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Decontamination Solutions and Techniques for Chemical, Biological, Radiological and Nuclear (CBRN) Incidents

Kimyasal, Biyolojik, Radyolojik ve Nükleer (KBRN) Olayları İçin Dekontaminasyon Solüsyonları ve Teknikleri

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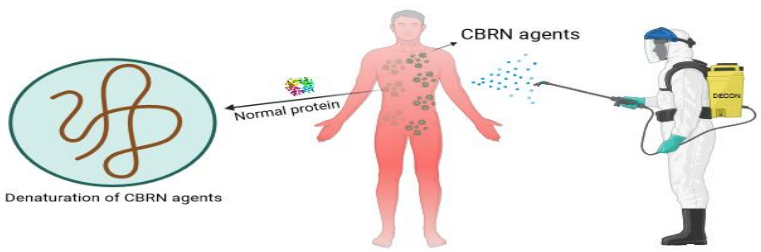
Önemli Noktalar / Highlights

Bazı kirletici maddeler (ör. VX) çok düşük konsantrasyonlarda ölümcül olabileceğinden kapsamlı ve etkili bir dekontaminasyon önemlidir. Kirliliğin neredeyse %100'ünün dekontaminasyon ile arındırılması gerekir, %70- %80'lik dekontaminasyon seviyeleri yeterli değildir. Fiziksel, kimyasal ve mekanik olmak üzere üç tür dekontaminasyon tekniği vardır. Bu nedenle sorumlu bir KBRN dekontaminasyonu için her kontaminasyona özel bir dekontaminasyon zorunludur. Bu çalışma KBRN sıvılarının hazırlanma tekniklerinin ve müdahale yöntemlerinin karşılatırılmalı olarak incelendiği ilk çalışmadır.

Grafiksel Özet / Graphical Abstract



Abstract

Chemical, Biological, Radiological, and Nuclear (CBRN) pollutants endanger people's health, environment and cause safety risks for population and property. In the chlorine gas attack that took place in Iraq in 2007, 16 people lost their lives and more than 100 people were injured. In 2013, it was determined that more than 100 people suffered from shortness of breath as a result of explosives emitting odor and smoke from airplanes in Hama province of Syria. Decontamination, a crucial step in CBRN events, eliminates the effects of chemical, biological, radioactive, and nuclear substances acting on people, vehicles, materials, buildings, and areas or reducing them to a level that does not pose a health threat. Thus, decontamination plays a vital role in the defense against CBRN Warfare agents. With decontaminants, the wounded exposed to war agents are cleaned from these agents, which is accomplished by physical removal or chemical inactivation of the warfare agent. Once contamination is recognized, it is estimated that 90% of decontamination will occur within one minute by applying skin decontamination and removing clothing. Decontaminants used for skin and instrument decontamination generally consist of commercially available products made from alcohol, iodine, sodium chloride derivatives. When using these decontaminants, they should be dissolved at the specified concentrations, used following the instructions for use, applied to the body in appropriate amounts, and applied to the places specified for the body. This article aims to outline the general rules for decontamination solutions and techniques used in CBRN incidents

Özet

Kimyasal, Biyolojik, Radyolojik ve Nükleer (KBRN) kirleticiler insanların sağlığını, çevreyi tehlikeye atmakta, nüfus ve mülk için güvenlik risklerine neden olmaktadır. Irak'ta 2007 yılında meydana gelen klor gazı saldırısında 16 kişi hayatını kaybetmiş, 100'den fazla kişi de yaralanmıştır. 2013 yılında Suriye'nin Hama ilinde uçaklardan atılan patlayıcıların koku ve duman yayması sonucu 100'den fazla kişinin nefes darlığı çektiği tespit edilmiştir. KBRN olaylarında çok önemli bir adım olan dekontaminasyon, insanlar, araçlar, malzemeler, binalar ve alanlar üzerinde etkili olan kimyasal, biyolojik, radyoaktif ve nükleer maddelerin etkilerini ortadan kaldırır veya sağlık tehdidi oluşturmayacak düzeye indirir. Bu nedenle, dekontaminasyon KBRN Savaş ajanlarına karşı savunmada hayati bir rol oynamaktadır. Dekontaminantlar ile savaş ajanlarına maruz kalan yaralılar bu ajanlardan temizlenir, bu da savaş ajanının çoğunlukla fiziksel olarak uzaklaştırılması veya kimyasal olarak inaktive edilmesi ile gerçekleştirilir. Kontaminasyon fark edildiğinde, cilt dekontaminasyonu uygulayarak ve giysileri çıkararak dekontaminasyonun %90'ının bir dakika içinde gerçekleşeceği tahmin edilmektedir. Cilt ve alet dekontaminasyonu için kullanılan dekontaminantlar genellikle alkol, iyot, sodyum klorür türevlerinden üretilen ve ticari olarak satılan ürünlerden oluşmaktadır. Bu dekontaminantlar kullanılırken belirtilen konsantrasyonlarda çözülmeli, kullanım talimatlarına uyularak kullanılmalı, vücuda uygun miktarlarda uygulanmalı ve vücut için belirtilen yerlere uygulanmalıdır. Bu makale, KBRN olaylarında kullanılan dekontaminasyon solüsyonları ve tekniklerine ilişkin genel kuralları ana hatlarıyla belirlemeyi amaçlamaktadır.

