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The costs of delaying remediation on human, ecological, and eco-cultural resources: Considerations for the Department of Energy: A methodological framework

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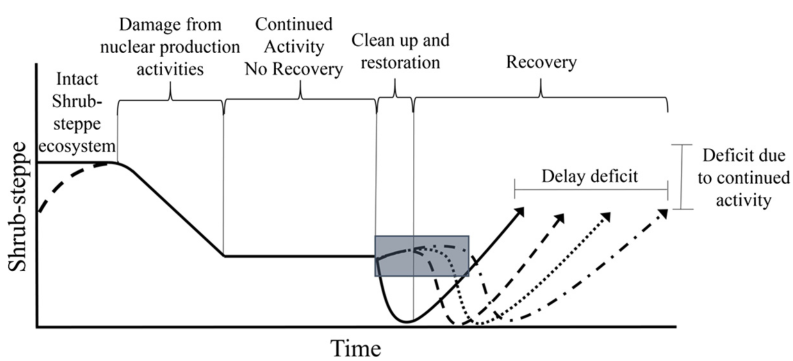
HIGHLIGHTS

- The Department of Energy has the largest remediation task in the World.
- A methodology for evaluating delays in remediation was developed.
- Delaying remediation has costs and benefits to human and ecological health.
- Delaying remediation of deteriorating facilities increases risks of human accidents.
- Delaying remediation of recovering ecosystems retards recovery.

GRAPHICAL ABSTRACT



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ABSTRACT

Remediation and restoration of the Nation's nuclear legacy of radiological and chemical contaminated areas is an ongoing and costly challenge for the U.S. Department of Energy (DOE). For large sites, such as the Hanford and Savannah River Sites, successful remediation involves complex decisions related to remedies, end-states, timing, and sequencing of cleanup of separate and related contaminated units within a site. Hanford Site cannot clean up every unit simultaneously due to limits in funding, personnel, and technology. This paper addresses one of the major considerations - the consequences of delaying remediation of a unit on different receptors (*e.g.* people, ecological, and eco-cultural resources), using the DOE Hanford Site as a case study. We develop a list of attributes that managers should consider for successful remediation, examine how delaying remediation could affect workers, the public and ecological resources (including water resources), and use some examples to illustrate potential effects of delays. The factors to consider when deciding whether and how long to delay remediation of a unit include personnel, information and data, funding, equipment, structural integrity, contaminant source, and resource vulnerability. Each of these factors affects receptors differently. Any remediation task may be dependent on other remediation projects, on the availability of transport, containers, interim storage and ultimate disposition decisions, or the availability of trained personnel. Delaying remediation may have consequences for people (*e.g.* workers, site neighbors), plants, animals, ecosystems, and eco-cultural resources (*i.e.* those cultural values

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that depend upon ecological resources). The risks, benefits, and uncertainties for evaluating the consequences of delaying remediation are described and discussed. Assessing the advantages and disadvantages of delaying remediation is important for health professionals, ecologists, resource trustees, regulators, Tribal members, recreationists, fishermen, hunters, conservationists, and a wide range of other stakeholders.

1. Introduction

In the United States (U. S.), local, state, and federal governmental agencies, and tribal entities have responsibility for cleaning up contaminated lands. Both federal and state agencies oversee remediation on large, complicated federal facilities. Remediation is a national priority in the U. S., within a framework of protecting public health, worker safety and ecological health, and compliance with regulatory requirements (DOE, 1994a,b; Lubbert and Chu, 2007), ideally with stakeholder engagement (Greenberg and Lowrie, 2001; Burger, 2011; Cundy et al., 2013). Thoughtful decisions are required about the timing, order, and extent of appropriate interim and final remediation, and future land uses that will enhance protection of human health and the environment. Successful cleanup requires long-term planning, management, and conceptualization of the overall cleanup process that will meet regulatory requirements.

Many U.S. sites requiring cleanup and restoration belong to the Department of Defense (DOD, 2001; Sheehy and Vik, 2003) and the Department of Energy (DOE, Crowley and Ahearne, 2002; DOE, 2002a,b). For U.S. Department of Energy (DOE) sites, regulatory drivers primarily fall under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) and the Resource Conservation and Recovery Act of 1976 (RCRA), as well as the regulatory mandates of the affected states.

