat. Under severe conditions large amounts of fluids, salt and electrolytes can be lost. Maximal sweating for those not acclimated to the heat is 1,500 cc/hr. In a hot, humid environment thirst and hunger do not provide enough incentive to provide for adequate intake of fluids. In

American military activities in desert conditions, soldiers are required to drink 8-10 liters of water and take 3-5 gm of salt per day to prevent dehydration. Camelbak® or other backpack hydrating systems may provide enough hydration to keep workers from having to spend the time to don and doff their gear as frequently for hydration breaks.

The content of the fluid also affects intake requirements; it is quite complex to determine the amount and type of hydrating fluid needed. The American College of Sports Medicine recommends pre-hydrating two hours prior to an athletic event with 500 ml of fluid and 30-60 g/hr of carbohydrates to delay the onset of muscle fatigue. Athletic training guidelines from the National Athletic Trainers Association (2000) recommend including 6% carbohydrate ratio to fluid intake while exercising. Replenishing fluids lost to sweat while exercising with ample isotonic or hypotonic sports drinks is more effective than water for improving performance (Maughan, Bethell and Leiper, 1996). A post-hydration protocol with sports drinks to restore electrolyte balance lost to sweat is also recommended by these organizations.

Research from the University of Connecticut (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC419512/>) (UConn) has shown that pre-hydrating with fluids containing glycerol can reduce the volume of sweat produced during exercise. Anderson, Cotter, Garnham, Casley, &

Febbraio (2001) (<http://www.ncbi.nlm.nih.gov/pubmed/11591882>) used a ratio of 1 g glycerol in 20 ml of water per kg of body weight (BW) 90-120 minutes pre-exercise and found the glycerol group retained more water and thus had less cardiovascular stress. Researchers at UConn studied trained cyclists after repeated dehydration. A group rehydrated with glycerol (1g/kg BW with water) had a 19% increased endurance and were slower to dehydrate than the water only group.

Researchers Horie, Tsutsui, and Miyazaki (2003) from the Department of Health Policy and Management, Institute of Industrial and Ecological Sciences at UOEH, Kitakyushu, Japan studied the use of diluted sports drinks with workers exposed to high heat at a steel factory. They found a 2% solution was preferred by the workers and resulted in less dehydration than the non-diluted beverage. Experts in the field may provide valuable resources for developing an effective hydration program for the workers on the ground at Fukushima.

Dehydration monitoring stations should strive to prevent weight loss of > 3% body weight (BW) after working (Howe et al, 2007). Assessing body weight before and after work sessions will indicate how dehydrated a worker is becoming and assist in developing an individualized hydration program. Calculators and multiple scales (Tanita (<http://www.tanita.co.jp/>)) for assessing body weight can be used to determine

the percentage of fluid loss. Workers could also self-monitor their urine volume and color; the goal is copious amounts, light in color (Howe et al, 2007).

Training workers in the signs and symptoms of heat illness and basic first aid is of primary importance. Heat stroke may progress rapidly, and under these conditions workers should not work alone. The stages of hyperthermia may not progress in a linear sequence, and a person can develop heat stroke without having heat exhaustion. Fatigue, lack of sleep, dehydration, chronic illness, and fever can alter the body's ability to regulate itself and can contribute to development of hyperthermia. Knowing this, workers can modify their behavior and protect themselves and each other.

Heat-related illness can become severe and life threatening quickly. Accurate assessment of the levels of dehydration, heat stresses, and available options may avert disaster. Workers developing fatigue with exposure to heat may result in uncoordinated movements and irrational behavior, which may limit their ability to work effectively and make good decisions. TEPCO is making progress and has provided 8 rest areas so far; a high priority is to continue to find ways to protect workers who continue to suffer from heat illness in the field. Rest areas can serve as acute care emergency reviving stations, providing rapid cooling for workers suffering from heat-related illness and reducing the risk of disability

or death.



Rest area

Fukushima workers would benefit from having the rest areas include an area for monitoring levels of dehydration, first aid and treatment of emergent heat illness. First aid response to the onset of pronounced symptoms of heat-related illness should be to cool first and transport second. Rapid cooling initiated as soon as possible after collapse or after reporting other symptoms of heat exhaustion is imperative in limiting death and disability. TEPCO (<http://www.tepco.co.jp/en/press/corp-com/release/11071301-e.html>) reported transporting workers almost immediately after they were found to have been ill. The best course of future action would be to hydrate and provide first aid with whole body cooling and monitoring prior to transporting workers suffering from heat stroke. Temperatures should be read every few minutes to assess the progress of the cooling efforts. Rectal temperatures are recommended for assessing actual (aortic or esophageal) core body temperature.