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1. INTRODUCTION

Disasters cause economic and social losses, interrupt social life and develop suddenly [1]. According to their formation, disasters can be divided into "natural disasters" without a human factor and "human-caused disasters" caused entirely by human influence. Chemical, biological, radiological, and nuclear disasters, known as CBRN, fall into human-caused disasters. As a result of exposure to chemical weapons, the toxic agent can enter the human body through different systems. While aerosol, vapor, and gas forms of chemical weapons are mainly inhaled from the respiratory system and included in the circulatory system, liquid, and solid forms are absorbed through the skin and taken into the body [2]. The eyes can also be the entry point of toxic agents in this context. Exposure can also occur with oral intake of foods and liquids contaminated by chemical weapons [3]. Nerve agents inhibit the enzyme Acetylcholinesterase and block nerve conduction, causing respiratory paralysis and death. Caustic agents cause skin, eye and respiratory lesions and irreversible damage of cell reactions. Physiological effects of blood poisoning agents include irritation of the nose and throat, chest tightness, choking sensation, coughing, increased respiration, difficulty breathing, redness and tearing of the eyes, headache, nausea and vomiting. The skin, which is the largest organ of the body and has the largest surface area in contact with the external environment, is one of the main targets of chemical warfare agents that can damage the skin or penetrate the skin and cause systemic poisoning [4]. Infection of skin with chemical warfare agent is a significant problem for military and civilian populations during modern-day wars or terrorist attacks [5-7]. For example, chemical warfare agents can cause muscle paralysis, increased heart rate, hypertension, anxiety, respiratory depression and coma [8,9]. Therefore, the CBRN agent in contact with the skin must be removed as soon as possible to reduce toxicity [10,11]. Moreover, effective decontamination increases the time interval for treatment.

When the literature is examined, decontamination is divided into three categories: physical, chemical and mechanical. Burying chemical agents underground in times of war etc. is classified as mechanical decontamination. While physical decontamination methods include procedures such as washing and evaporation, reaction with chemicals and hydrolysis procedures fall into the category of chemical decontamination [11]. Sodium hypochlorite and calcium hypochlorite were the first decontaminants used against chemical warfare agents. Decontamination solution (DS2) is another solution that is effective against sulfur mustard isopropyl methylphosphonofluoridate (GB), 3,3 dimethyl-2-butyl methyl phosphonofluoridate.

This review focuses on decontamination systems and techniques to reduce the toxic effects of CBRN agents, which pose a great risk to humanity, on humans, animals, and items.

2.DECONTAMINATION

The decontamination process at a CBRN scene ensures that the agent is removed from the environment, that victims or survivors do not contaminate the environment, that first aid providers are contaminated and that the number of contaminated people is limited (Figure 1). [12]. This work is carried out by physical removal or chemical inactivation [13]. Rapid decontamination is vital in cases exposed to liquid nerve agents or sulfur mustard, which are rapidly absorbed through the skin as they cause cellular damage to the skin within a few minutes of exposure [14]. It is estimated that approximately 80% of the decontamination can occur only by removing the clothing, as the yarns that make up the clothing fabric can capture and hold the chemical agent in liquid and vapor form [15]. Therefore, removing jewelry and watches, and clothing outside the treatment area reduces the risk of evaporation of contamination from these items. However, care should be taken to ensure that previously uncontaminated skin parts are not contaminated while removing the clothes.

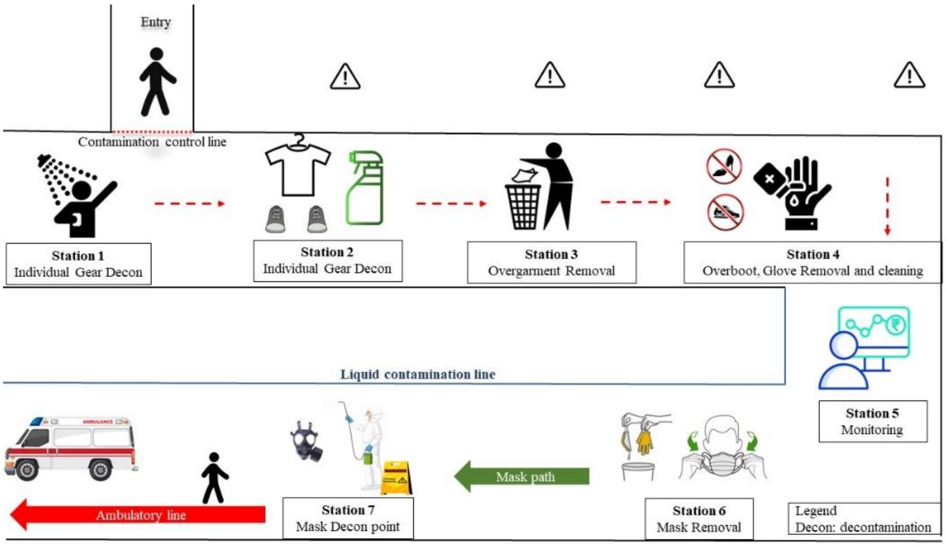

Figure 1: CBRN decontamination area.

