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Health Risks to Ecological Workers on Contaminated Sites - The Department of Energy as a Case Study

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Abstract

Background: At most contaminated sites the risk to workers focuses on those 'hazardous waste workers' directly exposed to chemicals or radionuclides, and to the elaborate approaches implemented to protecting their health and safety. Ecological workers generally are not considered.

Objectives: To explore the risks to the health and safety of ecological workers on sites with potential chemical and radiological exposures before, during or after remediation of contamination. To use the U.S. Department of Energy as a case study, and to develop concepts that apply generally to sites contaminated with hazardous or nuclear wastes,

Methods: Develop categories of ecological workers, describe their usual jobs, and provide information on the kinds of risks they face. Ecological activities include continued surveillance and monitoring work on any sites with residual contamination, subject to institutional controls and engineered barriers following closure as well as during the restoration.

Results: The categories of ecological workers and their tasks include 1) Ecological characterization, mapping and monitoring, 2) Biodiversity studies, 2) Contaminant fate and transport, 3) On-going industrial activities 4) Remediation activities (environmental management), 5) Environmental restoration, 6) Post-cleanup surveillance and monitoring, and 7) Post-closure future site activities. There are a set of functional activities that can occur with different frequencies and intensities, including visual inspection, collecting biological samples, collecting media physical samples, collecting biological debris, restoration planting, and maintaining ecosystems.

Conclusions: Ecological workers face different exposures and risks than other environmental cleanup workers. Many of their tasks mimic shift work with long hours leading to fatigue, and they are exposed to biological as well as chemical/radiological hazards. DOE and other entities need to examine the risks to ecological workers on site with an eye to risk reduction.

Keywords: Ecological studies; Risks; Threats; Risk reduction

Introduction

Governmental agencies, private companies, unions, and the public are interested in the health and well-being of people working in all different jobs and situations. Understanding the risks that workers face in the regular execution of their jobs is a critical component of occupational health and safety, and has emerged as an important discipline. A range of safety officers, industrial hygienists, radiologic technicians, and health professionals are involved in assessment, prevention and treatment of occupational exposures. Considerable attention is devoted to reducing accidents, and removing dangerous situations. Companies foster a safety culture, often placing signs at the edge of their property noting how many days they have gone without an accident (or worker fatality). Yet unsafe exposures and accidents occur at different rates, even for the same job, under different conditions [1-3].

Given that hazardous waste work occurs in largely uncontrolled and often incompletely characterized circumstances, special protections are required. The main mechanisms for hazard recognition and worker protection lie in hazardous waste worker training detailed in the OSHA HAZWOPER standard [4], and development and implementation of site specific Health and Safety Plans (HASPs) [5].

It has long been known that there are disparities in occupational exposures. Some trades are intrinsically hazardous [6], while others may become hazardous by inattention to safety or negligence. Occupational health disparities can be influenced by many factors, including race/ethnicity, gender, social class, age, and job insecurity, among others [7], as well as sleep deprivation [8]. Further, there are regional geographic variations in work injuries that suggest that work safety measures may be unevenly distributed with respect to regional socio-economic factors [1]. Workers recognize that their jobs affect their health, and many studies are completed with self-reported conditions or health effects [2].

In site remediation, the role of construction workers, such as heavy equipment operators, laborers, steel workers, truck drivers, and the specialist roles of chemical operators or radiation safety, have been studied. Likewise, first responders, police and firefighter risks have been examined, for example in the context of the 9/11 World Trade Center destruction [9,10]. It is recognized that such workers deserve ongoing health surveillance because of their exposures and increased risk [11]. One group of workers that has received relatively little attention is ecological workers who conduct field studies, such as monitoring natural ecosystems and environmental media, conducting biological and life history studies, conducting contaminant fate, transport and effects studies with contaminants, and conducting biomonitoring or assessments during all phases of environmental clean-up and restoration (before, during and after). More attention has been paid to the ecological receptors themselves, than to the workers investigating them [12]. Likewise, more attention has been devoted to how to sample environmental contaminants than to the exposure of environmental samplers [13].

