Evaluation of Occupational Glyphosate Exposures among Employees Applying Herbicides at a National Park

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Contents

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from a safety manager at a national park. The manager was concerned about employee exposures to the herbicide glyphosate when they mixed and applied it to control unwanted plants in the park.

What We Did

- We observed employees while they mixed and applied herbicides.
- We observed work practices and the use of personal protective equipment.
- We measured heat stress and estimated metabolic workloads for various work sites and job tasks.
- We asked employees about their work, use of personal protective equipment, herbicide exposure history, work-related symptoms, and health and safety concerns.
- We reviewed logs of work-related injuries and illnesses, written health and safety programs, and safety data sheets.

What We Found

- We found evidence of herbicide contamination on employees' boots and clothing and in some work areas.
- We observed inconsistent glove use, improper chemical handling practices, and hand washing methods that could create opportunities for herbicide exposure.
- Environmental conditions approached recommended exposure limits for heat stress at work.
- Some employees reported symptoms consistent with early heat illness.
- We observed ergonomic risk factors such as repetition, force, and awkward postures while employees performed some job tasks.
- Some employees reported musculoskeletal problems that affected their back, elbow, hands or wrists that could be related to their work.

> We evaluated employee exposures when they mixed and applied herbicides in a national park. We saw evidence of herbicide contamination on employees' boots, clothing, and in work areas. Environmental conditions approached limits for heat stress. Some employees reported symptoms that are consistent with early heat illness. Some employees reported musculoskeletal symptoms. We recommended improvements in training and developing written site-specific policies and procedures for herbicide handling.

What the Employer Can Do

- Develop written site-specific policies and procedures for properly storing, mixing, and applying herbicides. Train employees and volunteers on these procedures and re-evaluate periodically to ensure that the training is effective.

- Educate employees and volunteers on the hazards of working with herbicides, heat stress, and ergonomic stressors.
- Develop procedures to prevent the contamination of "clean" areas and equipment.
- Improve communication between managers and employees and volunteers regarding employee health and safety concerns.
- Modify work practices to minimize the risk for musculoskeletal disorders by decreasing repetition, force, and awkward postures when mixing, applying, and transporting herbicides.
- Encourage all employees and volunteers to promptly report work-related health and safety concerns.

What Employees Can Do

- Wash your hands and exposed areas of the body with soap and water after handling herbicides, before and after wearing gloves, and before eating, drinking, using the restroom, smoking, and leaving work.
- Change your uniform if it becomes contaminated with herbicide. Wash contaminated clothing before wearing it again using the dedicated washer in the workplace.
- Learn the signs and symptoms of heat-related illness and ways to prevent it.
- Modify your work practices so that you only perform work close to the body, above the knees, and below the shoulders.
- Tell your supervisor about symptoms that you believe are work related. If symptoms continue, see a healthcare provider who is knowledgeable in occupational medicine.
- Report injuries that happen at work to your supervisor.

Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists
CFR	Code of Federal Regulations
EPA	Environmental Protection Agency
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PPE	Personal protective equipment
REL	Recommended exposure limit
SDS	Safety data sheet
TLV®	Threshold limit value
TWA	Time-weighted average
WBGT	Wet bulb globe temperature

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Introduction

The Health Hazard Evaluation Program received a request from a safety manager at a national park. The manager was concerned about employees' exposure to the herbicide glyphosate when they mixed and applied it in the park. We visited the park in July 2016. We spoke with managers and employees and observed workplace conditions, work processes, and practices. In August 2016, we provided our preliminary findings and recommendations in a letter to the employer and employee representatives.

Background

We evaluated employees at a national park in the vegetation department, which consisted of two crews: exotics and revegetation. Employees in the exotics crew, which consisted of biological science technicians and biologists, mixed and applied herbicides to undesirable vegetation (invasive plant species). Employees in the revegetation crew cultivated and propagated native plants, though they would occasionally help the exotics crew during large-scale herbicide application projects throughout the year. Herbicide mixing and application tasks occurred year-round but peaked in the early spring, late summer, and early fall. During peak times, employees spent about 8 hours of their 10-hour work shift on these tasks. Employees worked 10-hour work shifts, Monday through Thursday and were either seasonal, working about 6 months out of the year, or term, working year-round.

Employees were required to wear park uniforms, which consisted of long-sleeved cotton shirts, cotton pants, and leather boots. Employees were also required to wear safety glasses and nitrile gloves when handling herbicides. Employees wore (and reused) long cuff green nitrile gloves. Some employees wore these nitrile gloves with white cotton liners. Employees had the option to wear gaiters (a 100% nylon leg covering with an inner urethane coating) to protect the lower part of their pants from liquid penetration and Tyvek® boot covers. A dedicated clothes washing machine and dryer were available onsite for laundering of reusable items such as cotton gloves, rags, gaiters, and uniforms. Vegetation department employees were included in a respiratory protection program; however, none of the tasks we observed required respiratory protection (per the employer). The program addressed voluntary use of respirators. However, it restricted voluntary use to filtering facepiece respirators, which would be inappropriate for herbicide applications. No respirators were worn during our visit.