Decontamination is usually carried out in the warm zone after the evacuation of the wounded from the hot zone [16]. This process can be broadly categorized as "wet" and "dry." Wet or water-based decontamination relies on water-based solutions to wash potentially contaminated areas of hair and skin. The main advantage of wet decontamination is that it is readily available, cheap, effective and water is ubiquitous in developed and developing countries [17]. If water-insoluble chemicals are present, soap products such as body wash or baby shampoo can be added to the water. Pouring these products onto a soft sponge and rubbing gently on the skin can facilitate the removal of the agent. A comprehensive decontamination system should have the following features [18,19]:

- Should not be abrasive
- It should not damage soft objects such as paint and coating,
- It should be easy to prepare and apply,
- The decontamination formulation should not be disrupted when used together with a surfactant,
- It should have low toxicity,

- It should have little harmful effect on the environment.

Providing pre-hospital care for a CBRN event is essential for the protection of health. Prevention can be achieved by having decontamination liquids in homes or pharmacies. Commercial products are available for skin decontamination, but simple decontamination can be done using the "rinse-wash-rinse" technique with plenty of soap and water. In case of eye exposure, the eyes should be washed thoroughly with plenty of water or 0.9% saline solution (NaCl) [15].

3. METHODS TO REMOVE CHEMICAL WARFARE AGENTS

Decontamination is the cleaning process carried out to prevent a wounded person contaminated with a CBRN agent from infecting other wounded and the personnel who intervene with him/her. In general, decontamination is divided into 3: mechanical, physical and chemical.

3.1. Mechanical

The most easily applicable method for decontaminating any object or substance is to remove or cover the contaminated surface. Digging into the soil with a wooden stick or wood can help remove the agent.

3.2. Physical

Physical removal, the cheapest and easiest method for CBRN agents, includes some procedures. Washing CBRN agent-contaminated skin or items with water-based solutions can neutralize a significant amount of agent, but it should be remembered that the agent can penetrate further with water.

4. DECONTAMINANTS USED FOR CHEMICAL AND BIOLOGY AGENTS

4.1. Reactive Skin Decontamination Lotion Kit

The Reactive Skin Decontamination Lotion kit is a U.S. Food and Drug Administration (FDA) approved product consisting of a lotion-impregnated sponge in an easy-to-open package [20]. RSDL, a commercial product, contains Decon 139 and small amounts of 2,3 butanedione monoxime [21]. 2,3 butanedione monoxime (also known as Diacetyl Monoxime) is a weak acid with a pKa of 9.3 [22]. The RSDL kit has been developed to remove or neutralize chemical warfare agents and T-2 toxins from the skin. Chemical neutralization takes place by a reaction mechanism known as nucleophilic substitution. The use of the kit includes wiping the skin area exposed to the chemical warfare agent with an impregnated sponge. The reactions between the lotion and various chemical warfare agents have been extensively studied *in vitro* and *in vivo*. It was shown that the obtained reaction products used in operational situations had been received [23]. The shelf life of a ready-to-use kit is five years from the date of manufacture when stored under recommended storage conditions. The kit should be stored in its original container between 15°C and 30°C in a cool, well-ventilated area, away from incompatible materials and food, and protected from direct sunlight. Burning may occur if it comes into contact with strong oxidizing chemicals (e.g., dry chlorine products), so opened packages should not be thrown into places where strong oxidizing substances are present. In case of exposure to a chemical warfare agent, the product starts to show its effectiveness within 2 minutes from opening the package. The first use of RSDL in the field was made by Canadian troops during the First Gulf War in 1991, and in the following years, the United States (U.S.) army applied to the Food and Drug Administration of the United States to incorporate this product. In 2002, the U.S. Food and Drug Administration granted a use permit for RSDL [23].

The volume of the RSDL kit contained in the 42 mL green pack is sufficient to decontaminate the forearms, hands, neck, and face. It removes or neutralizes RSDL, sarin (GB), tabun (GA), soman [24], cyclosarin (GF), VX, VR, Mustard, and T-2 toxins from the skin. In some animal in vivo studies, RSDL is more effective against chemical warfare agents than other decontamination methods [10,25]. However, reactive decontaminants can damage the skin if used in large quantities and not removed quickly. Furthermore, RSDL is known to cause eye irritation, and therefore eye contact should be avoided [25]. In addition, the direct application of RSDL to open wounds has been shown to impair wound strength and reduce the collagen content in the early stages of wound healing [26,27].

4.2. Decontamination Solution 2 (DS2)

In addition to the negative effects caused by hypochlorite solutions, the need to find more effective decontaminants has led researchers to investigate alternative methods for the decontamination of chemical warfare agents. In 1960, a new solution called DS2 (Decontamination Solution 2), which did not lose its activity even if stored for a long time and could be used between -26 °C and 52 °C, was developed for use in neutralizing chemical warfare agents [28]. DS2 is an anhydrous solution and contains 70% diethylenetriamine, 28% ethylene glycol monomethyl ether and 2% sodium hydroxide [29]. Although DS2 is a highly effective solution for decontaminating organophosphates and does not cause corrosion on most metal surfaces, it does damage materials made of plastic, rubber and leather. More importantly, it has a caustic effect on human skin [29].

4.3. Surfactant-Based Decontaminants for Chemical Warfare Agents

Surfactant-based decontamination solutions contain sodium dichloroisocyanurate and dichloroisocyanuric acids [30]. The solution is prepared with a mixture of approximately 1-15% hydrated dichloroisocyanuric acid salt and 1-9% lithium hypochlorite. In addition, it contains 1-10% propylene glycol co-solvent and 1-15% surfactant. The surfactant dissolves when it interacts with water and forms foam when in contact with air. With this solution, G agents, caustic agents and V agents are neutralized [30].