Exposure to contaminants can be through dermal exposure, ingestion or inhalation, the latter being particularly a problem for outdoor-workers in urban environments [14,15] or during dusty construction activities [16]. Certain dusts, rich in silica, alkaline fine particles or asbestos are particularly hazardous, increasing risks for respiratory and cardiovascular disease and cancer [16,17].

Study Goal

The primary goals of this study are to: 1) provide a framework for ecological worker categories that can be used at a variety of contaminated sites, and that will serve as a model for additional categories, descriptions, and assessment of risks at hazardous waste sites, 2) describe each category, 3) provide examples of activities of each, and 4) describe the hazards ecological workers face with respect to accidents, vehicles and heavy equipment, and biological, chemical and radiological exposure.

Background on the ecological resources on department of energy sites

The Department of Energy and its antecedent agencies were responsible for the development and production of nuclear weapons. The Cold War arms race left behind a legacy of nuclear and chemical waste which became evident after 1990, when DOE's attention shifted rather suddenly to environmental management [18-20]. The DOE complex is used as a case study to consider different kinds of ecological workers because DOE has a wide range of different environmental, ecological, and chemical/radiological exposures in varying states of anticipation, remediation, and completion. The DOE complex has 17 major cleanup sites under Environmental Management, in 11 states [21].

Many of the large DOE facilities (hundreds of square kilometers) incorporate large buffer areas of natural landscapes [22]. These lands, for example at Hanford (Washington) and Savannah River (South Carolina) have endangered and threatened species, as well as valuable, rare and unique ecosystems that have been undisturbed by people for 75 years. The Amchitka nuclear test site in the Aleutians was not only large, but remote, and contamination of its resources were of great concern to native subsistence communities [23].

Avoiding destruction of these ecosystems, while remediating contamination, is an important societal goal [23,24]. Many of the buffer lands on these DOE areas have been protected by the DOE as National Environmental Research Parks (NERPs [24]), both for protection and research. The rationale for this designation recognizes DOE's stewardship of the lands and promotion of basic and applied ecology research. Ecological workers are thus engaged in assessment and monitoring, predicting environmental responses to human activities (including remediation), and evaluating methods to minimize adverse ecological impacts [25].

For many years there have been important ecological studies on the DOE sites under the NERP program, conducted by ecologists, environmental scientists, radiation biologists and others [24]. Since these resources have been protected for 75 years without human disturbance, they are invaluable resources [24,26,27]. Thus remediation and restoration on these sites requires ecological evaluation so that endangered and threatened species, and sensitive and unique ecosystems are protected, now and in the future.

Materials and Methods

The conceptualization of the types of ecological workers, examples of indicators or activities, and risks faced by ecological workers described in this paper come from 25 years of conducting ecological studies at U.S Department of Energy site and New Jersey 'Superfund sites' by the authors. The studies were mainly funded by the Consortium for Risk Evaluation with stakeholder Participation.

The DOE sites range in size from small to 1/5th the size of New Jersey, from urban to rural, and from humid forests to dry shrub-steppe [21] - thus the ecological tasks differ widely. While other scientists might present a different classification system and examples, ours are meant to stimulate discussion and raise awareness of a type of worker not usually considered at remediation sites. Since this paper is a conceptualization of risks to a worker group usually ignored, references are used in the results section to demonstrate these types of effects in workers generally.

Results

Ecological worker categories and their activities

While the number of job titles for people working in ecological fields is long, depending upon the industry or agency, there are only a few components or ecological tasks that make up each job, most of which are outdoors (except for design, data analysis and writing). These field workers may be employed by Federal, State, Local or Tribal agencies, and by academia, contractors or consultants.

Their work may focus on biota (sampling, tagging, observing, bleeding animals) or on environmental media (drilling, collecting, analyzing). Their work may be incidental to the hazardous waste remediation mission or an integral part of assessment, monitoring, or restoration. They may be senior or junior scientists, the ecologic technicians, or ecologic work may be carried out by members of the construction work force including drillers, equipment operators, and laborers.

