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# Evidence-Based Patient Decontamination: An Integral Component of Mass Exposure Chemical Incident Planning and Response

**Adam D. Leary, MS, MA**,
Medical Countermeasure Strategy and Requirements Division, Office of Policy and Planning, Office of the Assistant Secretary for Preparedness and Response, Washington, DC.

**Michael D. Schwartz, MD**,
National Center for Environmental Health, Centers for Disease Control and Prevention, Washington, DC.

**Mark A. Kirk, MD**,
US Department of Health and Human Services; and Chemical Defense Program, Office of Health Affairs, US Department of Homeland Security, Washington, DC.

**Joselito S. Ignacio, MA, MPH**,
US Department of Health and Human Services; and Chemical Defense Program, Office of Health Affairs, US Department of Homeland Security, Washington, DC.

**Elaine B. Wencil, PhD**,
Medical Countermeasure Strategy and Requirements Division, Office of Policy and Planning, Office of the Assistant Secretary for Preparedness and Response, Washington, DC.

**Susan M. Cibulsky, PhD**
Medical Countermeasure Strategy and Requirements Division, Office of Policy and Planning, Office of the Assistant Secretary for Preparedness and Response, Washington, DC.

## Abstract

Decontaminating patients who have been exposed to hazardous chemicals can directly benefit the patients' health by saving lives and reducing the severity of toxicity. While the importance of decontaminating patients to prevent the spread of contamination has long been recognized, its role in improving patient health outcomes has not been as widely appreciated. Acute chemical toxicity may manifest rapidly—often minutes to hours after exposure. Patient decontamination and emergency medical treatment must be initiated as early as possible to terminate further exposure and treat the effects of the dose already absorbed. In a mass exposure chemical incident, responders and receivers are faced with the challenges of determining the type of care that each patient needs (including medical treatment, decontamination, and behavioral health support),

Correspondence and reprint requests to Susan M. Cibulsky, PhD, JFK Federal Building, 15 New Sudbury St, Ste 2126, Boston, MA 02203 (susan.cibulsky@hhs.gov).

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providing that care within the effective window of time, and protecting themselves from harm. The US Department of Health and Human Services and Department of Homeland Security have led the development of national planning guidance for mass patient decontamination in a chemical incident to help local communities meet these multiple, time-sensitive health demands. This report summarizes the science on which the guidance is based and the principles that form the core of the updated approach.

**Keywords**

decontamination; chemical hazard release; chemical warfare; emergency preparedness; hazardous substances

The exposure of people to a hazardous chemical release poses significant public health risk. Enormous quantities of chemicals are stored, transported, and used for industrial purposes worldwide. The large presence of these industrial chemicals raises the possibility of their accidental release. According to a recent analysis of the US Environmental Protection Agency's Risk Management Plan national database, approximately 2560 chemical facilities exist in the United States that could each put more than 10 000 people living nearby at risk in a worst-case scenario chemical release.[1] The Agency for Toxic Substances and Disease Registry estimates that more than 15 000 chemical incidents occurred in the United States in 2012.[2]

Previous industrial chemical accidents, such as the methyl isocyanate release in Bhopal, India,[3] and the chlorine release from a train derailment in Graniteville, South Carolina,[4] have indeed caused large numbers of deaths and severe illnesses. Highly toxic chemicals, including certain industrial chemicals as well as chemical warfare agents, also may serve as potential weapons with which terrorists could intentionally cause mass civilian casualties. The Aum Shinrikyo cult attacked civilians in Matsumoto and Tokyo, Japan, with the nerve agent sarin, which they had synthesized themselves.[5]

Hazardous chemicals cause harm to a person by being absorbed into the body, via multiple possible routes, and influencing the function of target molecules in a dose-dependent manner; within certain limits, as the amount of chemical absorbed increases, so do the toxic effects. Preventing or reducing the absorption of a hazardous chemical through decontamination of an exposed person is therefore an important strategy for protecting the health of that person. Very few chemical-specific antidotes exist, making it difficult to treat or reverse the effects of chemical intoxication once they have occurred. Thus, patient decontamination and supportive care are the only effective health interventions for exposure to a vast number of hazardous chemicals. Absorption of and toxicity from some chemicals may occur relatively rapidly, meaning an efficient patient decontamination process that is initiated as early as possible and fully integrated into the emergency response is most likely to be effective.