The Environmental Protection Agency's (EPA) Agricultural Worker Protection Standard requires any person who applies or supervises the use of pesticides to be certified in accordance with EPA regulations and state, territorial, and/or tribal laws [Environmental Protection Agency 2016]. Employees who handled pesticides (including herbicides, biocides, fungicides) at the park were required by the employer to hold a state-issued pesticide applicator license. The state required pesticide applicators to recertify every 3 years.

Some herbicide-related tasks involved work in areas close to main roads, while other tasks required employees to backpack to remote locations that are unreachable by vehicle. During peak times, it was common for crews to backpack into an area for the entire workweek. Additional tasks performed by the crews included repair and maintenance of herbicide mixing and application equipment and removal of weeds with hand or power tools such as a machete, hoe, hand saw, or string trimmer.

In 2012, glyphosate was the most widely used herbicide in the United States [Environmental Protection Agency 2017] and is the most used herbicide at the park. Glyphosate formulations generally consist of an aqueous mixture of the isopropylamine salt of glyphosate, a surfactant, and other components including antifoaming and color agents, biocides, and inorganic ions [Bradberry et al. 2004]. Employees used glyphosate and, on occasion, five other herbicides, based on the season and target plant species (Table 1).

Table 1. Estimated annual park herbicide usage (in ounces) for 2015

Active ingredient	Brand name	Ounces used	Target plant(s)
Glyphosate	Aquaneat®	6,056	Cheatgrass, Russian thistle
Imazapic	Plateau®	476	Cheatgrass
Imazapyr	Habitat®	35	Silverleaf nightshade, Russian olive
2-pyridine carboxylic acid	Milestone®	21	Scotch thistle, knapweeds
Metsulfuron-methyl	Escort-XP®	6	Whitetop, Scotch thistle
Triclopyr-2-butoxyethyl ester	Garlon 4 Ultra™	5	Tamarisk, Russian olive

Herbicide Mixing and Application

During our visit, employees created a general purpose herbicide mixture containing 3% Aquaneat (active ingredient glyphosate), Target Pro-Spreader/Activator and/or Kinetic® (a surfactant/adjuvant), Blazon® (blue dye), and water. Employees modified this mixture by adding Habitat to target a specific plant. Herbicide mixing took place at the plant nursery.

The most common herbicide application technique used in the park was backpack spraying. The equipment consisted of a tank, internal pump, hose, and spray wand. Employees also performed motorized spraying using a truck-mounted tank, pump, and spray hose with nozzle. Both sprayers were adjustable, allowing the employee to control the droplet size and spray pattern to reduce drift. Backpack sprayers generally operated at 15–95 pounds per square inch of pressure. The motorized sprayer operated at 140–180 pounds per square inch of pressure. Employees reported that a motorized sprayer mounted on a utility task vehicle had been tested, but its use was not yet adopted, nor was it used during our visit.

Other application techniques included cut stump treatment (applying 100% Aquaneat directly to a stump using a short-handled brush) and a new application technique (glove-in-glove) that involved directly applying the herbicide mixture to target plants using a cotton glove saturated with herbicide mixture that was placed over the employees' green nitrile gloves.

Methods

The objectives of this evaluation were to:

1. Observe work practices and procedures of employees working with herbicide mixtures to determine their potential for exposure.
2. Measure heat stress at work sites and estimate metabolic workloads.
3. Determine whether employees had workplace health and safety concerns.

Herbicide Mixing and Application

During our 3-day visit, we observed employees' work practices as they mixed herbicides at the nursery. We also observed employees using four different application techniques at five different work sites. Volunteers occasionally assisted employees with many of these tasks. No volunteers assisted employees with any of the work we observed during our visit.

Heat Stress

To measure the environmental conditions that contribute to heat stress, we used a Quest Technologies QUESTemp°36 instrument. We monitored the wet bulb globe temperature (WBGT) at each work location throughout the work shift. We documented tasks and task duration, and estimated metabolic workload (light, moderate, heavy, and very heavy) using National Institute for Occupational Safety and Health (NIOSH) and American Conference of Governmental Industrial Hygienists (ACGIH) heat stress criteria, which are the same [ACGIH 2017; NIOSH 2016]. All employees wore cotton uniforms, so no clothing adjustment to the WBGT was necessary [ACGIH 2017].

Employee Medical Interviews

We obtained a list of all employees working in the vegetation department and interviewed those that were present during our visit confidentially. We asked about employees' work, use of personal protective equipment (PPE), herbicide exposure history, work-related symptoms, and health and safety concerns.