Gochfeld et al. [28] characterized the demography of the hazardous waste industry involved in sampling and remediation circa 1985. However, at the time, workers engaged in ecological operations and tasks were not considered. Unlike radiation specialists, ecologists, biologists and environmental scientists are being trained at all major universities, and that workforce is being replenished by young

graduates. However, there are some older ecologists who may be employed at chemical, nuclear and other restoration sites, and accident or injury rates may be even higher in older ecologists because they are often working in uneven terrain where there are rocks, logs, and other debris [29-31].

They may be working when sleep deprived because of the importance of working long hours during a limited field season. Further, ecological workers often go into the field alone, and if they do have an accident away from their cell phones (or out of reach of cell towers), there is no one to rescue or aid them. This argues for always having ecological workers go into the field in pairs. Field work in remote areas requires special provisions in developing the Health and Safety Plan [32].

Hazardous waste sites may remain for decades awaiting decisions or funding for remediation. During this time period there may be monitoring or sampling activities on or adjacent to the contaminated site. Depending on the ecologic resources, ecological field assessments may be part of remediation feasibility studies. Sampling of ground water, surface water, soil and biota may be conducted in areas of varying contamination levels.

During remediation, which may require years for completion, sampling will be conducted to ascertain that contamination is contained as required by regulatory agencies. This is a period of high dust generation. Also there is the potential for structural collapse or heavy equipment exposures. Upon remediation completion, there is a wide range of restoration activities that are required to rehabilitate damaged ecosystems [33].

The major types of ecological workers on hazardous sites, such as those at the DOE, include monitoring eco-receptors, studying biota in the field, studying fate, transport and effects of contaminants, monitoring on-going DOE activities, and activities associated with environmental management, restoration, and closure (Table 1).

The definitions of these categories vary, as do the activities of each type. The categories that are most apt to be overlooked include those involved with buffer zones, those that occur during environmental restoration, and those that occur in the post-closure period. Further, after closure, ecological workers may be involved with new construction (Table 1).

Type of Worker	Description	Examples of Endpoints, Indicators, or Work Orders
Monitor Eco-receptors	Periodic censusing of population numbers, reproductive success or other indicators of ecosystem health.	-Number of salmon nests in Columbia River/km -Number of fish/km of Poplar Creek -Number of nesting bird species/ha of INEL shrub-steppe -Number of birds/ha in plots on and adjacent to contaminated site -Mean clutch size of an indicator species on and adjacent to contaminated site
Study Biota in the Field	In-depth studies of the biology, behavior, and life history information. Analyze behavior and distribution with respect to contamination or disturbance.	-Differences in reproductive success of birds as a function of habitat, weather, restores vs non-restored, adjacent to DOE or other buildings or 1 km away. -Number of salmon, deer, thrushes/h at different distances from a DOE or other facility -Life history parameters in different habitat. -Effect of dust suppression on vegetation along roads.
Study Contaminant Fate and Effects	Laboratory or field studies of the accumulation or effect of radionuclides or chemicals on behavior, survival or reproduction	-Levels of cesium in organisms on DOE sites versus off-site. -Radionuclide levels in tumbleweed in western US DOE sites -Levels of cesium in organisms in streams near a nuclear power plant. -Levels of mercury in organisms on and off-contaminated sites, and possible effects at these sites. -Effect of different concentrartions of hexavalent chromium on salmon reproduction -Accumulation of mercury in fish in Poplar Creek -Dose-response effects of mercury on fish reproduction -Movement of contaminant on the site.
On-going Activities at DOE sites or other chemical sites	Biologist involved in planning and executing methods for fire suppression, for reducing exposure of biota to contaminants, or dealing with unwanted plants or animals on site.	-Remove tumbleweed from fences that provide a line of tinder that can spread fire. -Search for biota on DOE operations facilities that could be contaminated. -Remove snakes, bats or other organisms for active facilities. -Cut grass and remove invasive plants or animals from grounds or facilities. -Planting around facilities.
Environmental Management	Biologists involved with planning or executing methods to reduce effects in buffer zones around environmental cleanup actions	-Spraying water to reduce blowing sand from digging and trucking soil – determine the effect of increased water on roadside plants. -Develop plans to reduce invasive seed dispersal by trucks and other vehicles involved in cleanup. -Removing unwanted plants or animals from the work area.