4.4. Water Based Decontamination

In water-based decontamination solutions of chemical warfare agents, 90 g benzyltrimethylammonium chloride, 25 g benzyltriethylammonium chloride, 185 g 2-amino-2-methyl-1-propanol are mixed with 20 g water. Finally, the pH of the resulting solution is adjusted to 10.6 by adding approximately 20% water [31].

4.5. Chlorine and Chlorine Compounds

Chlorine and chlorine-containing compounds have highly oxidizing properties and show similar chemical reactions despite their different structures. The most important sources of chlorine are chlorine gas and hypochlorites [32]. A hypochlorite solution consists of household bleach, which is approximately 5.25% sodium hypochlorite (NaCl). Household bleach should contain 5.25% (50.000 ppm) sodium hypochlorite (NaOCI) [32]. 0.5% sodium hypochlorite solution is used for skin decontamination. To prepare a 0.5% solution, 1 part of bleach is mixed with 9 parts of water, but this solution may be contraindicated for use in different parts of the body, especially the eyes [33]. In the case of chemical warfare, it is recommended to use a newly prepared, diluted, alkaline 0.5% hypochlorite solution for decontamination [34-36]. The 0.5% prepared solution has been proven to be effective in oxidizing the mustard agent and organic phosphorus compounds [34, 36]. The effectiveness of chlorine and chlorine compounds is the inhibition of the intracellular enzymatic reactions, denaturation of proteins, inactivation of nucleic acids, and killing microorganisms [37].

Hypochlorites are destroyed in light, so they should be stored in opaque containers, closed. It is actively used because of its rapid effects, low cost, broad-spectrum antibacterial activity, and toxic residues [37]. Chlorine and chlorine compounds are also widely used in drinking water disinfection, swimming pool cleaning, household cleaning [38]. Hypochlorite solutions should not be used undiluted because they are toxic to the skin and may do more harm than decontaminate [39]. For example, in one study, rabbits exposed to sarin gas were not affected when they were not decontaminated, but skin irritation was observed when washed with 5.0% bleach [40]. On the other hand, diluted use of bleach (0.5%) is preferred since it does not have any irritant properties for human skin [41]. The virucidal activity of sodium hypochlorite (NaCIO) is related to the chlorine concentration of active chlorine expressed as a % or ppm (parts per million) [42]. It was found that 0.63% (6300 ppm) sodium hypochlorite significantly reduced the number of polioviruses [42].

4.6. Activated Aluminum Oxide-based Decontaminant

The surface contaminated with a CBRN agent is washed with aluminum oxide to remove the contamination and then decontaminated [43]. The absorbent material may contain not only activated aluminum oxide but also a mixture of magnesium monoperoxyphthalate. It should be noted that magnesium monoperoxyphthalate should be in the range of 1-50%.

4.7. Oxidizing Gels

Gels with oxidizing properties are formed by the combination of oxidizing agents and gels. In this way, detoxification is achieved by applying it to the area contaminated with chemical and biological agents. When gel-forming substances such as sodium alginate, pectin and silica form a gel, they do not flow on the applied surface and form a colloidal structure. Oxidizing agents dispersed in water or organic solution can form gels when combined with colloidal matter in the range of about 10-30%. If the necessary substances are available, it can be prepared in a warm area or hospital where the CBRN agent is located and can be applied quickly by spraying. After decontamination, gel residues can be cleaned with water or vacuumed. For example, a gel consisting of a combination of 5.5% NaOCI and 13.5% fumed silica has been found to be effective against chemical agents.

4.8. Reactive Sorbent

It is obtained by mixing 148 g of sodium methoxide solution with 38.6 diethylenetriamine for 1 hour. The resulting solution is added to carbon with a surface area of 1800 m2/g and waited for it to dry. This solution is effectively used to decontaminate chemical and biological agents [44].

4.9. Alcohol and Alcohol Derivatives

Alcohol-based disinfectants have a broad-spectrum bactericidal effect, although they are recommended by the US Centers for Disease Control and Prevention [45]. Alcohols act by disrupting the 3-dimensional structure of proteins (Enzymes), disrupting the random ringing of polypeptide chains and the helical structure [46,47]. Alcohol-based decontaminants are the leading decontaminants that provide the fastest and most significant reduction in microbial counts on the skin [46].

Ethyl alcohol 60%, isopropyl alcohol 50%, and n-propyl alcohol 40% show sufficient effect in concentrations. Although ethyl alcohol shows sufficient effect at 60-80% concentrations, the concentration where it is optimally effective for skin decontamination is 70% [37].

Proteins are denatured easily in the presence of water, so water is necessary for the antimicrobial activity of alcohols. A much stronger and longer efficacy can be achieved by adding substances such as povidone iodine and chlorhexidine into alcohol. It has been determined that the antimicrobial activity in the abdomen and groin area cleaned with the solution obtained by mixing 2% chlorhexidine gluconate into 70% isopropyl alcohol is more effective against 70% isopropyl alcohol and 2% aqueous chlorhexidine gluconate [48]. Healthcare personnel should perform hand hygiene with 60-95% alcohol-based disinfectants before and after wearing gloves [49]. On the other hand, the main disadvantage of alcohol is that they do not have permanent effects and can irritate the skin [50]. In addition to the ineffectiveness of alcohol-based disinfectants against non-enveloped viruses, methyl alcohol is not used much in the health sector due to its weak bactericidal effect. [51].