Document Review

We reviewed the Occupational Safety and Health Administration (OSHA) Form 300 Log of Work-Related Injuries and Illnesses and incident reports for the period covering 2012–2016. We also reviewed medical records for one employee who visited a healthcare provider because of symptoms possibly related to exposure to herbicides after motorized spraying. In addition, we reviewed the manufacturer's safety data sheets (SDS) for Aquaneat, Habitat, Target Pro-Spreader Activator, Kinetic, and Blazon.

Results and Discussion

Because our evaluation was observational by design, we did not collect samples to estimate employees' exposure to the chemicals in the herbicide mixtures. However, on the basis of our observations, it appeared that the primary route of exposure was via skin contact (dermal). We observed the potential for skin exposures during the following tasks: pouring, mixing, transferring, and applying herbicides; cleaning equipment between and after applications; putting on and removing contaminated PPE, clothing, and boots; and coming in contact with contaminated equipment.

Herbicide Mixing and Application

Before mixing herbicides, employees determined the appropriate chemicals, quantity, and equipment needed. Employees usually mixed enough herbicides to last a few days in 1-gallon and 5-gallon plastic containers which were placed on the ground in a plastic containment tray. A garden hose dedicated solely for mixing herbicides was used to add water to the mixing containers (Figure 1).

Figure 1. An employee adds water while mixing the formulation in a plastic container placed in a containment tray. Photo by NIOSH.

Employees used plastic measuring cups and eyedroppers to measure and dispense concentrated herbicides into the mixing containers. We observed employees filling a measuring cup to the rim when dispensing and transferring liquids into mixing containers and backpack sprayers. This practice increases the risk of spills.

Herbicides were also mixed in the 250-gallon truck-mounted tank (Figure 2) which was primarily used to transport and dispense herbicide mixtures into backpack sprayers. On occasion, employees used the attached motorized sprayer to apply herbicide mixtures.

Figure 2. Employees add Habitat to the glyphosate mixture before dispensing it into the truck-mounted tank. Photo by NIOSH.

Although dermal exposure was the primary route, employees also could be exposed via inhalation of spray mists during applications. The potential for inhalation exposure appeared to be greater with motorized spraying than backpack spraying because of higher nozzle pressure and increased likelihood of generating a mist composed of smaller droplets. Smaller droplets tend to remain in the air longer than the larger droplets. Motorized sprayers were used for broadcast and spot treatment applications while backpack sprayers were only used for spot treatment applications. During backpack spraying, no drift was observed. However, during motorized spraying, drift was observed (Figure 3).

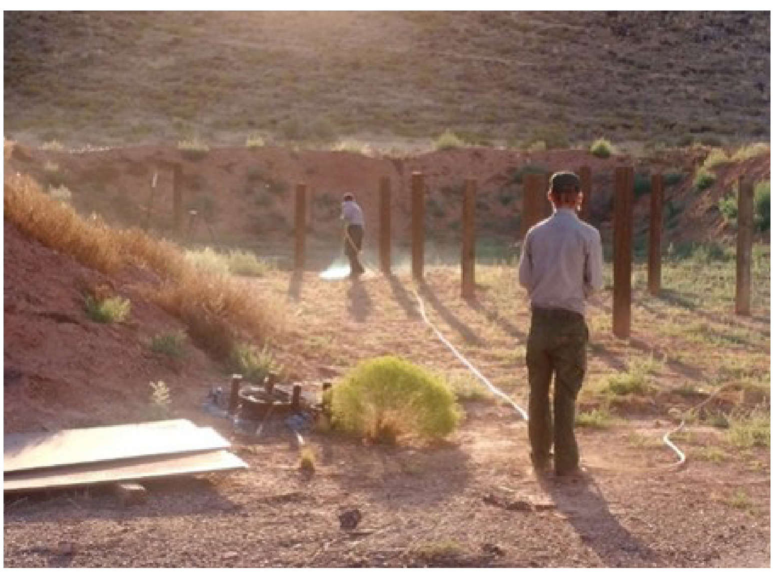

Figure 3. One employee using the truck-mounted motorized sprayer while another employee guided the hose to keep it out of treated areas. Photo by NIOSH.

The employee performing the motorized spraying wore gaiters to protect the lower part of his pants. We noticed that this employee walked through a small area that had already been sprayed at the beginning of the task, however, he adjusted his application technique for the rest of the process to avoid the need to walk in sprayed areas. After treating about one third of the area, employees adjusted the pressure of the motorized sprayer to reduce drift. At this work site, employees followed up the motorized spraying application with additional backpack sprayer spot treatments to reach areas inaccessible with the hose of the motorized sprayer. When finished with motorized spraying, while still wearing gloves, employees wiped the hose off with a rag before retracting it onto the truck-mounted reel. We did, however, notice the nozzle leaked a small amount of herbicide mixture onto the inside of the truck bed (Figure 4).