Environmental Restoration	Ecologists who plan and execute the physical and biotic environment for remediation sites	-Determine what kind of slope to make, how many and what size of water bodies to create. -What kind of native plants to plant; planting and tending the plants -Monitoring success of restoration of plants. -Monitoring presence of invertebrates, such as pollinators -Monitoring invasive species. -Supervising heavy equipment operators -Grading slope, or planting native plants, watering or removing invasive species. -Planting, mowing, spraying herbicide or insecticide
Post clean up Monitoring	Ecologists or others tasked with monitoring to ensure that there is not failure of institutional or engineered controls	-Set up monitoring plans and execute them with reasonable periodicity. -Insure the efficacy of institutional and physical barriers on sites where contamination remains. -Collect samples where necessary and make sure results are within specifications.
Post cleanup development	Ecological surveys for regulatory purposes (for state or federal mandates)	-Following cleanup, developers and others will use the land or build on it, biologists will again conduct studies (which might involve collecting, see above categories). -Number of birds on site -Levels of contaminants -Exposure and risk assessments for future users/occupants

Table 1: Types of ecological workers at contaminated sites (e.g. Department of Energy or other sites) with examples of the kinds of problems they are investigating or the tasks they are assigned. These are illustrative only. Workers may be employed by federal, state or local agencies, contractors, academia, or consulting firms.

Exposure or risk categories

There are several ways to examine exposure (leading to risk categories), but the major categories of risks presented are those that can decease health and safety. These categories include traumatic injuries or common industrial-type trauma (slips, trips falls, or cuts, being hit by objects), vehicular or heavy equipment accidents (large, heavy equipment used for cleanup operations), media exposure (soil, dust, water), biological exposures (diseases, noxious animals), chemical exposures, and radiological exposures [34].

Any ecological worker may be exposed to any combination of these exposures, in any intensity, for any length of time (Table 2). It is up to the personnel responsible for ecological workers to determine their relative exposure.

The exposure categories are described below. Table 2 lists the major health and safety risks, the risks associated with each ecological worker activity, and a brief description of each type. For each activity, the potential risk is indicated for a person at the edge of the remediation site, on-site, and in buildings on site because the risks differ as a function of location.

Activity	Falls, cuts, being hit by things	Vehicular Equipment Accident	Heavy Equipment Accident	Physical and Media Exposure[a]	Biological Exposure[a]	Chemical Exposure	Radiologic Exposure	Comments
Visual inspection Edge of site On-site In buildings	X X X	X X	X		X X	X X	X X	Do not touch biota or media; Use mainly cameras, binoculars, field computers
Collect biota samples From edge On-site In buildings	X X X	X X	X X		X X	X X	X X	Use collecting materials and traps, seines, boats
Collect media and physical samples from soil or water From edge On-site In buildings	X X X	X	X X		X X	X X	X X	Collect invertebrates and other organisms in soil, involves digging, cores, secchi disks and other equipment, boats.

Collect biological debris[b] or invasive species From edge On-site In buildings	X X X	X X	X X		X X	X X	X X	Collection of materials, includes using traps, seines, and boats. Can include removal of tumbleweed for fire suppression.
Plant native species, introduce animals as part of remediation	X	X	X		X			Use of shovels and other equipment to dig, plant for restoration.
Maintain ecosystems	X	X	X	X	X			May include removal of invasive plants or watering of new seedlings, introduction of propagules or pollenators
[a]For example, rabies from raccoons; exposure to poison ivy, poison oak or poisonous snakes; Responses to insects and other biotic allergies. Can also include bites by animals. [b]For example, contaminated Tumbleweed, fish kills from biological agents								

Table 2: Health and safety risks to ecological workers from different components of their work environment on DOE sites. Any of the worker types use some or all of the worker activities, and all are vulnerable to fatigue, sun exposure (when outside), and temperature extremes. "From edge" refers to the edge of the site (off-site).