Patient decontamination has a greater role in protecting a patient's health in a chemical incident than in a biological or radiological incident due to fundamental differences in the mechanisms by which chemical, biological, and radiological materials cause their ill effects. A primary goal of patient decontamination in biological and radiological incidents is to prevent the spread of contamination, thereby protecting the health of responders and hospital workers, and the integrity of health care infrastructure. Decontamination of chemically contaminated patients achieves this critical outcome of protecting personnel and infrastructure. Yet, for chemical incidents, timely patient decontamination is also a direct intervention to terminate patients' exposures by interrupting absorption of the chemical. As members of a federal interagency working group, the authors have developed updated, evidence-based guidance that is centered on this uniquely important and time-sensitive medical role of patient decontamination in a chemical incident: *Patient Decontamination in a Mass Chemical Exposure Incident: National Planning Guidance for Communities* (referred to hereafter as the guidance; US Department of Homeland Security and Department of Health and Human Services, draft, 2014). The guidance is also focused on the problem of mass patient exposure, whereby responders and receivers are faced with challenges of triaging and treating a large number of potentially exposed people within a short window of time. It is the authors' intent that this article provide an overview in the key areas of the chemical exposure principles, scientific evidence, policy, challenges of mass exposure incidents, and recommended approach that underpin the guidance, as well as suggestions on implementation.

## TOXICOLOGY OF CHEMICAL EXPOSURE

In most instances, the type and magnitude of adverse health effects from a chemical exposure are dependent on the dose received by the patient. This principle of dose-response was noted as early as the 15th century when Paracelsus indicated that all things can be a poison, but the dose determines the difference between a poison and a remedy.[6] Dose refers to the total amount of chemical absorbed, and it is dependent on a number of factors, including the following[7]:

- the physical and chemical characteristics of the material, which influence how readily and by what route(s) it can be absorbed;
- environmental conditions, which influence the material's physical state and persistence at the site of release in a readily absorbable form;
- the characteristics of the exposure pathway(s) through which absorption can occur; and
- the concentration, frequency and duration of exposure.

Dose is directly related to the concentration of the chemical; the higher the concentration of the chemical on a person or in a person's environment, the greater the amount that can be absorbed over a given period of time. Except at the extremes, a greater dose leads to greater effects. Exposures of long duration provide increased contact time with the skin and other tissues, allowing an increase in the total dose.[7] Repetitive exposures, even to a low concentration of a chemical, may lead to an increased total dose if there is subsequent bioaccumulation.

The concentration of the chemical and duration of exposure can be controlled by responders and receivers. For the purposes of this discussion, we assume a single acute exposure, and potential additional exposures will be eliminated through proper patient decontamination. Patient decontamination—any process, method, or action that reduces, removes, or inactivates chemical contamination of a patient—can reduce both the concentration of the chemical to which the patient is exposed and the duration of that exposure. Decontamination begins with removing a patient from the area of chemical release and into a clean environment (evacuation), thereby reducing exposure duration. Other actions, including clothing removal and water-based decontamination, also reduce the exposure duration by physically removing the chemical agent from the skin.

Although evidence suggests that water-based decontamination acts primarily through physical removal of contaminants,[8] it may also help to reduce concentration through dilution of the chemical remaining on the skin.[9] From the perspective of the patient's health, the objective of patient decontamination is to minimize the dose of chemical absorbed by reducing the chemical concentration and/or the duration of exposure. This reduction in dose can lessen the consequent adverse health effects and lead to a more favorable health outcome for the patient.

During a mass chemical exposure incident, responders and receivers have no control over the physical and chemical properties of the contaminant, the environmental conditions, or the characteristics of the exposure pathway. However, these and other factors will influence the means and the speed with which a chemical is absorbed and the total dose received by a patient. The guidance notes that these factors should be considered in a risk-based response approach, which tailors the operational steps in the response, including patient decontamination, to the specific situation.

