INTODUCTION IN MEANS AND METHODS USED IN CHEMICAL, BIOLOGICAL, RADIOLOGICAL, AND NUCLEAR DECONTAMINATION

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When facing a *Chemical, Biological, Radiological, and Nuclear* (CBRN) incident, decontamination is a key element in safeguarding individuals and property. First responders are using decontamination technique to minimize exposure to hazardous substances and limit the spread of contamination. The disposables decontamination means and methods are very divers, and an evaluation of the most appropriate aspects often encountered in the real cases could determine the adequate methods to be used. However, there is not only one universal method applicable in all situations, but a smart combination of known decontamination methods can be used to obtain very best results. The main goal in using the decontamination methods is to try to restore the initial state of the affected surface whether on the objects or living beings. In this respect, the present paper is focused to present a short introduction in the means and methods used to minimalize the CBRN effects.

Key words: CBRN, decontamination, physical decontamination, chemical decontamination, biological decontamination, radiological decontamination.

1. INTRODUCTION

Chemical, Biological, Radiological and Nuclear threats (often abbreviated to CBRN) are requesting protective measures taken in situations in which any of these four hazards are present. CBRN defense consists in passive protection, contamination avoidance and mitigation. The term CBRN is commonly used in disaster and emergency situations by in charge organizations around the world. At the regional level, countries are providing opportunities to develop and merge emergency services with CBRN equipment, personnel and training [1].

CBRN emergencies can arise from some accidents, human errors, natural calamities, sabotage activities, or in the form of CBRN agents released deliberately in air, and can result in fire, explosion, and/or toxic release. Another aspect of these emergencies is contamination. If countermeasures are not taken care, the contamination can be fatal. The removal of contamination is termed as decontamination.

Whether resulting from deliberate or accidental release of CBRN elements, there are three types of hazards: chemical, biological, and radiological/nuclear [2].

A chemical hazard refers to any chemical manufactured, used, transported, or stored which can cause death or other harm through toxic properties of those materials. This includes chemical agents used in warfare (CWA), as well as *Toxic Industrial Chemicals* (TIC).

Biological hazards means any organism, or substance derived from an organism, that poses a threat to human or animal health. This can include medical waste, samples of a microorganism, virus, or toxin (from a biological source) that can impact human health.

Radiological hazards include any nuclear radiation (*i.e.*, electromagnetic or particle radiation) that is capable of producing ions that cause damage, injury, or destruction.

A CBRN incident is often associated with spreading of CBRN materials in the environment, therefore, contamination mitigation consist in planning and actions taken to prepare for and recover from contamination associated with all CBRN hazards and prevent the loss of lives and assets. Usually, decontamination measures are needed to be taken in order to limit the spread of contamination and neutralize the effects, to maximize the mitigation efforts.

Decontamination in general is defined as the removal of hazardous materials from areas, objects and humans where it is not wanted [3]. Joint efforts are needed to safeguard property and people that have been exposed to chemical, nuclear, biological and radiological or nuclear agents. There are two main objectives in decontamination activities, first objective is to make humans and animals free from the contaminants, or, if complete removal of the agents is not possible, to reduce the concentration of the contaminants to a level that is safe for survival. The second objective is to make property and the environment safe for habitation.

2. DECONTAMINATION METHODS

There are a variety of decontamination methods and strategies that can be used to solve CBRN problems. In most cases, the selected method depends on the nature of the contaminant. We can compare decontamination activities with the cleaning of dirt, grease, or rust on the affected surface. Decontamination must be performed to remove any harmful chemicals, infectious organisms or radioactive particles that may have adhered to those places where are not wanted to be.

Decontamination methods could be used either to (1) physically remove contaminants, (2) chemically (electrochemically) remove contaminants or inactivate them by chemical detoxification or disinfection/sterilization, or (3) remove contaminants by a combination of both physical and chemical means [4]. The most representative's methods and their domain of utilization are synthetized in Table 1.

Table 1

Decontamination methods in CBRN emergency

Chemical Chemical Detoxification	Biological Disinfection/Sterilization	Radiological/Nuclear Contaminant Removal
Halogen stripping Neutralization Oxidation/reduction Thermal degradation	Chemical disinfection Dry heat sterilization Gas/vapor sterilization Irradiation Steam sterilization	Water rinse Leaching and extraction Evaporation/vaporization Pressurized air jets Scrubbing/scraping Steam jets
*Removal and disposal of:		
Contaminated surfaces Deeply permeated materials Protective coverings/coatings		

* Valid for all methods

2.1. PHYSICAL REMOVAL

Physical decontamination methods involve mechanical action, such as abrasion, scrubbing or grinding of the surface, to remove the contaminant or the contaminant together with the host surface. In many cases, gross contamination can be removed by physical means involving dislodging/displacement, rinsing, wiping off, and evaporation. Methods involving high pressure and/or heat should be used only as necessary and with caution since they can spread contamination and cause burns. We can classify the contaminants that can be removed by physical means as follows:

(a) *Loose contaminants*. Most contaminants in the form of dusts and vapors hang to equipment and workers or become trapped in small openings, such as the weave of the clothing textile, can be removed with water or a liquid rinse. In this case, removal of electrostatically attached materials can be enhanced by covering the clothing or equipment with anti-static solutions. These anti-static substances are commercially available as wash additives or anti-static sprays.