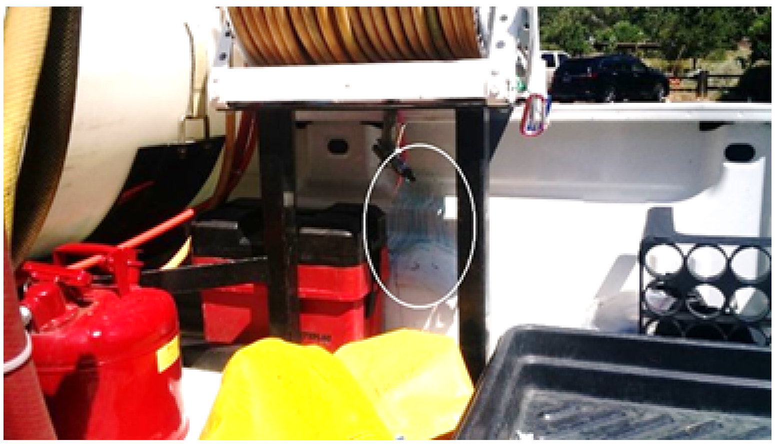

Figure 4. Blue dye stains are visible inside the truck bed from herbicide mixtures leaking from the spray reel. Photo by NIOSH.

We noticed that several employees had evidence of contamination (blue dye stains) on their boots, gloves, and uniforms at the end of their work shift. The dye, which is intended to identify areas sprayed, also aided in identifying leaks from equipment and showed up on contaminated clothing or skin. Blue dye stains were also visible on the tailgate. In addition, we noticed a rag had been tied around a section of the motorized sprayer pump to contain a leak (Figure 5).

Figure 5. Employees used a rag to contain a leak on the motorized spray equipment. Photo by NIOSH.

For the cut-stump applications, employees first removed soil from around the base of the plant and then cut the plant close to the ground with hand shears, leaving a stump. This step was followed by applying the herbicide (100% Aquaneat) to the stump using a brush.

For glove-in-glove applications, employees used a cotton glove saturated with the glyphosate mixture over their green nitrile glove to apply the herbicides directly to target plants. To minimize the potential for spills, employees prepared a 1-gallon bucket of herbicide mixture with a sponge in the bottom of it. One employee placed their gloved hand in the bucket, saturated it with the herbicide mixture, and then wiped it onto the targeted plant while another employee held the bucket. At the end of the work shift, we observed employees using the washing machine to clean cotton gloves and some rags. Some employees also washed their white cotton inner gloves.

Heat Stress

WBGT measurements over the three workdays ranged from 63.9°F–86.4°F. The WBGT value includes humidity, radiant heat, solar load, and wind speed, and is not the same as the measured air temperature. It provides an index of the environmental conditions in which an employee works.

We observed employees while they performed different activities/tasks and estimated the metabolic workload for each (Table 2). We compared these results to 1-hour work and rest schedules recommended by NIOSH [2016].

Table 2. Estimation of metabolic workloads for herbicide mixing and application activities

Day	Task	Duration (minutes)	Metabolic workload*	WBGT (°F)	NIOSH REL (°F)	NIOSH REL exceeded (Y/N)	NIOSH recommended 1-hour work/rest schedule (minutes)
1	Mixing	64	Light	65.6	86	N	—
	Glove-in-glove	30	Moderate	69.6	82.4	N	—
	Glove-in-glove	98	Moderate	80.8	82.4	N	—
	Mixing/ Cleaning	24	Light	79.9	86	N	—
2	Backpack Spraying	74	Moderate	69.2	82.4	N	—
	Backpack Spraying	42	Moderate	81.5	82.4	N	—
	Cut stump	152	Moderate	84.3	82.4	Y	45/15
3	Motorized spraying	75	Moderate	65.1	82.4	N	—
	Backpack spraying	30	Moderate	70.9	82.4	N	—
	Backpack spraying	115	Moderate	77.9	82.4	N	—

REL = Recommended exposure limit

Environmental conditions (heat stress) exceeded the recommended exposure limit (REL) in only one task (cut stump). Heat stress risks were managed under the department's written heat stress management policy, and we observed good compliance with the policy among employees and supervisors. Supervisors directed employees to take rest breaks according to the work/rest schedule of their heat stress management policy. According to this policy, employees performing cut stump activities would have been on a 40/20 work/rest schedule, which is similar to what we determined for the conditions that existed on the day of our evaluation. All of the observed employees took breaks at their own discretion (outside of their scheduled breaks) and drank fluids to stay adequately hydrated. Supervisors monitored work site ambient air temperature using thermometers and adjusted work/rest schedules accordingly. Employees were working in pairs, using the buddy system to monitor each other for heat stress symptoms, and site supervisors had a radio for emergency communications. Ice water was provided at each work site.