## DECONTAMINATION PROTECTS THE PATIENT: EVIDENCE OF EFFICACY

The arguments presented above in support of patient decontamination as a health intervention for the patient are based on toxicological principles. The benefits of patient decontamination can also be examined through research. The efficacy of patient decontamination in saving lives has been best demonstrated by several well-designed, controlled experimental animal studies. In these studies, a chemical warfare agent was applied to the skin of animals, followed by skin decontamination for some animals and no decontamination or other treatment for control animals. Although experimental details varied, all studies produced results showing that under certain conditions (different chemical exposures, duration of exposure, different decontamination solutions), skin decontamination prevents death.[10–13]

Animal studies also have demonstrated the ability of skin decontamination to reduce morbidity due to chemical warfare agent exposure; sulfur mustard-induced skin damage[14] and VX-induced signs of organophosphate poisoning[12] were reduced by post-exposure skin decontamination. A study in which animals were exposed to phenol, a common toxic industrial chemical, showed that decontamination by various methods reduced the severity and extent of phenol-induced skin damage.[15] The health benefits were time sensitive; the window of time for effective decontamination depends on the specific chemical contaminant and the dose received.

Few published studies or reports from actual incidents assess patient health outcomes after decontamination, perhaps because the potential patient health benefits have not been widely recognized. Nevertheless, evidence of the efficacy of decontamination has been documented and is summarized here. Due to ethical reasons, patient decontamination efficacy against harmful chemicals cannot be directly tested in controlled prospective human experiments. A limited number of controlled retrospective analyses of actual incidents have yielded evidence of efficacy, with 3 examples provided here. Among 83 patients treated for corrosive chemical bums (acids, alkalis) in the Baltimore Regional Bum Center from 1976 through 1985, those for whom flushing with water was begun within 3 minutes of exposure experienced a statistically lower incidence of full-thickness injury and delayed complications, and a significantly shorter hospital stay than those patients whose bums were not flushed with water until after a delay of longer than 3 minutes.[16,17]

A similar study of 51 chemical bum cases at the University of Kansas Medical Center led the authors to conclude that a group of patients who had received immediate water or neutralization therapy had a greater rate of survival, lower rate of skin grafting, and shorter duration hospital stay than a group of patients who had received delayed or inappropriate treatment. However, the researchers did not include an analysis of the statistical significance of these results.[18] Evidence of the efficacy of evacuation in and of itself, which we consider to be one method of patient decontamination, is provided in an analysis of data from the Hazardous Substances Emergency Events Surveillance program of the Agency for Toxic Substances and Disease Registry, US Department of Health and Human Services. When ammonia, chlorine, or an acid was released, incidents in which evacuation was ordered resulted in a significantly lower number of victims (defined as a person experiencing at least 1 adverse health effect within 24 hours that likely resulted from the chemical release) per incident than those in which evacuation was not ordered.[19]

Indirect support for the concept that decontamination protects the patient is found in controlled studies demonstrating that various decontamination methods reduce the amount of a chemical simulant on subjects' skin.[20–23] These studies directly measured the amount of a relatively harmless fluorescent chemical on a subject's skin prior to and following a decontamination procedure. The evident reduction in contamination suggested that other, hazardous chemical agents might be removed using common decontamination methods, which could then lead to less absorption of the chemical and decreased local and/or systemic toxicity.

## POLICY: PATIENT DECONTAMINATION IS A MEDICAL COUNTERMEASURE

Recent broadening of definitions of the term *medical countermeasure* reflects a trend toward acceptance of the concept of patient decontamination as a medical intervention. Use of the term medical countermeasure was originally confined to pharmaceuticals intended for military personnel as prophylactic measures against chemical or biological warfare agents. Since 9/11 and the 2001 anthrax attacks in the United States, medical countermeasures have received increased attention for use in civilian settings; they are the focus of Homeland Security Presidential Directive (HSPD)-18 and are addressed in a number of recent laws. The Pandemic and All-Hazards Preparedness Act of 2006 maintained a relatively narrow focus on drags, biological products, and devices in its definition of medical countermeasure.

However, in recent years a wide variety of technologies and practices have been recognized for their effectiveness in preventing, diagnosing, or treating the health effects of exposure to chemical, biological, or radiological materials. The Public Health Emergency Medical Countermeasure Enterprise, a US Department of Health and Human Services-led federal interagency effort to direct medical countermeasure research, development, procurement, stockpiling, deployment, and utilization policies, published the following definition of medical countermeasure in its 2012 strategy[24]:

> Medical countermeasures include both pharmaceutical interventions, such as vaccines, antimicrobials, antidotes, and antitoxins, and non-pharmaceutical interventions, such as ventilators, diagnostics, personal protective equipment (PPE), and patient decontamination that may be used to prevent, mitigate, or treat the adverse health effects of an intentional, accidental or naturally occurring public health emergency.