Resources for treating individuals suffering from heat stroke are essential. If body temperatures are near 40.4° C (104.7° F), the most rapid cooling of

the body can be achieved with full body ice water immersion

(<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2629045/>). This measure is crucial if core body temperatures reach 41.7° C \pm .3° C (107° F) to 42.2° C (108° F). In this setting small plastic pools with ice water would suffice to cool the body to 38.8° C (102° F) in 20 minutes at a rate of .2° C/min.

TEPCO announced June 30 (<http://www.tepco.co.jp/en/press/corp-com/release/11063013-e.html>) their updated Medical System, which includes doctors at 24 hour off-site offices in J Village and Dai-ni. Hiroshima University organized an enhanced emergency medical system at Fukushima in concert with TEPCO and government agencies. They have opened a new eight bed Emergency Medical Treatment Room in Unit 5/6 Service Building, covered by doctors from UOEH and the Japan Labor Health and Welfare Organization that will focus on treating more significant injuries and heat-related illness from July 1 till the end of September. While TEPCO is currently addressing many of the administrative issues to protect the workers from heat stress, attention needs to be paid to the symptoms of heat related illness in each individual, and their symptoms must not be ignored.

Heat-related symptoms may or may not occur along a continuum. A summary of potential effects of heat-related illnesses from muscle

cramps to heat stroke follows. Muscle cramps are most common in the legs and may be severe and spasmodic, lasting 15 minutes or longer. Inadequate salt in-take or water intoxication may cause heat cramps. Stretching and gentle massage or shaking may relax the muscle. Heat rash is also common and will dissipate once the body is cool.

Heat syncope and heat exhaustion are two forms of heat-related illness that are caused by exertion in a hot environment. Inadequate fluid intake produces dehydration causing decreased blood flow to the brain. This in turn causes syncope (fainting); victims feel faint and perceive a rapid heart rate that is often accompanied by nausea, vomiting, headache, dizziness, restlessness, and brief loss of consciousness. Facial color is usually red and sweating is common, but both may vary.

Heat syncope occurs within normal body temperatures. If someone feels faint, they should lie down with their feet elevated and be protected from the sun. The person should be moved to a cooler environment as soon as possible, and fluids should be provided with salt if available. Only after urine output is normalized should the person cautiously attempt to resume work.

Heat exhaustion, with a core body temperature between 39-40°C (102-104°F), limits people's ability to perform normal tasks. They are usually sweaty and pale with low energy and weakness.

They may stagger, hyperventilate or have the urge to defecate. Treatment for heat exhaustion is the same as that for heat syncope, but temperature should be monitored along with more aggressive cooling efforts. Victims of heat exhaustion are dehydrated, sometimes with low sodium, and should be seen by a doctor before returning to work.

Heat stroke is a medical emergency. Uncompensated heat stress produces a core body temperature $>40^{\circ}\text{C}$ (104°F). It is the most severe form of heat illness and is likely to cause permanent disability or death. Workers may develop sudden symptoms of altered mental status or lethargy after working in a hot, humid environment. Confusion, irrational behavior, delirium, convulsions, collapse, coma and lack of coordination may occur. Heart rate and respiratory rates are elevated and become faint as multisystem failure rapidly ensues. Early recognition and immediate actions to cool the victim may prevent death and disability. In the case of heat stroke full body immersion in ice water or cold water at about 15°C (59°F) is most effective and requires less time to cool the victim than other methods. Superficial temperatures are not accurate at these high core body temperatures. Taking a rectal temperature every few minutes is of value to prevent overcooling. Emergency first aid is needed to monitor respiration, pulse and blood pressure and provide hydration until emergency medical

assistance is available. Cardio pulmonary resuscitation (CPR) may be necessary if blood flow is inadequate. Once cooling has been achieved to 38.9°C (102°F), the worker should be evacuated as soon as possible.

Clearly, to prevent heat-related illness under the extreme conditions found at the Fukushima Nuclear Power Plant, it is advisable to have professional guidance to develop a well thought-out heat stress management plan that includes environmental modifications and human factors. Providing workers with proper equipment and rest areas equipped with a first aid zone to assess hydration issues and treat heat-related illnesses will safeguard workers' health. A basic management plan should include: health screening, acclimatization, a hydration protocol with regular rest breaks, worker monitoring with vigilance, and training to detect early symptoms of dehydration such as irrational, argumentative behavior or unsteady ambulation. With these things in place, trained workers should recognize signs and symptoms of heat-related illness and be able to take immediate action to save lives and avert potentially disastrous workplace accidents. Furthermore, additional research on extreme conditions at Fukushima can create a new body of information on heat-related illnesses that will improve conditions for workers of today and in the future.

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Her earlier work, Feeling the Heat in Fukushima, is available here (<http://www.japanfocus.org/events/view/99>)

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