Injuries

Gochfeld et al. [28] discussed the growth of the hazardous waste industry as well as its deployment into various categories, not including ecologic work. At that time the workforce was young (90% under age 50 [28]). That workforce has aged over the last three decades. There is a bimodal distribution of risk for injuries. Young and inexperienced workers are more prone to injury [1], while older workers are more vulnerable to the impacts of injury from heavy equipment [35] and suffer more extensive and longer disability [36]. Many of the chemical, nuclear and DOE facilities are working with aging workforces, partly because of an overall loss of graduate training in these areas. An aging workforce has been associated with reduced productivity and increased accident rates [37,38]. Adverse health conditions affect workplace productivity, through absenteeism, productivity and accidents at DOE National Laboratories [39].

Vehicular equipment

Traffic-related fatalities are the leading cause of work-related deaths, even in the industrial setting [29,40]. Vehicles provide many opportunities for risk and ecological workers are at risk, both as drivers and pedestrians. While ecological workers are not professional vehicle operators, they are operating vehicles on chemical, nuclear and remediation sites, and they are often driving early in the morning or late at night to complete their ecological studies. Sleep deprivation is a major risk factor for accidents and near misses [2]; roughly between 16 % and 20 % of all traffic accidents are related to driver sleepiness [2]. Sleeping for more than 7 hours a night is protective for accidents and near misses for transportation operators.

Heavy equipment

Heavy equipment on DOE and other construction or remediation sites poses a particular risk to workers through accidents [29]. Ecological workers could avoid exposure to heavy equipment during most of their work because they can schedule activities. However, if determining the effects of heavy equipment on animals was an objective, then they would be in the area where heavy equipment is operated. Although there are safety protocols for heavy equipment to protect bystanders, if the field workers are not employed by the same contractors, they may be unfamiliar with site safety procedures while conversely, those developing safety procedures may be unaware of the proximity of ecologic work. Further, ecological workers engaged in restoration would be operating or directing heavy equipment when they create wetlands, pools or different elevational gradients on restored land.

Physical and media exposure

This refers to exposure to sun, air, water, soil, and sediment that can affect health and safety of ecological workers. Outdoor workers, including most ecological workers, spend time outdoors increasing exposure to ultraviolet light [41]. Since the ecological workers described in this paper are mainly outdoors working with natural and managed ecosystems, UV exposure is an occupational risk, predisposing such workers to higher rates of both basal and squamous cell carcinoma compared with indoor workers [42,43]. These cancers and the underlying keratosis are being recognized as compensable occupational diseases [44]. This exposure risk is likely to increase with global warming. Sun exposure leading to skin cancer, however, is a delayed occupational hazard. Climate change related exposures to heat, ozone, pathogenic microorganisms, vector-borne diseases, wildfire and chemicals will differentially affect workers [45], but will especially affect ecological workers that spend a great deal of time outside. Kalankesh et al. [46] found increased rates of trauma associated with high temperature and low humidity, with risk particularly high over age 60. Work requiring protective clothing interferes with thermoregulation, and heat stress is thus a significant risk for outdoor workers [47], particularly when they wear encapsulating garments for chemical protection [48].

There are other media exposures from air, water, and soil (including dust [49]). Exposure to dust is particularly a problem during demolition of structures and on sites where large quantities of

contaminated dirt are removed. Truck traffic on non-paved roads also generates dust. Ecological workers are exposed when they work close to such sites, or even when they study the effect of roads, traffic or truck movement on introduction of invasive plants (seeds on truck wheels, with the dust). Or they may be studying how dust suppression with water alters vegetation distribution adjacent to roads.

