Review of Materials and Technologies Used for Chemical and Radiological Decontamination

Daniela PULPEA, Marian BUNEA, Traian ROTARIU, Raluca GINGHINĂ, Gabriela TOADER, Andreea MOLDOVAN, and Bogdan PULPEA

[1]***Abstract*—This paper reviews several modern decontamination methods for radiological and chemical warfare agents. For a better understanding of the interaction mechanism between the toxic agent decontaminant solutions, basic principles of decontamination were explained.**

***Index Terms*—Chemical warfare agent (CWA), radioactive warfare agent (RWA), decontamination, contamination, nuclear fallout**

I. Introduction

The contamination consists in any form of undesirable toxic material that is accumulated, retained or deposited on surfaces, equipment, structures, large areas, and even on living beings, therefore it is limiting the personnel activities and usage of surfaces. After the contamination occurs, the surfaces of the materials and equipments become inoperative and the humans may exhibit health problems.

There are certain measures to be taken when a contamination may occur:

1. if possible, avoiding the contaminated area;
2. performing immediate or operational decontamination;
3. disposing of the materials used for decontamination.

Contamination control is defined as the action taken to avoid, reduce, remove the hazardous materials from contaminated surface or to turn them into harmless substances. [1]

Globally there are conventions, regulations and standards prohibiting the use, research and development of toxic warfare, such as:

- Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or other Gases, and of Bacteriological Methods of Warfare, usually called the Geneva Protocol [2]
- Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction (the Chemical Weapons Convention or CWC); [3]
- Convention on Physical Protection for Nuclear Material; [4-6]
- Treaty on the Non-Proliferation of Nuclear Weapons; [7]
- Treaty Banning Nuclear Weapon Tests In The Atmosphere, In Outer Space And Under Water, also known as the Partial Test Ban Treaty (PTBT); [8]
- Comprehensive Nuclear-Test-Ban Treaty (CTBT); [9]
- Treaty on the Prohibition of Nuclear Weapons (TPNW); [10]
- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal; [11]
- Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade; [12]
- Stockholm Convention on Persistent Organic Pollutants; [13]
- Joint convention on the safety of spent fuel management and on the safety of radioactive waste management. [14]

Toxic, hazardous chemicals and carcinogens are represented by any element (chemical, biological, radioactive, and/or physical), with the capacity to cause harm to living beings or the environment, either by itself or through interaction with other factors.

The chemical weapon is characterized by the Organisation for the Prohibition of Chemical Weapons (OPCW) to be any devices, munitions or other equipment specifically designed to be load with a chemical warfare agent (CWA).

The Chemical Weapons Convention (CWC) is intended to eliminate a category of weapons of mass destruction by prohibiting the development, production, acquisition, stockpiling, retention, transfer or use of chemical weapons by States Parties. The convention applies not only to chemical warfare agents (CWA), which can be used in war or by terrorists due to their toxicity, but also to associated substances, including substances that can be used to produce CWA and the degradation products of CWA. In the majority of cases, the products that come from the CWA deterioration are used as raw materials to manufacture them. [15]

The radioactive particles that settle to the ground after a nuclear explosion or after an accident that involves radioactive materials is called radioactive fallout. It consists of weapon debris, fission products and radiated soil.

The particles may vary in size from 10^3 mm, which fall easily on the earth, to less than 5 µm, that can contaminate the atmosphere for a longer period of time [16]. In addition to nuclear fallout, radioactive waste is another category of hazardous materials that needs decontamination. Radioactive waste is defined as material that contains, or is

D. PULPEA is with the Military Technical Academy "Ferdinand I", Bucharest, Romania (e-mail: pulpea.daniela@gmail.com)
M. BUNEA is with the Military Technical Academy "Ferdinand I", Bucharest, Romania
T. ROTARIU is with the Military Technical Academy "Ferdinand I", Bucharest, Romania
R. GINGHINĂ is with the Center for CBRN Defense and Ecology Scientific Research, Bucharest, Romania
G. TOADER, is with the Military Technical Academy "Ferdinand I", Bucharest, Romania
A. MOLDOVAN is with the Military Technical Academy "Ferdinand I", Bucharest, Romania
B. PULPEA is with the Military Technical Academy "Ferdinand I", Bucharest, Romania (e-mail: bogdan.pulpea@mta.ro)

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contaminated with, radionuclides at concentrations or activities greater than clearance levels as established by individual countries regulatory authorities, and for which no use is currently foreseen. [17]

In specialized literature various researchers have contributed to the field of decontamination of hazardous materials through articles such as:

- ❖ Jonathan G. Weis and Timothy M. Swager have synthesized dithienobenzotro-pone-based conjugated alternating copolymers that change color upon exposure to the chemical warfare agent mimic diethylchlorophosphate (DCP); [18]
- ❖ Josef Holecek n, Petr Otahal National have tested various varnishes to evaluate the use of manufactured strippable coatings for radiation decontamination; [19]
- ❖ Daniela Gurau and Radu Deju have made a technical research study for testing the decontamination using chemical gels and have demonstrated that these gels could be an efficient way to reduce contamination and minimize the potential for spreading contamination; [20]
- ❖ L. Palestini has presented the effects of SX34 (an innovative decontamination product developed for sensible surfaces decontamination from biological and chemical agents) on contaminated surfaces and its effectiveness compared to classic decontaminants SX34; [21]
- ❖ Jonathon A. Brame and the U.S. Army Engineer Research and Development Center (ERDC) have developed a deployable effluent treatment system that could be used to treat the waste from decontamination operations for responsible discharge or potential reuse in decontamination activities [22];
- ❖ Dennis M. Hoffman has patented a gel composition containing oxidizing agents and thickening or gelling agents, used to detoxify chemical and biological agents by application directly to a contaminated area [23];
- ❖ Hee-Man Yang has developed a magnet-sensitive and strippable polymeric coating that consists of a magnetic adsorbent with ^{137}Cs adsorption properties using a polyacrylamide (PAAm)/alginate(Alg)-based hydrogel with highly elastic properties for surface decontamination [24];
- ❖ L. Thors has evaluated the skin decontamination procedures with reactive skin decontamination lotion (RSDL) of human epidermis exposed to low volatile organophosphorus compounds [25];
- ❖ Gabriela Toader has reported a novel approach for water-based strippable coatings for surface decontamination consisting in the development of a new method of removing heavy metals from contaminated surfaces by using polyvinyl alcohol strippable coatings containing bentonite clay [26].

II. TYPES OF CONTAMINANTS

The most common hazardous materials are radioactive materials (nuclear fallout, radioactive waste), chemical substances (that can be flammable, corrosive, oxidising, neurotoxic, asphyxiating, blistering, explosive) or biomaterials (that can be hazardous, pathogenic, allergenic, carcinogenic). This paper reviews only the issues related to radiological and chemical warfare agents.

In order for a substance to be considered a Chemical Warfare Agent (CWA) or a Radiological Warfare Agent (RWA), it must meet several requirements, for instance:

- To have a proper state of aggregation that can contaminate the human body,
- To have high toxicity,
- To be resistant to humidity, atmospheric oxygen, light and have reduced reactivity to metals,
- To be insidious,
- To require a simple manufacturing process and must be made from easily accessible raw materials,
- To be difficult to identify and detect,
- To be resistant to decontamination,
- To require very laborious antidotes and medications,
- To have physiological effects that are difficult to heal,
- To have a long-lasting storage time.

CWA are substances witch through their actions cause death, temporary incapacitations or permanent harm to humans or animals. Herein can be noticed several types of CWA, represented also in Fig. 1, such as:

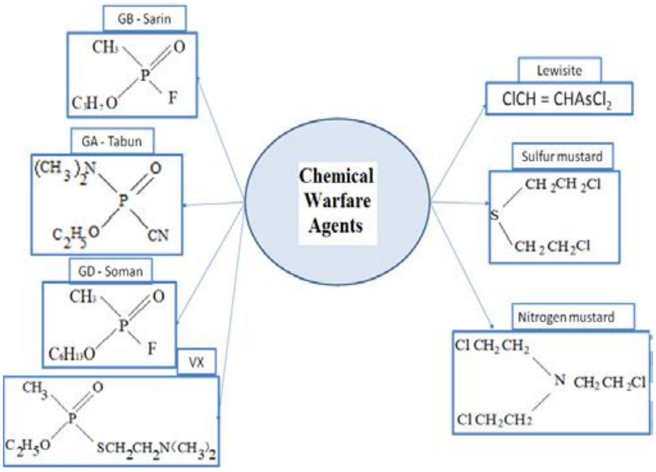

Figure 1. CWA materials

- *Choking agents*: can cause injury on the respiratory tract and can irritate the throat, nose, and the lungs (Ex: Chlorine, Chloropicrin, Diphosgene, Phosgene). The choking agents are usually dispersed in the gaseous form and absorbed into the lungs, then the fluid builds up in lungs and as a result the victim suffocates.
- *Blood agents*: can inhibit the ability of blood cells to use and transfer oxygen. They are dispersed as gas and absorbed through lungs causing the body to suffocate (Ex: hydrogen cyanide, cyanogen chloride, Arsine).
- *Blister agents*: can affect the eyes, skin and respiratory tract, first is acting as an irritant and then as a cell poison. Exposure can cause large skin blisters and often results in blindness and permanent damage to the respiratory system however, death is not a major outcome (Ex: Sulfur mustard, Nitrogen mustard, Lewisite and Phosgene oxime). Blister agents can be dispersed as a aerosol, liquid, vapor or/and dust and is absorbed through lungs and skin.
- *Riot control agents*: can temporarily incapacitate a person by causing irritation to the eyes, throat, mouth, lungs, and skin. They are dispersed as liquid or aerosol and are absorbed through skin, lungs and eyes (Ex: Tear gas, Pepper spray).

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- *Nerve agents*: are highly toxic with rapid effects and can block impulses between nerve cells or across synapses. The dispersal forms for these agents are aerosol, liquid, vapour and dust, that are absorbed through lungs (Ex: Tabun, Sarin, Soman, Cyclosarin) or in contact with the skin (Ex: VX) and can cause seizures, paralyses muscles, loss of body control and death. [27-28]

A nuclear weapon is an explosive device that receives its destructive energy from nuclear fission or fusion reactions. On the other hand, radiological weapon consists of any method of dispersing radioactive materials in order to kill the population or cause destruction in a particular area. Radioactive materials are those substances that release radiation without relying on a fusion or fission reaction. Very important for the safe handling of radioactive substances is the radioactive waste classification scheme presented in Fig. 2 on which is based the manipulation of such hazardous materials.

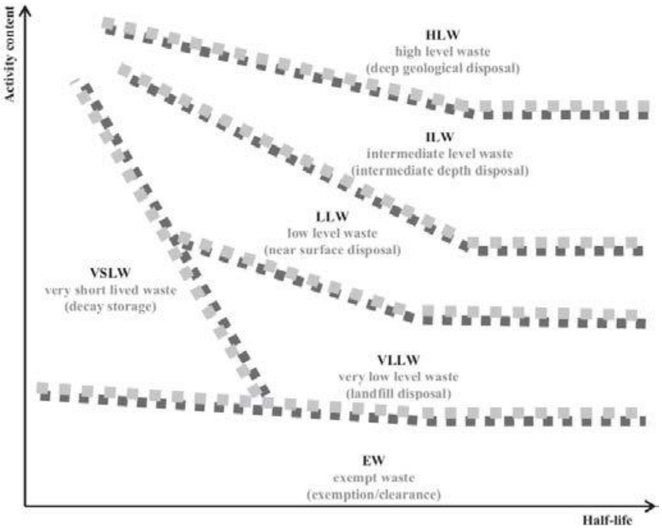

Figure 2. Radioactive waste classification scheme [29]

III. Interaction Contaminants - Environment

CWA can be dispersed on the surfaces in the form of droplets, liquid film or vapors. Depending on the type of contaminated surfaces, CWA may penetrate or not the surfaces. Therefore, dispersion phenomena of the liquid on surfaces as well as deep penetration phenomena have occurred, as schematically represented in Fig. 3.

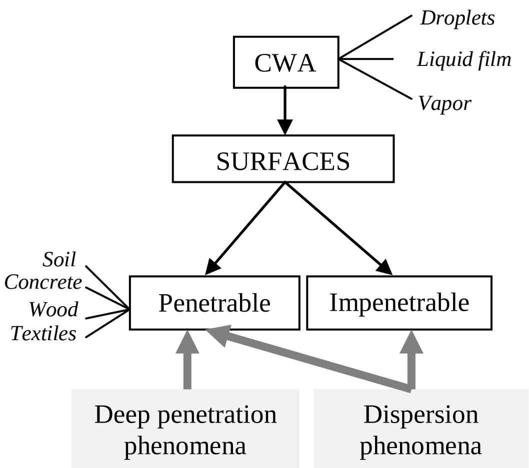

Figure 3. CWA interaction with surfaces

For nuclear fallout, which may be in the form of aerosols or solid particles, the interaction with the surfaces is distinctive. In this case there are three fallout-retaining mechanisms that are listed in Fig. 4.