Employee Medical Interviews

We held confidential medical interviews with 8 of 12 vegetation department employees who were present during our visit and had applied herbicide at work. Employees reported working at the park an average of 1.2 years (range: 3 months–4 years); most of the employees were seasonal (usually April to September). Four of the eight employees had previously worked at another park. Average age of employees was 34 years (range: 22–49), and five were female. Employees usually worked 40 hours a week with occasional overtime, and they had two daily scheduled rest breaks of 15 minutes each with a 30-minute lunch break and other breaks as needed as specified in the heat stress management policy.

Employees were asked to respond “yes” or “no” to a question regarding exposure to herbicides. Seven of eight employees reported working with Aquaneat approximately 7 hours per shift. All employees reported having worked with other herbicides on a work shift. Three employees reported working with herbicides at home, and four employees reported working with herbicides at a previous job.

When asked specific questions regarding changes in job tasks, procedures, and products used since the beginning of the year (the past 6 months), most employees reported that the products and procedures had been consistent. However, some employees reported that procedures had been implemented including a new hand technique for applying herbicide to long fescue grass, a heat stress management policy, and instructions on when to wash pants after handling herbicides, namely, if gaiters were used then washing their pants at the end of their work shift was not needed.

All employees reported having adequate access to drinking water and staying hydrated by consuming an average of approximately 4 liters a day. They also reported having access to ice and electrolyte replacement packets. Four employees reported they drank coffee, or took a caffeine pill, either in the morning or at some time during the day.

Most of the employees reported wearing safety glasses, nitrile gloves with cotton liners, boots, and hearing protection (when using the string trimmer or seed cleaning machine) while at work. One employee reported they cleaned their nitrile gloves once a month unless visibly contaminated with blue dye stains in which case they would be immediately cleaned. Another employee reported obtaining a new pair of nitrile gloves every other week. All employees reported not wearing aprons and only sometimes wearing gaiters when applying herbicide if there was known to be tall grass or when wanting to protect the lower part of their pants.

All employees reported occasionally noticing blue dye stains on their clothes, especially their boots and pants, or on their body during or at the end of their work shift. An employee reported that the newer backpack O-rings appeared not to leak as frequently as the old style of sprayer. Employees stated they often use rags over the filler neck and cap of the older backpack sprayers to catch leaks. During our visit, an employee reported that, while performing the new glove-in-glove application technique, they noticed blue dye stains on their hands that they thought was due to a torn glove.

Most employees reported they did not attend an in-service training or other educational session about herbicide exposure. However, all employees reported having a current state-issued pesticide applicator license. In addition, some employees reported that they had reviewed the SDSs for chemicals used on the job. They reported that briefings occurred for new tasks, for volunteers on ways they could keep themselves safe, and for new hires, on ”best management practices” on how to spray, adjust, and calibrate equipment, as well as on proper application rates.

When we asked employees if they were currently experiencing any symptoms that may be associated with their work, two of eight employees reported an occasional unpleasant smell and/or taste in mouth and/or nasal mucous turning light blue at the end of the work shift after backpack spraying. Also, when we asked employees if they had experienced any symptoms in the past 30 days, while working in hot conditions, six of eight employees reported at least one nonspecific symptom that could be related to exposure to a hot environment. Five employees reported more than one symptom. Three employees reported lightheadedness, three reported heat cramps and/or unusual soreness in back or hands/wrists, two reported weakness and fatigue, two reported changes in mood, one reported heat rash (skin bumps on hand), one reported moist skin, and one reported darker urine than normal. In addition while working in hot conditions, not counting scheduled work breaks, five employees reported having had to stop working because of exhaustion or because it was too hot. Four employees reported having seasonal allergies.

We asked employees an open-ended question regarding what, if any, health or safety concerns they had about their work. All employees reported at least one health or safety concern. The health concerns reported by three employees included musculoskeletal symptoms such as pain, burning, numbness, or tingling that affected their back, elbow, hands, or wrists. Those employees believed their musculoskeletal symptoms were due to repetitive and forceful movements associated with pumping to pressurize the backpack sprayers and spraying. Two of three employees who used the motorized sprayer reported either feeling "unwell" after herbicide applications with symptoms of sore throat, mild body aches, and dehydration or had concerns about exposures. Other concerns reported by two employees included potential long-term health effects of glyphosate.

Safety concerns reported by employees included the lack of clear guidance on what items or areas were considered "clean" or "dirty" and examples included labels on equipment, gloves in a storage cabinet, and fan or light switches inside the conex (storage containing unit). Other safety concerns included leaking sprayers, exposure to herbicides and heat stress, inadequate training for new seasonal employees and volunteers, and not knowing if reporting a health or safety concern was encouraged. One employee reported that a quick reference guide for appropriate emergency response may be helpful for the field crews. Some employees reported they have good safety protocols and good use of PPE, supervisors are supportive of safety, and they have seen noticeable improvements in safety over the last 4 months including better containment of spills.