4.10. Iodophor

Iodophores are solutions containing iodine and a solubilizing agent [52]. Iodophores penetrate the cell wall and membranes of microorganisms and disrupt DNA synthesis, but are less effective than other disinfectants in preventing biofilm formation of microorganisms [53]. Iodine solutions have been used for skin decontamination for many years. However, its use as decontamination is limited due to its poor solubility in water, low stability, staining of surfaces, and odor. However, this was significantly reduced by complexing the iodine with a polymer [54]. Polyvidone iodide, a compound of iodine and polyvinylpyrrolidone, is the most widely used iodophor [55]. Contaminated hand and arm decontamination involves initial scrubbing with 0.7% povidone iodine (PI) and a secondary cleaning with 10.0% PI [56]. Iodophors are moderate decontaminants effective against plant bacteria, enveloped viruses, fungi, and some micro-bacteria. Its mechanism of action occurs through the oxidation of amino acids, which eliminates the cell's ability to synthesize protein [54]. Free iodine oxidizes the -SH groups of proteins and enzymes and transforms them into disulfide (S-S) forms, thereby distorting the structures and shapes of these substances. It is known to be effective against bacteria, such as broad-spectrum antibiotics and fungi and viruses, including HIV. Iodine, whose importance was unknown until 1950, found its place in the current usage areas with its molecular combination with polyvinylpyrilidone [57,58]. 7.5% PI solution is used for decontamination in the surgical field [59]. Clinical studies have shown that many microorganisms are destroyed by rubbing using povidone-iodine, and intra-abdominal bacterial infection development is reduced by peritoneal washing. In studies examining the bactericidal and cytotoxic effects of 10% povidone-iodine (diluted 1:10), it was found that it inhibited the viability of Gram (-) and Gram (+) bacteria and was not harmful to normal fibroblast cells [60,61]. It should be noted that iodine also stains the skin an intense yellow-brownish color, causes blue stains on clothing in the presence of starch, and combines with iron and other metals.

4.11. EasyDECON^{TM} DF200 Solution

It is found in commercially available products that are produced to neutralize chemical and biological warfare agents. One of them is the EasyDECON^{TM} DF200 solution, which can be applied as a foam and spray. The environmentally friendly solution has little or no effect on the skin. The product, which is used by the American army and fire departments, is used by military and civilian organizations in many other countries [62]. While preparing the solution, three different liquids called Part1, Part2, and Part 3 are used. In addition, it does not stain or damage the fabric/fabric so that it can be used on all surfaces without any problems. It is a mixture of ordinary household substances that neutralizes both chemical and biological agents in less than 30 minutes and is environmentally friendly. EastDecon 200 is effective against G-series nerve agents, VX nerve agents, H-series caustics, L-series caustics, phosgene oxime and chicken pox, anthrax, E. coli, SARS-Coronavirus, hoof and mouth diseases. The solution absorbs the existing contamination with its application, chemically oxidizes, and neutralizes it [62].

4.12. Hydrogen Peroxide(H_2O_2)

Hydrogen peroxide (H_2O_2) is used in sterilization, disinfection and as an antiseptic biocide. It is a colorless liquid. Although sporicidal activity increases significantly in the plasma phase, higher concentrations of hydrogen peroxide (10-30%) and longer contact times are required. Hydrogen peroxide is a strong oxidizing agent as it produces free hydroxyl radicals. Free hydroxyl radicals are known to bind to cell components such as DNA, lipids and proteins and specifically target sulfhydryl groups and double bonds. Generally, 20°C and 6 hours contact time is accepted for sterilization with 7.5% hydrogen peroxide and 30 minutes contact time for disinfection under the same conditions [63].

Louis Thenard discovered H_2O_2 in 1818, and B. W. Richardson first suggested its use as a disinfectant in 1891 [64]. Today, it is widely used, mainly since it decomposes non-toxic by-products (e.g., oxygen and water). Few literature studies are discussing the mechanism of the biocidal effect of H_2O_2 as suggested in general studies on the mechanisms of action of biocides in general. H_2O_2 acts as a reactive oxidizing agent with biomolecules (proteins, lipids, nucleic acids, etc.) that make up cellular function [65]. In addition, compounds with hydrogen peroxide are a strong oxidizing agent, acting through the formation of hydroxyl free radicals (OH), which cause denaturation of the cellular component [65].

Today, the importance of no-touch disinfection (NTD) systems, which are automatic disinfection robots, has increased rapidly in combating pathogenic microorganisms colonized on the environmental surfaces of healthcare facilities. No-touch disinfection systems are broad-spectrum effective even against bacterial endospores and are based on hydrogen peroxide, which, unlike alternative disinfectants, does not have carcinogenic properties [64]. These systems are being which aim to provide more effective disinfection than routine cleaning methods. To obtain the gas phase of approximately 1 micron by heating the 30% hydrogen peroxide aqueous solution after the ambient humidity and temperature is adjusted according to the disinfection condition and release hydrogen peroxide vapor in the appropriate amount of the volume of the environment to be disinfected [66]. Portable no-touch disinfection robots can perform disinfection in the environment where they are placed without human intervention after specific parameters are entered. Therefore, inside a building such as a house, apartment, or hotel, H_2O_2 solution can be used to kill biological microorganisms such as coronavirus. An important point that should not be forgotten during this process; It is closing openings such as windows, doors, and ventilation in the environment.