This key concept of patient decontamination as a medical countermeasure allows us to better describe patient decontamination as one element of a risk-based response to a mass exposure chemical incident. Patient decontamination is complementary to other life-saving interventions and may occur before, after, or concurrent with measures similarly aimed at mitigating adverse health effects. As the guidance notes, informed decisions, based on indications/contraindications and benefit/risk, about the applicability of patient decontamination in a given situation should govern its use.

## CHALLENGES TO CONDUCTING MASS PATIENT DECONTAMINATION

It is not enough to recognize the optimized approach for mass patient decontamination by referencing evidence in academic work. For evidence to influence patient outcomes, it is essential that the guidance provide practical strategies for those in the field, allowing them to operationalize ideas and evidence into a structured approach for making decisions and a feasible way to deliver an evidenced-based “ideal” process to a large number of people efficiently. This goal was part of the working group’s approach to development of the guidance, and a key way in which it differs from previous documents. The best guidance and plans take into account realities—what actually happens and what people actually do in a disaster—rather than theories about what should happen.[25–27]

Published reports on past incidents and disaster research provide evidence of common challenges responders and receivers are likely to face in any large-scale chemical incident[4,5,25–28]:

- Large numbers of patients will be present at the scene, potentially exposed to harmful chemicals.

- The hazardous material and its source may not be known for a significant period of time, perhaps hours.
- Adequate resources will not be immediately available at the scene to perform decontamination of all patients with potential exposure.
- A proportion of potentially contaminated patients will self-evacuate from the scene before a decontamination procedure is performed and present to hospitals as walk-ins; at the time of arrival of the first walk-ins, hospital facilities may not be aware of the incident.
- Thorough decontamination of all potentially contaminated patients at the scene will delay transport of patients to definitive care.
- Patient decontamination decisions and procedures are often not integrated with the medical aspects of a response. The decontamination corridor can be a bottleneck delaying evaluation and treatment.[29]

The decision to perform mass decontamination is one of the most important decisions made during the emergency response to a large-scale chemical incident. Such a timely decision, likely affecting many other elements in the response, often must be made in a “fog of war” with limited information to guide that decision.

Deciding to decontaminate all patients at the scene or on arrival to the hospital can quickly overwhelm resources, consuming substantial personnel and equipment, and eroding the effectiveness of the entire response. This decision may lead to problems such as delays in treating the most seriously ill patients. On the other hand, if a decision is not made or is delayed, the default to a full-scale decontamination of all patients may occur, causing the same results. At the same time, the imperative to protect the health of responders and receivers through a combination of proper use of PPE and patient decontamination will factor into decisions. Knowledge, decision support tools, and evidence-based protocols can provide a structured approach that will enhance the scene and hospital incident commander’s ability to recognize the need for and then implement the appropriate level of decontamination.

## RECOMMENDED APPROACH TO CONDUCTING PATIENT DECONTAMINATION

The recommended approach recognizes patient decontamination as a medical countermeasure by better integrating it with other response activities and by defining the goals of decontamination in terms of health outcomes. Patients who receive large chemical exposures may need both decontamination and other life-saving medical treatment urgently. Risk-based decision-making will help to determine which patients receive which type of care and when. Thus, the order of interventions and thoroughness of decontamination may differ among patients, based on the goal of ensuring the best health outcome for the most people. Likely challenges in a mass-exposure chemical incident are addressed through a flexible, scalable approach that takes into account the evidence of how past chemical incidents have unfolded, how affected populations have behaved, and what affected communities have needed.

## Reduce Contamination As Soon As Possible Without Introducing Excess Risk to the Patient

The guidance strongly encourages the adoption of a risk-based, scalable, flexible, and tiered approach to patient decontamination that allows for the range of possible circumstances encountered in a chemical mass exposure incident. How patient decontamination is conducted in any one event should be dictated by (1) the type, form, and extent of the chemical contamination; (2) the size of the potentially exposed population; (3) the resources and capabilities of the responding agencies; and (4) an assessment of the risks inherent in the decontamination procedure itself.