Document Review

We confirmed that the park had no written, site-specific, standard operating procedures for pesticide handling. Also, employees reported they only received basic instructions on the locations of herbicides, equipment, and PPE. While these basic instructions ensured each employee meets federal and state requirements for competency, this may have led to the inconsistencies we observed between employees' perceptions of contaminated and noncontaminated areas, work surfaces, equipment, and PPE.

The OSHA Logs for 2012–2016 contained reports of two injuries (one in 2012 and one in 2014) among employees in the vegetation department. The injuries were documented as "a foreign body in eye" and a "stress injury of the foot."

We reviewed the medical records for one employee who had visited a healthcare provider because of symptoms (such as headache, nausea) possibly related to a workplace exposure to herbicides, especially after motorized spraying. The healthcare provider noted that the employee was wearing eye and skin protection, but not respiratory protection. The healthcare provider noted after reviewing the employee's history of present illness and the SDSs for Kinetic, Target, and herbicide, that there was no causal determination at the time of that visit, but contact with and suspected exposure to hazardous chemicals was diagnosed. The employee was given instructions to consider measures to limit inhalation exposure of the herbicides. Occupational (such as physical exertion) or nonoccupational factors could also be exacerbating the employee's symptoms.

According to the SDS for Aquaneat, the PPE requirements were goggles or safety glasses, long pants and shirts, socks and shoes, and chemical-resistant gloves. Respiratory protection was "not normally required." The SDS also stated that the product was odorless and has low inhalation toxicity, but may cause some eye irritation. The manufacturer also stated that the product can produce some toxicity to the skin, but it was considered nonirritating. Approximately 45% of the components listed on the SDS were reported as "trade secret." There are no occupational exposure limits (OELs) for glyphosate. Appendix A has more information about glyphosate.

According to the SDS for Habitat, the PPE requirements were safety glasses with side-shields or safety goggles, long pants and shirts, and chemical-resistant gloves. The product may cause slight eye and skin irritation. Approximately 72% of the components listed on the SDS were unnamed "proprietary ingredients." There are no OELs for this herbicide.

Activator adjuvants (combinations of surfactants) are a broad category of chemicals that are used to enhance herbicide performance. They also facilitate and enhance the absorbing, emulsifying, dispersing, spreading, sticking, wetting, or penetrating properties of herbicides [Mullin et al. 2016]. In particular, surfactants are used to reduce the surface tension between the spray droplet and leaf surface. They include nonionic, anionic, cationic, and organosilicones [Curran et al. 1999]. According to the SDS, Kinetic (nonionic surfactant/adjuvant) has an odor, causes eye and skin irritation, and may cause an allergic skin reaction. Additionally, the Target Pro-Spreader Activator (surfactant/adjuvant) was described as a mixture of nonionic surfactants that have a mild alcohol odor and may cause eye and skin irritation especially during contact with vapors or mists.

Because surfactants and adjuvants do not fall under the EPA pesticide registration guidelines [Environmental Protection Agency 2016], manufacturers often list components on their product SDS as trade secret or proprietary. This makes it difficult to determine the safety profile of an herbicide mixture. Each SDS we reviewed listed some portion of the contents as trade secret or proprietary.

Other Observations

We noticed that employees brought spill containment kits and first aid kits with them to work sites, but no emergency eye wash kits.

We observed diligent use of PPE (e.g., uniforms, boots, safety glasses, nitrile gloves) by employees during our visit. However, we noticed differences in how employees handled their green nitrile gloves. Some employees would lay their gloves in a nearby location and then put them on for continued use without cleaning them first. Some employees would roll the glove material at the wrist to form an inside-out cuff to provide a "clean" surface to grab when putting them on. Once these cuffed gloves were used to handle contaminated items, they could become contaminated and lead to dermal exposure. Improper glove decontamination procedures can spread chemicals into areas or items other employees might consider clean. It is important to remember that once the glove material is exposed to a chemical, the permeation process begins, and never stops; washing does not remove absorbed chemicals. The chemical(s) will continue to migrate though the material and eventually break through the unexposed surface and possibly contaminate unprotected skin [Forsberg 2014].

In general, employees were not aware of which areas were clean and which were dirty. This occurred predominantly at the nursery where employees began and ended their work shifts. For example, we noticed two employees handling herbicides wearing their green nitrile gloves, but an additional pair of gloves was observed on the ground near the vehicle (Figure 2). Such a work practice made identifying clean versus contaminated areas difficult. We observed some employees did not wash their hands after applying herbicides and removing their gloves and before eating or smoking.