(b) *Adhering contaminants*. This type of contaminants adheres by forces other than electrostatic attraction. The quality of adhesion is dependent of the temperature and of specific composition of the contaminant. For example, contaminants such as glues, cements, resins, and muds have great adhesive properties and consequently, are difficult to remove by physical means. Physical removal methods for gross contaminants include scraping, brushing, and wiping. The removal process of the adhesive contaminants can be enhanced through certain methods such as solidifying, freezing (*e.g.*, using dry ice or ice water), adsorption or absorption (*e.g.*, with powdered lime or talcum), or melting.

(c) *Volatile liquids*. Usually, this type of contaminants can be removed from protective clothing or equipment by evaporation followed by a water rinse.

To enhance evaporation of volatile liquids steam jets can be successfully utilized. When using evaporation or vaporization technique, a special care must to be taken to avoid inhalation of the vaporized chemicals by the involved personnel.

2.2. CHEMICAL REMOVAL

Chemical decontamination methods include those techniques that involve placing a liquid or chemical solution in contact with a contaminated surface for a predetermined time and allowing the chemical properties of the chemicals, the contaminants, and the host matrices to react and perform the decontamination. If physical removal of gross contamination is followed by a wash/rinse process using cleaning solutions, the chance for a successful decontamination is increased. The cleaning solutions are the means to be utilized on the following methods:

(a) *Dissolving contaminants*. With this method, surface contaminants are chemical removed by dissolving them in a solvent. Some protective personnel garments are made of organic materials that could be damaged or dissolved by organic solvents. This is the reason why the solvent must be chemically compatible with the surface of the equipment being cleaned. When using this method, a special care must be taken in selecting, and disposing of the organic solvents that may be flammable or potentially toxic. Frequently, the organic solvents include alcohols, ethers, ketones, aromatics, straight-chain alkanes, and common petroleum products. Because of their toxicity and their incompatibility with personnel protective garment, halogenated solvents should not be used for decontamination. Table 2 provides a general description of the solubility of several contaminant categories in four types of solvents: water, dilute acids, dilutes bases, and organic solvents.

Table 2

Examples of the solubility of contaminants in four solvent types

Solvents	Soluble Contaminants
Water	Low-chain hydrocarbons Inorganic compounds Salts Organic acids and polar compounds
Dilute Acids	Basic (caustic) compounds Amines Hydrazine's
Dilute Bases: – detergent – soap	Acid compounds Phenols Thiols Nitro and sulfonic compounds
Organic Solvents*: – alcohols – ethers – ketones – aromatics – straight-chain alkanes (*e.g.*, hexane) – common petroleum products (*e.g.*, gasoline, diesel, kerosene)	Nonpolar compounds (organic compounds)

*NOTE: Organic solvents can permeate and degrade the protective garment

Always, decontamination using chemicals should be done only by qualified personnel, to avoid potential hazards.

(b) *Surfactants*. These substances improve physical decontamination methods by reducing adhesion forces between contaminants and the surface being cleaned, and by preventing redeposit of the contaminants. Most common surfactants are among the household detergents. To improve the dissolving and dispersal of contaminants into the solvent, some detergents can be successfully used with organic solvents.

(c) *Solidification*. Physical removal of liquid or gel contaminants can be enhanced by their solidification. There are 3 mechanisms of solidification: (1) moisture removal through the use of absorbents such as grounded clay or powdered lime: (2) chemical reactions *via* polymerization catalysts and chemical reagents; and (3) freezing using ice water.

(d) *Rinsing*. Rinsing is the most popular decontamination method. It removes contaminants through dilution, physical attraction, and solubilization. Multiple rinses with clean solutions are more effective to remove more contaminants than a single rinse with the same volume of solution. It is practically demonstrated that continuous rinsing with large volumes will remove even more contaminants than multiple rinsing's with a lesser total volume.