Many ecological studies are conducted in streams and rivers where there are a number of hazards when ecological workers are monitoring fish populations or collecting samples for chemical analysis. In addition to normal accidents and exposures that can happen on the water (including excess sun), unexpected storms can capsize boats and upend samples [50].

Biological exposure

Biological exposures provide the risks that are associated with plants or animals. This includes exposures to poisonous plants or animals (e.g., Poison Ivy, Poison Oak, poisonous snakes or spiders), vector-borne diseases (Rickettsial diseases, Lyme, Erlichiosis and perhaps Zika [51]), brambles, and dangerous animals. Many animals, even familiar research subjects, are unpredictable – Large mammals may charge and attack field workers, or may pose a hazard for vehicular accidents. Rabid Raccoons (*Procyon lotor*) may behave unpredictably, posing a hazard in general, or particularly to field workers trapping them for biomonitoring [52]. Even walking across a field can be hazardous because the vegetation may grow in hummocks – making the ground very uneven. Further, there may be burrows hidden in the grass, resulting in broken ankles or bad falls. Ecological workers are exposed to more biological hazards than most workers because they are out in ecosystems most of their work day. Conversely, ecologic workers are likely to be called for animal control purposes, as when reactor decommissioning workers at Hanford encountered rattlesnakes denning in the buildings (personal experience).

In addition biological samples can contain chemicals or radionuclides which were unexpected, exposing workers before samples have been tested. In the early days of DOE and other chemical/radiological facilities, the exact locations where chemicals were dumped were not recorded, making it possible to inadvertently collect dangerously contaminated samples.

Chemical exposure

During field work on or adjacent to contaminated sites, ecological workers can be exposed to toxic chemicals in air, in soil they handle, and in water they consume, as well as when they come in contact with building materials or biological material that is contaminated. The exposure can cause immediate effects (respiratory symptoms), slightly delayed effects (skin rashes, infections), or long term effects such as cancer [53]. A particular threat is from collecting or processing plants or animals before their level of contamination is known. Even far from contaminated sites, ecologic workers may collect specimens (for example migratory birds, mammals, or fish), that became contaminated elsewhere. Of particular interest at Hanford was the handling of potentially contaminated Tumbleweed (dried dead, Russian Thistle Salsola kali), that grew on contaminated soil, sending taproots deep to reach contaminated ground water, and then carrying their accumulated radiologic or metals levels over long distances ([54], finally coming to rest on fences where they pose a fire hazard with the potential to release airborne contamination. Ecological workers removing these tumbleweeds may be unaware of the problem.

Radiological exposure

Ecological workers are exposed to radionuclides in the same way as they are to chemicals – from building materials, media, or biological materials that are contaminated [55,56]. Radiologic workers on DOE facilities regularly wear dosimeters measuring their cumulative exposure to radiation. However, this may not be required for ecological workers. The possibility of unknown radiological levels at sites on buffer areas thought to be safe is one of the biggest problems, given that the legacy from the Cold War goes back 75 years when there were few environmental regulations, and fewer records of where contaminants were dumped.

Finally, possible interventions for reducing these risks was not the objective of this paper, but rather to call attention to the components of jobs held by ecological worker, and the complexity of their potential exposure scenarios. Thus several biologists studying different components of species or ecosystems will have different exposures to the components identified in this paper. A person's job may be classified as "landscaper", but this job may differ from company to company, or location to location. The components of exposure may differ, and each needs to be considered separately, in each geographic location and for each type of hazardous waste site.

Discussion

Categories of ecological workers and functional activities

The different categories of workers were defined based on both the type of activity (monitoring, studies, contaminant work), and the remediation period (before, during active clean, post cleanup period). Many sites will be remediated by containing residual contamination and by capping with clean soil or pavement. Human exposure to these sites will be reduced by a combination of engineered barriers and institutional controls [57,58], but there will be a need for ecologic assessments and surveillance. These categories provide managers and the public with a framework to appreciate the broad range of activities performed by ecological workers, and the kinds of studies that they conduct. The examples of each ecological worker category illustrate what ecological workers might be doing on the site at any time in the life cycle of the facility (Table 1).