We observed ergonomic risk factors such as repetition, force, and awkward postures among employees related to lifting and using heavy herbicide mixing and application equipment. Additionally, repetitive and forceful movements were required to operate the pump that pressurized the backpack sprayer. Some tasks associated with mixing the herbicides required employees to bend over to lift and pour mixing containers into backpack sprayers. Also, these mixing containers and backpack sprayers had to be placed onto the truck bed, often requiring employees to extend their arms at or above shoulder height and also twist their trunk. Most tasks associated with cut stump applications required employees to stoop and kneel and use their hands and hand tools to remove soil from around the base of the plant thereby creating a risk for musculoskeletal disorders of the hands or wrists and contact stress in the knee joints.

We noticed hazard warning information on some secondary containers was inadequate or missing. Employees had been trying different labeling methods but had yet to find a suitable solution for all containers. The employer is not required to label portable containers into which hazardous chemicals are transferred from labeled containers, and which are intended only for the immediate use of the employee who performs the transfer [OSHA 2012]. Employees complied with this OSHA requirement for most daily tasks (e.g., mixing, cut-stump, glove-in-glove), but this was not the case with backpack sprayers as some were stored overnight in the conex with unemptied tanks.

We saw lightly powdered latex gloves in the nursery office. This type of glove has been shown to cause allergic reactions including asthma in some people. The Food and Drug Administration banned powdered latex gloves in January 2017 because of the substantial risk of allergic reactions [Food and Drug Administration 2016]. In addition, we saw hand cleaning wipes present and available to employees for decontaminating their hands, surfaces, and equipment. In a 2011 NIOSH health hazard evaluation report, these same hand wipes, referred to in the report as blue hand wipes, were tested for skin irritation and sensitization and investigators found that they may result in skin sensitization and cause allergies [NIOSH 2011].

Evaluation Limitations

This evaluation had some limitations. We only assessed a relatively small number of employees over 3 days and may not have evaluated worst-case herbicide-related activities (early spring, late summer, and early fall) or environmental heat stress conditions (late summer). Our evaluation occurred between these seasons.

Conclusions

On the basis of our observations and employee interviews, we concluded that skin contact was the main route of employee exposure to herbicides; however, inhalation of spray mists is a potential route of exposure. We observed inconsistent use and inappropriate reuse of gloves as well as inconsistent hand washing methods. Environmental conditions approached published limits for heat stress, and some employees reported symptoms consistent with early heat illness. We observed good compliance with the department's written heat stress management policy among employees and supervisors. Mixing and applying herbicides involved repetitive, forceful movements and awkward postures. The unpleasant smell and/or taste in mouth reported by a couple of employees is consistent with exposure to herbicide mixtures. However, herbicide mixtures, containing different adjuvants and surfactants, make it difficult to identify the specific ingredient(s), which may be responsible for the reported symptoms.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the national park to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation in the vegetation department.

Our recommendations are based on an approach known as the hierarchy of controls (Appendix A). This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and PPE may be needed.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Use properly sized measuring cups when mixing herbicides to reduce the likelihood of spills.
2. Investigate options for replacing hand application (glove-in-glove) methods with a

more ergonomically acceptable application device to prevent contact stress to the knees and bending of the back.

3. Provide an adjustable table or bench to aid in mixing herbicides in the plastic containment tray. This measure will reduce the risk of ergonomic problems associated with mixing on the ground. Also, investigate options for providing a detachable step or ladder that can be attached to a truck tailgate or hitch to prevent lifting at or above shoulder height or away from the body when loading and unloading equipment.

Administrative Controls

The term administrative controls refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Develop a site-specific written training program for all employees and volunteers who handle herbicides. This program should include policies and procedures for properly storing, mixing, and applying herbicides. Periodically review the program and observe employee work practices to evaluate its effectiveness in reducing exposure.

2. Inspect and maintain spraying equipment as recommended by the manufacturer. Make repairs in a timely fashion. Ensure compatibility of equipment and components with all chemicals used.

3. Provide clean water and soap at every work site for washing hands or other skin after contact with herbicides. Wash hands after removing gloves and before eating, drinking, chewing gum, smoking, and before and after using the restroom.

4. Provide portable eyewash stations capable of providing a minimal 15-minute eye wash in each vehicle and install a permanent eyewash station at the nursery.

5. Improve communication between managers and employees and volunteers regarding employee health and safety concerns. Employees and volunteers should be informed what actions have been or will be taken regarding their concerns, and concerns should be addressed in a timely manner.

6. Label secondary containers as required by the OSHA hazard communication standard [29 CFR 1910.1200].

7. Ensure that employees and volunteers potentially exposed to hot environments and physically demanding tasks are trained on heat stress prevention. NIOSH has updated the *Criteria for a Recommended Standard: Occupational Exposure to Hot Environments* document, which includes information on physiological monitoring and work/rest schedules that can be used to prevent heat stress and strain, https://www.cdc.gov/niosh/docs/2016-106/. Additional recommendations can be found in the NIOSH document "Preventing Heat-related Illness or Death of Outdoor Workers" at http://www.cdc.gov/niosh/docs/wp-solutions/2013-143/pdfs/2013-143.pdf and on the OSHA website, which gives guidance on heat stress prevention in outdoor workers at https://www.osha.gov/SLTC/heatstress/.