Large sites, such as the Hanford Site, located in the State of Washington adjacent to the Columbia River, have more than a hundred spatial or structural units that have been cleaned up, are currently undergoing remediation, or must be addressed. Most of the DOE sites that engaged in the production or testing of nuclear weapons had industrial facilities on only a small proportion of their lands (usually <10%). These undeveloped buffers were meant to provide security and ensure secrecy (Greenberg et al., 2003; Burger et al., 2006). Some of the buffer lands used for experimental purposes to determine the effects of radionuclides on ecosystems and species have been designated as National Environmental Research Parks (DOE, 1994a,b). Further, many of the larger DOE sites have on-site National Laboratories that conduct research and development, and execute remediation operations.

Following the end of the Cold War (1989), the U.S. DOE's mission turned to management of the legacy nuclear wastes, including removal and remediation (*e.g.* DOE, 1996). The projected cost of remediation of these legacy sites was estimated at many billion dollars, depending on the cleanup targets imposed at each site (Cary, 2016). Determining how to manage the risk to people and ecosystems from the legacy and on-going wastes at the DOE complex in a reasonable and consistent manner, and harmonizing remedies with future land uses and institutional controls, has occupied DOE risk managers since the 1980s (NRC, 1983, 1993, 1995; Kamrin, 1997; Greenberg et al., 1997). Recognition that sequencing with respect to time is essential to remediation decisions acknowledges the fact that not all remediation projects can be undertaken and completed at once, and that some projects must be delayed because of finances, personnel, or technological limitations, more urgent, time-critical cleanups, or to reduce worker risk. Delays may be short term (a few months) or much longer, depending upon the particular remediation unit or problem.

This paper examines some of the consequences of delaying remediation of contaminated sites on receptors, using the Hanford Site as a case study. Thus we: 1) developed a list of attributes that managers should consider for successful remediation, 2) examined how delaying remediation affects receptors with respect to the list of attributes, and 3) used examples to illustrate potential effects of delays. Specifically, the effect of delaying remediation is considered with respect to workers and public health, and on ecological resources and eco-cultural resources. As a Nation, the U.S. is faced with increasing costs for remediation, increasing risks from contamination on these sites, potential deterioration of facilities (resulting in increased risk to workers), and a recognition that the ecological and eco-cultural resources on their sites are important to Native American Tribes, neighbors, and the Nation. We need a national and international dialogue about the real risks and benefits from delaying remediation of some sites or subarea of larger contaminated sites.

For this paper, "delay" refers to a time interval prior to beginning any remediation action, or to the time between completion of an interim remedy and the onset of the next remediation phase. Delay may involve years or decades. Our overall goal was to provide insights into the potential consequences of delay in remediation, which in turn, will help inform time sequencing of cleanup actions. Understanding data needs, data gaps, and uncertainties associated with delaying specific remediation tasks on receptors (public, workers, ecological, eco-cultural) will allow for more informed-based decision-making (*e.g.* Cvitanovic et al., 2016). The Hanford Site, other DOE sites, and other entities considering delaying remediation can use the information provided to help assess the risks to receptors from delaying remediation. Our approach was inter-disciplinary, recognizing the importance of integrating physical, natural, and social sciences with stakeholder engagement (Virapongse et al., 2016).

Delaying remediation of a site does not mean 'no action'. Sites must be investigated, characterized, monitored, and maintained. During delays, institutional controls to reduce contamination remain in place as natural attenuation progresses that in some cases reduces risk at a site (DOE, 2015a). Natural attenuation requires time, and groundwater contamination plumes may become larger (although more dilute), with the potential to reach new receptors. Moreover, sites may not have completed enough characterization to proceed, or the technology may not exist to remediate a site, leading to natural attenuation. Using unproven technologies may increase the risk to receptors, rather than decrease it. Delaying remediation provides an opportunity to learn more about the site, and to employ adaptive management whereby learning leads to improvement in cleanup methodology and results (ACE, 2004). Over time, regulatory drivers may change as well, allowing or requiring cleanup target levels to change. In considering "delay" we recognize that the management of a unit may proceed in phases, such that an interim, perhaps time-critical, cleanup action may be conducted to stabilize a facility and interdict the spread of contamination, followed by a long period of surveillance and maintenance before additional remedial phases such as demolition, final remedy, or remedy corrections occur (DOE, 2017f; CRESP, 2018). This paper does not deal directly with the economic costs of delaying remediation, although these are important components for decision-making.

Delaying remediation has implications for protecting human health (workers, co-workers, off-site residents); relevant exposure pathways and barriers are often identified in conceptual site models (Mayer and Greenberg, 2005), but implications for ecological and cultural resources are less obvious. Many of the large DOE sites have important Native American and other cultural resources, as well as rare, threatened, or endangered species of animals and plants, and unique ecosystems and habitats for their regions and for the Nation generally (ESA, 1973;