Contributing factors to risk

There are many contributing factors that affect the risk from exposures, including demographics (age gender), geography, chronic health conditions, and sleep deprivation that may result from shift work [8,39]. While this paper does not focus on these factors that affect both exposure and risk, some need mentioning, including age, shift work, and level of ecological worker. Understanding how these factors affect risk can lead to risk reduction.

The nuclear industry workforce is aging, largely due to a decrease in the number of institutions training graduate students and an over 20 year period without the licensing of new nuclear power facilities. Many employers in several industries are dependent upon an older workforce [39], but this level of experience is accompanied by a higher accident rate [59-63]. It is not only older workers, however, that are vulnerable to increased accident rates, but there are elevated accident rates among younger workers as well, and these vary somewhat regionally [1]. Ecological workers can be any age, and the effect of age on accidents of ecological workers should be examined geographically and by activity

type, particularly for industries and companies with contamination on site.

Shift work schedules include those outside of the normal work day (8 hrs between 6 AM and 6 PM). While ecologists and biologists normally do not consider themselves shift workers, clearly many ecological projects involve monitoring or recording observations early in the morning or late in the afternoon (e.g. many birds), or even at night (e.g., for bats). Further, ecological studies often require long hours in the field, much longer than the "typical" work day of 8 hours. Under these circumstances, workers may be sleep-deprived. Such variable work schedules can be associated with poor health, fatigue, and cognitive impairment [64-66]. It is, however, the nature of ecological research to be limited seasonally, and to be partly dependent on the hours of daylight (e.g., longer work hours in June than November). Thus although ecological workers would not normally be called shift workers, their activities sometimes mimic shift work because they may be working at odd hours to collect the data that are needed. Some sites are so large (e.g., Hanford) that it may take hours to get to a field site, providing a rationale for ecological workers to remain longer than they should to complete a task (rather than having to come back the next day).

Level of ecological worker relates to the relative role and training that a worker has relative to a particular project. For example, a lead scientist or group of scientists may design and oversee the study, but the work will often be implemented by people with much less training, who may be more vulnerable to accidents. And much of the work may be relegated to laborers with very little training. An ecologist involved in restoring a remediated cleanup site at the Department of Energy is not likely to operate the equipment or to grade the site, but may be close at hand supervising. Field ecologists may take an active part in site restoration including planting seedlings, spraying pesticides, and evaluating success. Overall, worker's perception of their jobs affects their health risk [67], and since ecologists generally like their job, these perceptions may mitigate the difficult or long working conditions.

Recommendations

Since ecologists may work alone, often in remote areas of a site, and sometimes at odd hours, they may be more at risk than other workers who have more stable and predictable working conditions. The on-going ecological monitoring programs at large sites, such as at DOE sites, workers usually have consistent hours, work in pairs or groups, or are otherwise monitored. But at a time of decreasing funds and personnel, and an increase in contractors in many industries, it is imperative to understand the risk that ecological workers face and consider methods of risk reduction.

Information on worker accidents, injuries, and exposures comes from self-reporting, from industry information, and from compensation claims. It would be useful to compare the data from these three sources for ecological accidents and injuries to determine discrepancies that might also lead to risk reductions. Injury prevention could then be linked to demographics, local conditions, and socio-economic factors.

Recommendations flowing from this paper include the need to survey ecological worker experiences, accidents, and other exposures on contaminated sites, including sites in different stages of remediation and restoration. With a number of surveys from different regions, with different conditions it will be possible to quantify the types of injuries and accidents that are more common, the level of job (e.g., lead scientist, laborer), and the contributing factors. This information may help public health professionals and occupational personnel develop appropriate training programs and standard operating procedures. Planning for the health and safety for ecological workers should be included in the standard procedures and planning for the health and safety of hazardous workers generally.

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