8. Educate employees and volunteers on additional hazards to outdoor workers such as poisonous plants and venomous wildlife and insects. Recommendations can be found at https://www.cdc.gov/niosh/topics/outdoor/default.html.
9. Educate employees and volunteers on musculoskeletal disorders and ergonomics. Cover ways to recognize and adjust specific activities that could cause musculoskeletal disorders.
10. Discourage employees and volunteers from using caffeine while working in hot conditions as this behavior may increase the risk of heat-related illness.
11. Use hand wipes that do not contain potential skin sensitizers.
12. Encourage employees and volunteers to report potential work-related health and safety concerns to their supervisors. Employees and volunteers with persistent symptoms (such as eye, skin, or upper airway irritation, heat-related, musculoskeletal) should promptly seek medical attention from a healthcare provider who is knowledgeable in occupational medicine.

Personal Protective Equipment

Personal protective equipment is the least effective means for controlling hazardous exposures. Proper use of PPE requires a comprehensive program and a high level of employee involvement and commitment. The right PPE must be chosen for each hazard. Supporting programs such as training, change-out schedules, and medical assessment may be needed. Personal protective equipment should not be the sole method for controlling hazardous exposures. Rather, PPE should be used until effective engineering and administrative controls are in place.

1. Re-evaluate glove selection, use, decontamination, and change-out policies to ensure employees' hands are protected. Proper glove selection and use will help employees avoid transferring herbicides to exposed skin during mixing and application tasks and prevent the contamination of clean areas (employees' clothing, vehicle interiors, clean areas inside the conex, office and break areas, etc.). Check with glove manufacturers to estimate when gloves should be changed out after use/contamination.
2. Follow all safety instructions listed on herbicide labels, including using adequate PPE such as safety glasses or goggles, long pants and shirts, and chemical-resistant gloves, when mixing or applying herbicides. Wash or replace PPE when contaminated.
3. Replace the lightly powdered latex gloves with disposable nitrile gloves.

Appendix A: Occupational Exposure Limits and Health Effects

NIOSH investigators refer to mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a pre-existing medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a time-weighted average (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limit or ceiling values. Unless otherwise noted, the short-term exposure limit is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- The U.S. Department of Labor OSHA permissible exposure limits (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH recommended exposure limits are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, PPE, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Another set of OELs commonly used and cited in the United States is the ACGIH threshold limit values (TLVs). The TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2017].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/GESTIS/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions. NIOSH investigators also encourage use of the hierarchy of controls approach to eliminate or minimize workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) PPE (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health. Control banding focuses on how broad categories of risk should be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement existing OELs.

Glyphosate

Glyphosate is a nonselective herbicide that is effective in controlling weeds and grasses. Although it contains phosphorus, it does not inhibit acetylcholinesterase and instead inhibits the critical enzyme of the shikimate pathway in plants which is not present in humans [Bradberry et al. 2004]. Inhalation of spray mist may cause oral or nasal discomfort and throat irritation. Acute toxicity studies have shown low oral toxicity (> 5,000 milligrams per kilogram bodyweight) and low dermal toxicity (> 2,000 milligrams per kilogram bodyweight) [Bradberry et al. 2004]. Glyphosate is excreted mostly unchanged in the feces and in urine and undergoes little metabolism [Williams et al. 2000]. According to an occupational exposure study, farmers who did not use rubber gloves during application had higher mean urinary concentrations of glyphosate than other farmers [Acquavella et al. 2004].

The California EPA Pesticide Illness Surveillance Program for the years 1982–1997 found that the most common glyphosate-related symptom was irritation without systemic symptoms. Of all 815 glyphosate cases identified during that timeframe, only 22 systemic cases were found to be probably or definitely related to glyphosate exposure alone [Goldstein et al. 2002]. In addition, a comprehensive review article that looked at several journal publications on glyphosate found that there were no adverse effects with glyphosate and that under present and expected conditions it does not pose a health risk to humans [Williams et al. 2000]. However, in March 2015, the International Agency for Research on Cancer of the World Health Organization classified glyphosate as Group 2A, "probably carcinogenic to humans" on the basis of epidemiological, animal, and in vitro studies with limited evidence for the risk of non-Hodgkin lymphoma [IARC 2017]. Of note, there is considerable debate surrounding the carcinogenic potential of glyphosate because of the conflicting results between human studies. The EPA is scheduled to publish its draft glyphosate human health and ecological risk assessments for public comment in 2017 and is doing a periodic registration review required by law. Additional details are available at: https://www.epa.gov/pesticides/scientific-advisory-panel-report-glyphosate-available.

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