A hydrogen peroxide solution in a concentration as small as 0.5% effectively inactivates coronaviruses (e.g., SARS, MERS) on inanimate surfaces within 1 minute [67]. Clinically recommended and commercially available H_2O_2 solutions at concentrations of 3.0% and 1.5% show the minimal virucidal effect 15 seconds after administration [68].

Table 1: Decontaminant/disinfectant applied against microorganisms and the concentration to be applied.

Decontaminant	Concentration to be applied	Application Place	Microorganism Affected
Sodium Hypochlorite	%0.5 (5000 ppm)	Skin	Vegetative bacteria, Enterococcus, Staphylococcus, gram-positive and gram-negative bacteria –

Alcohol Ethyl or isopropyl alcohol	%70.0	Surface and skin	Gram-positive and gram-negative bacteria, Bacillus and Clostridium spores
Iodophores	30-50 ppm free iodine	Surface and skin	Bacteria, mycobacteria, viruses
Phenol and phenol compounds	%0.4-5	Surface and tool	Bacteria, fungus
Aldehyde Formaldehyde	%6-8	Surface	Bacteria, fungi, viruses, spores, mycobacteria
Glutaraldehyde	%2-3.2		Bacteria, fungi, viruses, spores, mycobacteria
Orthophytalaldehyde (OPA)	%0.55	Skin	
Hydrogen Perokside	%3.0	Tool and surface	Bacteria, viruses, fungi

4.13. Factors Affecting Decontamination

In order for the decontamination solution to be effective, it must have certain properties. Some of these include the duration of the area contaminated with the agent, contamination intensity, size of the affected area, type of agent, and temperature of the environment. The preparedness of the personnel wearing A-B-C-D level protective clothing and the roughness or curve of the surface of the contaminated object are also of great importance in decontamination.

5. EFFECTS OF RADIOLOGICAL AND NUCLEAR AGENTS AND PROTECTION TECHNIQUES

In 1945, the US dropped an atomic bomb on Hiroshima, killing 60,000-70,000, and three days later on Nagasaki, killing 34,000 [69]. These two bombs are thought to have caused a total of 340,000 deaths over five years, mostly civilians. In 2016, a 16-year-old boy who found the missing Iridium -192 source in Sakarya and took it home was diagnosed with skin injury due to radiation exposure and at least 10 relatives were also affected by radiation [70]. Radiological and nuclear threats can take the form of the transportation and distribution of radioactive material or the detonation of a nuclear weapon [71]. In the event of a terrorist incident, intervention can only be possible by organizing appropriate response action plans that have been practiced on previously produced scenarios. For the success of pre-developed response action plans for radiological material emitting devices, there is a need for health personnel who are informed about basic radiation biology, appropriate medical support, the ability to train post-event medical support, urgent referral of knowledgeable and experienced people to centers for acute treatment, and long-term follow-up. According to the basic radiation protection standards recommended by International Radiological Protection [72], dose limits for whole body irradiation are as follows [72]:

- 2.5 µSv/hour
- 20 µSv/day
- 100 µSv/week
- 5000 µSv/year

Exceeding these values may cause various damages in the body. Exposure to radioactive fallout generally occurs in three ways: inhalation, ingestion and through the skin. Exposure up to 0.75 Sv (Sievert) is the amount of radiation that is considered safe for everyone and is called the combat dose. As the exposure dose increases, a number of clinical symptoms begin to occur (Table 2).

Table 2. Clinical conditions that develop depending on the radiation dose exposed [73].

REM	Sievert	Clinical Effects
0-25	0-250	No observable clinical effects
25-100	250-1000	Minor changes in the blood picture
100-200	1000-2000	• fatigue and loss of appetite • Nausea and vomiting within 3 hours • Moderate changes in the blood picture
200-600	2000-6000	• Vomiting in 2 hours or less • Internal bleeding and infection • Major change in blood picture • Hair loss within 2 weeks
600-1000	6000-10000	• Vomiting within 1 hour or less • With a major change in the blood picture • Internal bleeding and infection • (80% to 100% of deaths occur within 2 months, and survivors take a long time to recover)

A radiological weapon is a device that causes damage and severe injury and death by spreading the radiation released due to the halving of the radioactive material contained in it specifically. These weapons, also called radiation weapons, cause pollution by scattering radioactive material around them. The primary sources of this pollution are generally nuclear power plants, nuclear weapons development facilities, nuclear research centers, and wastes. When a nuclear weapon explodes, air molecules are pushed out from the center of the explosion due to the high heat generated there collide and form a blast. While the power created by the heat and pressure that creates the blast causes damage to the living creatures and structures in the first moment, the blast collapses inwards due to the rapidly falling air pressure in the blast after a short time, resulting in a second shock wave. While the power created by the heat and pressure that creates the blast causes damage to the living things and structures in the first moment, the blast collapses inwards due to the rapidly falling air pressure in the blast after a short time and a second shock wave is formed. Human beings, items, and animals that are slightly damaged by the first effect are destroyed mainly by this second shock wave. The effects of the weapon occur due to the radiation emitted to the environment. These effects depend on the type and quantity of the weapon used, the height of the explosion, and the structure of the region. When the bomb is detonated at or near the surface, residual effects increase in severity.