The overarching principle used to determine the appropriate decontamination approach is to begin the process of reducing contamination as soon as possible, without introducing additional risk to the patients by doing so. As an example, immediate disrobing and decontaminating patients with water in cool weather may risk hypothermia, which itself may lead to morbidity and mortality in excess of any toxicity that would be incurred if a delay in water-based decontamination is introduced.

On the other hand, when there are no environmental limitations to immediate decontamination, or hazards specific to the chemical (eg, need for a specialized decontamination solution), a delay in initiating any decontamination while extensive infrastructure (eg, tents, water supply, triage, transport resources) is set up increases contact time and dose, which can worsen toxicity unnecessarily. A tiered approach allows for progressively more involved decontamination, if necessary. Self-care, such as removing oneself from the source of ongoing contamination, removing contaminated clothing, and rudimentary waterless removal (spot decontamination) of localized visible contaminant on skin can be performed without a water source and, in many cases, without assistance from responders—self-care can be initiated immediately. Gross decontamination with water from a hose, hydrant, or fire truck can be performed sooner than a more comprehensive decontamination using specialized equipment.

The flexibility in a risk-based, tiered approach, as supported by the guidance, is that it can eliminate steps that, at a minimum, do not incrementally improve health outcomes and, at most, may lead to otherwise avoidable excess morbidity. Water-based decontamination is often cited as dogma, yet performing it in a circumstance (eg, natural gas leak) in which evacuation was the only intervention required introduces unnecessary risk (eg, if a patient slips and falls during showering or develops hypothermia). The guidance allows for alternative practices in circumstances in which common practices may be inappropriate: (1) evacuation in lieu of water-based decontamination for contaminants with minimal residence on the skin (eg, volatile organic compounds, carbon monoxide); (2) disrobing and/or spot decontamination and delayed water-based decontamination when environmental conditions carry too much risk for outdoor water-based decontamination; and (3) consideration of alternative decontamination solutions when water is known to be inferior or is contraindicated (eg, contamination with phenol[15] or water-reactive solids).

### Decontaminate to Improve Patient Health Outcome Rather Than to Achieve an Arbitrary Level of Contamination Reduction

The goal of patient decontamination is to mitigate morbidity and mortality from chemical toxicity. Achieving this goal may or may not entail removing 100% of contaminant from the skin. Several arguments can be made against completely cleaning a patient. First, the resources (eg, time, personnel, equipment, and supplies) needed for mass patient decontamination are finite. If the decontamination effort and resources required to completely remove a chemical from the first 10 patients means that the remaining 90 die or suffer severe toxicity due to delays in their decontamination, then a focus on complete chemical removal has created a worse outcome for a majority of patients. Second, an accepted principle in environmental public health is the reduction of risk through substantial, but not necessarily total, mitigation of exposure. Allowable exposure levels for some chemicals have been established to protect human health[30,31]; these levels are usually greater than zero. Third, excessive water-based decontamination may in some cases increase absorption of chemicals by excessively hydrating the skin, by mechanically disrupting some of the barrier function of the skin (eg, through vigorous scrubbing), or by increasing blood flow to the skin when warm water is used. This increased absorption is known as the "wash-in" effect.[32]

How clean is clean enough? The question characterizes not only a conceptual problem but also a practical one: currently no practical means to quantitatively measure a chemical of concern on human skin during an incident are available. Instead, surrogate endpoints, such as absence of visible contamination on skin and improvement or resolution of symptoms, are necessary, absent validated analytical methods to rapidly and accurately determine when a patient has been sufficiently decontaminated. Even in an incident in which a comprehensive patient decontamination is deemed necessary, adequate decontamination for all patients is the best way to do the most good for the most people in the shortest time.

### Patient Decontamination Should Permit Faster Access to and not Delay Medical Evaluation and Treatment

Contamination can present a challenge to providing medical treatment, including life-saving antidotes, to the patient. Many response plans allow for medical evaluation and treatment only after a patient has undergone decontamination or a decision not to decontaminate has been made.[33] This approach is well justified, especially by the goal of protecting the health and safety of responders and receivers. However, delaying medical care until decontamination is complete in all cases is not ideal, as it may result in increased patient morbidity and mortality if the dose already received before decontamination interrupts further absorption is enough to cause severe effects. Decontamination can be a bottleneck, and many patients may be forced to wait for significant durations before undergoing medical evaluation and treatment.