(e) *Disinfection/Sterilization*. This method use chemical disinfectants as practical means of inactivating infectious agents. Unfortunately, standard sterilization techniques are generally impractical for large equipment and for personal protective clothing equipment. For this reason, disposable *Personal Protective Equipment* (PPE) is recommended for use with infectious agents. In this case choosing the most appropriate method and chemical mean could be of great importance [5].

Selection of a decontamination method is influenced by many factors, such as availability, cost, and ease of implementation.

3. DECONTAMINATION FACTOR

Decontamination is utilized to loose CBRN contaminants, to reduce the harmful influence that workers may receive from an object or surface and to reduce the potential for airborne of CBRN agents. Contamination can be classified into removable and fixed type. The removable contamination can be easily eliminated by wiping the surface, while the fixed contamination is held tightly to the surface and can be removed only by mechanical or chemical methods. Sometimes, removable contamination is generated in the process of decontamination or attempting to remove fixed contamination. In this way, fixed contamination become removable and can be evacuated and properly treated and disposed.

The ratio of the initial concentration of a contaminant to the final concentration resulting from a process of removal defines the decontamination factor (DF). In practice, the decontamination factor measures the effectiveness of a decontamination process. The effectiveness of the decontamination can be mathematically expressed as:

$$DF = \frac{Concentration\ of\ contamination\ before\ removal}{Concentration\ of\ contamination\ after\ removal}$$

As can be seen from the equation above, any decontamination process that removes contaminants will result in a DF greater than 1. Therefore, the percentage of contamination removed from the surface can be given by the formula:

$$\%\ of\ contamination\ removed = (1 - \frac{1}{DF}) \times 100$$

In Table 3 some examples are illustrated by applying the presented reasoning in evaluating decontamination methods.

Table 3

The DF factor for different stages of decontamination

DF	removed contamination
2	50%
5	80%
10	90%
20	95%
25	96%
50	98%
100	99%

To test the effectiveness of chosen decontamination method, the wipe test is the most convenient as ease of performing. Usually, dry or wet filter papers are wiped over the contaminated surface and send to the laboratory for analysis.

In order to obtain a good contamination removal, selection of the most appropriate decontamination method is essential. This is the reason why an evaluation of several considerations can help in determine of which specific methods is the most suitable to be applied. In determining the selection of decontamination methods there are some factors to be taken into account before making any decision:

(1) The nature of the contaminant and its present state;

(2) The nature of the surface on which the contaminant is present;

(3) The dimensions of the area affected by contamination;

(4) Position and handiness of the contaminated area;

(5) The required effectiveness of decontamination;

(6) Physical and chemical proprieties of the surface to be preserved during the decontamination activities;

(7) Availability of suitable materials and equipment;

(8) Safety of the personnel involved.

Despite the fact that this work addresses only decontamination methods, it is important to note that treatment should be explored as a potential option in cases where decontamination is not feasible. Treatment is defined by altering the composition of a hazardous contaminant through chemical, biological, or physical means to reduce its toxicity, mobility, or volume. The concept of treatment does not only deal with destroying the hazardous material, but may also involve stabilizing the contaminant. It may also include stabilization or fixation technology in which an additive chemically or physically bonds with the contaminant and by immobilizing it prevents the contaminant from migrating. Such technology should generally achieve a standard of treatment of 90% to 99% reduction in concentration or mobility [6].

4. DECONTAMINATION MEANS

The nature of contaminants and supporting surfaces is different among a variety of situations, requesting decontamination methods with specific decontamination means available. Each method has one or more specific means to be used in the most appropriate situation. Analyzing each situation before is very important in establishing the method with its specific mean that shall be applied. Sometimes, a combination of means and methods could be used to achieve an optimum decontamination level.

(1) *Mechanical decontamination means* can be used on any material where contamination is limited to near surface. It works best on large, regular surfaces that are readily accessible and unobstructed by other objects. As with chemical decontamination, the selection of the most effective technique depends on many variables, such as contaminants involved, surface material, and cost. The selected treatment may have to be applied several times to meet the established decontamination objectives. Physical decontamination, also referred to in the literature as mechanical decontamination, is the removal of surface contamination by physical means such as flushing, wiping, brushing, vacuuming, grinding, blasting, scabbling, shaving, spalling, peening, scaling, other forms of scarifying, or the application of strippable coatings. The means for physical decontamination can be divided into surface cleaning means and surface removal means. Surface cleaning include flushing, wiping, brushing, vacuuming, and strippable coatings, where the surface remains intact but contamination on the surface is mechanically dislodged. Surface removal include grinding, blasting, scabbling, shaving, spalling, peening, and scaling, where the contamination is removed together with an entire layer of the surface.