Radiological and Nuclear accidents cause significant loss of life and property and cause great casualties to countries. The nuclear reactor, which houses the 9M370 cruise missile belonging to Russia, exploded in 2019, resulting in 5 deaths and 3 severe injuries due to radiation [74]. As a result of the unwitting transport of Iridium 192 cargo packages on the passenger plane flying between Cairo-Zurich-Bussel in 2017, it was revealed that 26 passengers were exposed to higher doses of radiation than allowed [75]. Therefore, decontamination is vital to reduce the number of such accidents. For this purpose, the immediate and careful removal of the outer clothing of the wounded ensures that 90% of the CBRN warfare materials are removed. Decontamination is not only the removal of activity from people, but also the collection of evidence about the activity to which they have been exposed and the provision of preliminary data on the possible effects of radiation.

5.1. First Responder

When faced with a patient contaminated with a radioactive substance, the first action to be taken is to intervene to ensure the survival of the injured person or to prevent the situation from getting worse, rather than the contamination itself. It should not interfere with the medical treatment to be applied to the injured and if necessary, the contaminated casualty should be admitted to the hospital. Injured persons who are transferred to a health facility after a radiological or nuclear event should be kept in the health facility until it is determined that they are not contaminated. Removing radioactive substances from people and belongings is not a simple and easy process and requires high amounts of personnel and material resources.

5.2. Decontamination Methods

Radioactive substances cannot be neutralized like chemicals. Instead, it is removed from the environment. This should not be forgotten when performing radiologic decontamination. Therefore, the difficult process is to remove the radioactive substance from the environment without contaminating it. While the patient is stabilized in the emergency room, his clothes are removed. Care should be taken to remove clothing regularly to avoid contamination of medical personnel and other personnel. Rather than tearing the patient's clothing, it should be removed or cut away from the airway and the radiological material should be kept inside the clothing. Priorities for skin decontamination are cleaning wounds and holes around the face. Finally, the decontamination process is completed successfully on clean skin. To prevent contamination from flowing into the wound, the area around the wound is still decontaminated with a soft sponge. In addition, curtains should be worn at certain intervals to prevent contaminated agent from contaminating the environment. The wound is washed with sterile 0.9% NaCI (saline). The purpose of the initial washing is to try to remove contamination as much as possible. The floor should be sloped so that any saline or agents that fall on the floor can be collected in a multi-bin or in a different drain. The collected waste should be collected in a predetermined room for disposal. If there is bleeding after decontamination, the wound is re-bandaged. The skin should not be rubbed during decontamination; rubbing the skin accelerates the penetration of the agent into the skin [76,77].

Before decontamination, swabs taken from the ear, nostrils and wound sites of the wounded may give an idea about whether there is a risk of internal contamination. The specimens should be stored in separate vials or sealed tubes with identification information, where and from which side they were taken. These samples are a source of analysis not only for clinical investigations but also for forensic investigations. Transportation to health facilities without such study and recording procedures may not only increase the fear of health workers who do not have sufficient knowledge about radiation, but may also result in contamination of health facilities.

To carry out the decontamination process, it is necessary to define the various radiation zones of the crime scene. The purpose of defining zones is to minimize unnecessary radiation exposure and allow the quick and efficient recovery of the injured and preserve their health. For this purpose, as shown in Figure 2, the amount of radiation in and around the incident area should be measured. The environmental radiation exposure rate in these zones should be below 0.1 mR/h (1 microSv/h). When the radiation exposure level is 100 mR/hour, a medium level radiation exposure boundary is established, and when it is 1000 mR/hour, a high-level radiation exposure boundary is established (Figure 2). If the areas to be zoned area in open land, inside a building or in case of fire, cordon distances may vary between 30 and 400 meters depending on the scene [78]. These zones and their widths are determined according to the dose rates in the radiological-nuclear incident. In addition, meteorological information on wind direction and intensity is also needed when deciding on the zones, their distances and the placement of control points. The incident-specific personnel should intervene by wearing the necessary protective clothing.

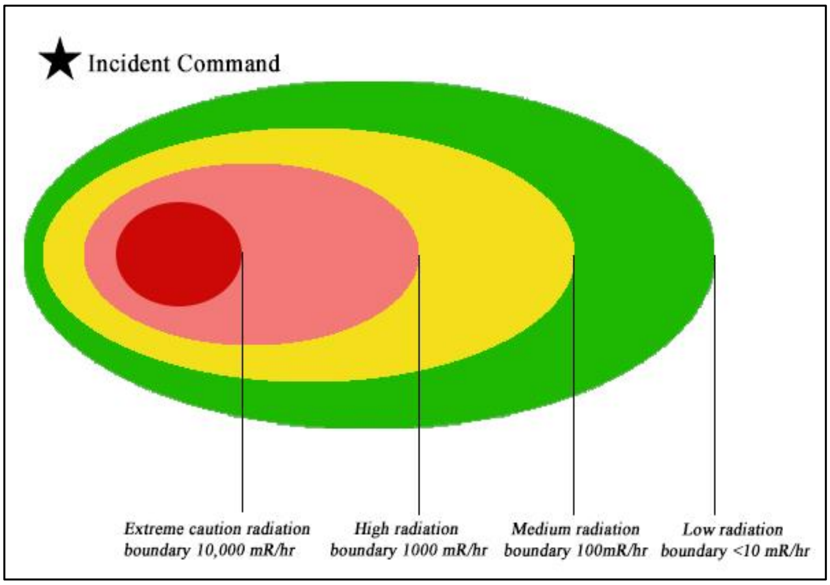

Figure 2: Radiation fields.