Some existing guidance documents and other authors have advocated for providing medical care in the warm or hot zone, where patients have not been decontaminated, particularly when the condition or injuries sustained impose a greater risk to the patient than the contamination itself.[34,35] The guidance states that for treatment to be provided before a patient is decontaminated, the responder or receiver must be appropriately trained and wear the proper PPE. The PPE itself can present barriers to and introduce delays in care being provided to patients, as some PPE significantly hinders interactions and reduces dexterity and senses that are required for administration of medical treatment. Both tactics—delaying medical treatment until decontamination is complete and administering medical treatment concurrently or prior to decontamination—have limitations. The guidance supports a proper balance, unique for each incident, among timely removal of contamination from patients, expeditious provision of medical care, and protection of responders, receivers, health care equipment, and facilities.

Accurate decision-making on the need for and the appropriate nature and level of decontamination will facilitate efficient handling of patients. The guidance recommends that patients should be prioritized according to the urgency for decontamination, including consideration of the need for immediate, life-saving measures. When appropriate, the decontamination process itself should be executed as efficiently as possible. Unfortunately, the working group established that little evidence is available to suggest the most effective methods for evaluating the need for and conducting mass patient decontamination. Responders and receivers should rely on the resources at their disposal, such as their skills at recognizing signs and symptoms of chemical toxicity.

## MOVING FORWARD: ENHANCING COMMUNITY PREPAREDNESS

The recommendations in the guidance are evidence based (or when evidence is lacking, consensus based) and written from a strategic perspective to guide planning but not prescribe specific procedures. The recommended actions are scalable, allowing each community to operationalize them around their unique resources and capabilities. To convert these strategic statements into actions requires a stepwise approach, beginning with communication and outreach. Leaders from professional organizations and federal, state, and local agencies may engage a broad audience through presentations at conferences and meetings of stakeholder organizations, as well as articles such as this in peer-reviewed and trade publications.

The guidance is robust and can be applied to several levels of community emergency preparedness. Examples of how the guidance might be used by the target audience include:

- Planners: Incorporate current evidence-based recommendations during development or revision of an organization’s response plans.
- Community leaders, public health officials: Enhance system wide coordination and develop plans for communicating with patients and the whole community.
- Trainers: Develop, improve, or augment training of response personnel for patient decontamination operations.
- Emergency managers: Generate policy and plans to address issues related to system-wide coordination, the whole community response, and crisis and risk communications, as well as other overarching issues.

The guidance may also benefit our nation’s preparedness by effectively uncovering the gaps in our knowledge and giving us the ability to clearly focus future research efforts in ways that will enhance community preparedness by the greatest degree. Aligning a research roadmap with funding agencies' priorities, federal programs, academic, and industry efforts affords the best chance of collecting new knowledge and evidence to shape effective practices. It is hoped that combining new research findings with identified best practices for operationalizing this guidance will evolve an effective approach for communities to provide patient decontamination for mass exposure to chemicals in the most efficient and evidence-based ways possible.

## CONCLUSION

The concept of patient decontamination as a medical intervention that must be executed soon after exposure to a hazardous chemical to affect patient health has only recently begun to gain wide acceptance. The guidance described here provides recommendations for the integration of this fundamental concept into emergency response plans. A risk-based approach that takes into account the various hazards, medical needs, available resources, and time constraints of the situation is suggested for decision-making, execution, and evaluation of results regarding patient decontamination.

The goal of the guidance is to provide local emergency response organizations with the best available evidence-based strategies to incorporate into response plans and training curricula so that medical and public health preparedness for mass patient chemical exposure incidents can be enhanced. During development of the guidance, key knowledge gaps also have been identified. Research programs aimed at these priority knowledge gaps can further advance preparedness. The benefits of this work will be realized most efficiently through a sustainable, cyclical system for regularly disseminating the guidance, supporting its implementation, reviewing the evidence, updating the guidance, updating research priorities, and repeating the process.

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