(2) *Chemical decontamination means* are widely used as long the agents able to chemically transform and remove contamination are easy to be found. Chemical decontamination means converts the toxic CWAs and/or TICs into inoffensive products which can be handled safely, whereas in the physical process they are just removed from the objects surface. Theoretically, chemical decontamination means can remove any contaminant. Practically, limitations occur because the same reactions that stroke the contaminant can also stroke the material layer in direct contact with the contaminant. This is the reason why not all the surfaces (*e.g.*, high porosity materials) are suitable for this use. In CBRN emergencies, a wide spectrum of chemicals means are used in order to clean people, objects and the environment. For instance, in chemical emergencies chemical decontamination procedures include nucleophilic reactions, electrophilic reaction (oxidations), thermal destruction, photochemical and radiochemical reactions, whereas in biological emergencies procedures include washing, chemical disinfection and sterilization. Chemical means can be used to decontaminate property and persons exposed to biological contaminants. Low concentration solutions like liquid bleach works good as a general biological decontamination solution for equipment and property. An effective decontamination mean can be prepared my mixing one part of liquid bleach with nine parts of water, obtaining an approximately 0.5% of solution. This is effective to decontaminate the skin on living persons, excepting the face with the eyes area. Full strength bleach (*e.g.* 5% of sodium hypochlorite) can be used to decontaminate equipment and materials. Clothes and protective garments should be soaking in a bucket filled with bleach. Because it takes some time for the decontamination mean to kill germs, viruses and spores it is necessary to wait awhile (*e.g.* for at least fifteen minutes) before removing it with water.

Alcohol solutions (*e.g.* 70% alcohol) are effective on most biological contaminants. It can be used to decontaminate non-porous surfaces and personal property. It is suitable to clean small superficial wounds on persons and animals (*e.g.* solutions with 70% ethyl or isopropyl alcohol) followed by flushing with clean water. But, the most popular means in decontamination are soap and water providing a good personal decontamination. Generally speaking, washing with plentiful amounts of hot soapy water will remove most chemical, biological and radiological contaminants from emergency responders who have been exposed to CBRN agents.

5. TRENDS FOR FUTURE DEVELOPMENTS

CBRN threats pose almost unimaginable burden to our society.

Considerable efforts are needed in every CBRN emergency to determine what type of agent has been deployed and to establish the countermeasures to be taken. In this point, science research plays a major role is the development of a

broad spectrum decontaminants that are easy to use, and do not destroy the environment into which they are utilized. In this respect, scientists have been developing materials that can detect and decontaminate chemical and biological agents [7]. Such a material would rapidly destroy biological and nerve agents upon hydration. The availability of glucose and water in blood and body fluids would allow this biomaterial, to be used internally or as a wound dressing, because it has the capacity to kill bacteria, viruses and even spores. This multi-functional material could also decontaminate both chemical and biological agents without cross interference with either process.

Another revolutionary material is the so called self-decontaminating photocatalytic textile [8] based on layer-by-layer approach and successfully used under solar light illumination for the photocatalytic degradation of organophosphorous and organosulfide chemical weapon agents. Applied to textile substrates using polyethyleneimine as counter polyelectrolyte for homogeneously functionalizing textiles, is highly efficient toward the removal under solar light of the yperite blister live agent and of dimethylmethylphosphonate as neurotoxic agent simulant. It can be used for yperite live agent destruction with a complete removal of the toxicity within 20 min.

Cold plasmas applications in medicine are well known due to its ability to destroy a wide range of infectious agents, and thereby speed wound healing. Also cold plasmas have a high capacity to selectively break chemical bonds and initiate the polymerization reaction. Due to its capability of ion and electron bombardment cold plasmas can be used to clean surfaces. All these proprieties recommend cold plasmas to be used in CBRN emergencies [9]. Atmospheric discharge cold plasmas, usually called “non thermal decontamination” have shown their efficiency as germicidal agent [10, 11].

A comprehensive review of current trends and future development in CBRN decontamination technologies can be found in reference [12].

6. CONCLUSION

As it was shown in the present paper, CBRN decontamination is the process of removing or neutralizing contaminants that have accumulated on personnel, equipment, materials and environment that could be critical to health and safety of the first responders. Decontamination protects workers from hazardous substances that may contaminate and eventually affect (permeate) the protective clothing, respiratory equipment, tools, vehicles, and other equipment used in CBRN emergencies. Performing a good decontamination means preventing of uncontrolled transfer of harmful materials into clean areas and protecting the population, property and environment from CBRN hazards. Decontamination means and methods vary in their effectiveness for removing different CBRN agents. It is very

important that the effectiveness of any decontamination mean and method should be assessed at the beginning of any program and periodically throughout the lifetime of the program. If contaminated materials are not properly removed and they are affecting or penetrating protective equipment and trough this affecting the involved personnel, the decontamination program must be revised.

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