Substances that can cause radiological and nuclear contamination can be in solid and gaseous form. The most common radioactive contaminants are alpha and beta emitters. While substances emitting gamma rays cause damage to the whole body, beta emitters cause burns on the skin. There is a Geiger Müller (GM) counter to determine the amount of contamination and exposure. GM is used to measure the type and amount of radioactive material found on the surface and for body contamination screening [79]. The most important way to control radioactive contamination is to limit the spread of the material [79]. This process controls the entrances and exits to the hot area, wearing ABC-level protective clothing and personnel monitoring [76]. Removing outer clothing and shoes and washing the hair quickly provides

90% of the contamination. It may be necessary to decontaminate the casualty's skin and eyes (if there is any sign of eye contamination) after the clothing is removed.

After the casualty's clothes and accessories are removed, the measurement is retaken. Before applying the clean wash and rinse technique, it is recommended to comb and shake the hair instead of cutting it. After washing, measurements are retaken from the injured people. If the level on which the dose is known is higher than the determined limits, the washing process is continued until the quantity falls below the level. If more than 10% reduction cannot be achieved according to the previous measurement results, the process is continued [79]. Washing the skin by rubbing it hard with hot water should also be avoided for decontamination. Rubbing and cleaning can cause radionuclide or radioactive material to enter between the stratum corneum layers in the skin and increase exposure[80,81].

Since radiation-induced illnesses can take hours or days to manifest clinically, hospital emergency department staff should have the ability to triage victims of radiological terrorism incidents according to urgency using traditional medical methods and trauma criteria. Patients should first be medically stabilized and radiation injuries should be assessed, taking into account clinical findings, dose exposure, type of radionuclide and the presence or absence of internal contamination [82]. The treatment of a patient who has received radiation may vary depending on the type of radiation (gamma, neutron), the type of radionuclide (cesium, plutonium, etc.), the dose received, the level of exposure (full or partial body), the location of exposure (internal or external), and whether there are concurrent trauma or burn injuries. Furthermore, in the setting of a radiological nuclear incident or terrorist attack, it is inevitable that individuals will have co-morbidities such as diabetes, hypertension, heart failure. Among them, a more vulnerable population is pregnant women, older people, children and young people.

5.3. QuickDECONTM Radiation Decontamination Solution

QuickDECON™ is a radionuclide ion-specific decontamination solution. The main technology used is called Mass Effect™. After applying QuickDECON™ to a radiation-affected surface, radioactive substances adhered to the surface are mobilized and detached from the surface. QuickDECON™ solution enables radioactive ions to mobilize, break off from the most non-porous surfaces, and pass into the water-based solution.

The solutions have been developed to provide the most effective purification possible and to be easy to use. It is water-based and environmentally friendly and applied using the spray method and wiping method. It is also used to remove radioactive substances from human skin. It has been accepted by The United States Food and Drug Administration (FDA) to be suitable for superficial use on human skin. QuickDECON™ is used in military and civil defense, nuclear medicine, hospitals and laboratories, nuclear power generation plants, nuclear waste handling facilities, civilian first responders, bomb disposal teams, and homeland security [62]. Substances inactivated by both EasyDECON™ and QuickDECON™ solutions are shown in Table 3.

Table 3: Substances purified by EasyDECON DF200 solution and Quick DECONTM radiation decontamination solution.

Halogens	Transition Metals	Actinides
Fluorine, phosphorous, sulfur, chlorine, arsenicselenium, bromine, iodine, astatine	Lithium, beryllium, sodium, magnesium, potassium, calcium, chromium, manganese, iron, cobalt, nickel, copper, zinc, gallium, rubidium, strontium, indium, cesium, barium, thallium	Scandium, titanium, vanadium, yttrium, zirconium, niobium, molybdenum, technetium, ruthenium, rhodium, palladium, silver, cadmium, hafnium, tantalum, tongston, rhenium, osmium, iridium, platinum, gold, mercury, radium, lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, luterium, actinium, thorium, protactinium, uranium, plutonium, americium.

6. RESULTS

As in the past, CBRN warfare agents continue to be used for deterrent purposes, harming people, other living things, land and food, and polluting the environment. The cleaning of this contamination is carried out by trained personnel using different chemicals and equipment. While decontamination is generally performed for chemical agent pollution, for biological agents, removal is carried out by disinfection. Decontamination is vital both for the patient's life and for stopping the spread of pollution. The cleaning process is carried out by physically removing the agent and rendering it ineffective by destroying its chemical structure. Although water is the most commonly used liquid during this process, it exists in different chemical solutions. When preparing these solutions, it is crucial to know the appropriate amounts of the necessary chemicals not to irritate the casualty and neutralize the agent. Apart from decontamination, methods such as burning contaminated tools and objects, turning the contaminated area with a strip, closing it for use, leaving it out, and waiting for the agent to inactivate itself are applied.

7. FUTURE STUDIES

Developments in the field of CBRN defense and studies on solutions, decontamination kits or decontamination powder for CBRN decontamination applications continue all over the world. The reason for conducting studies in the field of decontamination is that existing decontamination systems are difficult to use, can leave waste in the environment after decontamination, and are not applicable in all kinds of environments and conditions, etc. Decontamination systems to be constructed in the future must be user-friendly, non-corrosive, and contain stable active compounds. For this purpose, hydrogels, nanoporous structures, nanosized systems that allow drug release have the potential to be used due to their promising properties.

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Kemal BAŞ: Writing- review & editing, Writing-original draft, Investigation, Conceptualization.

Serdar KARAKURT: Writing- review & editing, Validation.

CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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