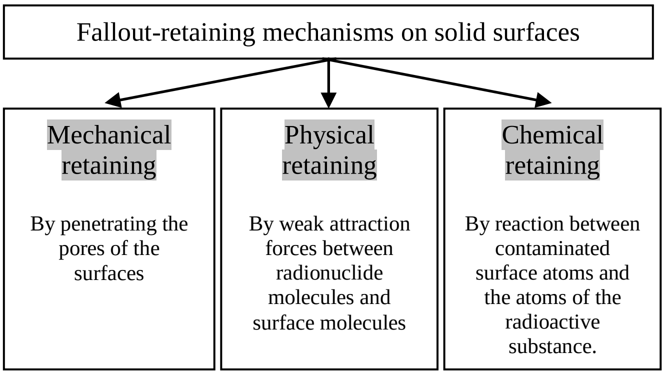

Figure 4. RWA interaction with surfaces

Toxic agents that contaminate liquid media may be in the form of droplets, in the case of CWA, or solid particles, in the case of CWA and RWA. The process by which liquid media are contaminated is different from that of surface contamination, since toxic liquids may have a certain decontamination power over CWA. For example, water has hydrolytic action and can convert CWA into non-toxic or less toxic products. To the contrary, organic liquids do not react with CWA. In the case of RWA, liquids have no effect on them because these products cannot be decomposed, in which case the decontamination consists of their physical removal from the environment. In time, the degree of radioactive contamination of liquid media decreases due to the natural disintegration of radioisotopes. Fig. 5 schematically illustrates how toxic agents interact with liquid media.

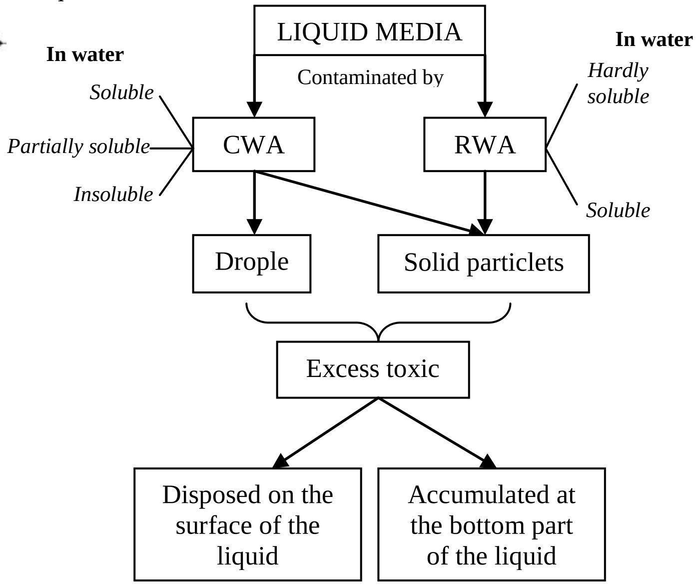

Figure 5. CWA and RWA interaction with liquid media

The atmosphere can be contaminated by toxic gases that may be in the shape of a toxic cloud. The person who uses CWA seeks to achieve a high-persistence toxic cloud. These aspects depend mainly on the atmospheric characteristics (such as: wind, precipitation, relief, buildings) and the properties of the toxic substance that are used (such as vapor density). In the case of RWA, after a nuclear explosion or a major accident the resulting radioactive dust rises in the atmosphere. Inside the toxic clouds loaded with radioactive dust, vapors condensation centers are formed, resulting in "radioactive precipitation". However, particles with a diameter of less than 5 µm remain in the atmosphere for a longer period of time. This cycle of the radioactive material trail in nature is described in Fig. 6.

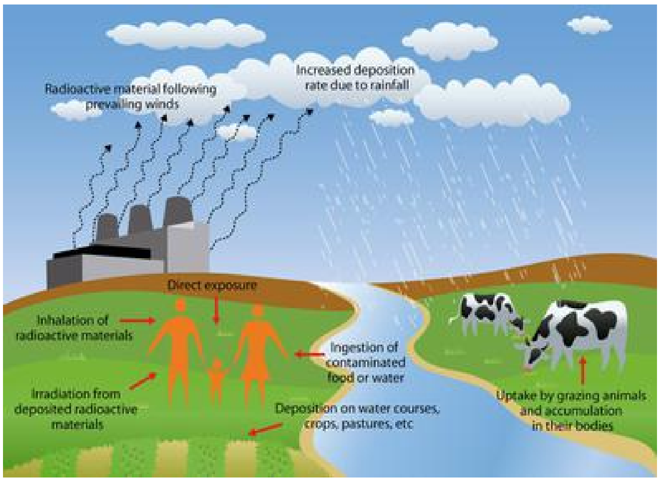

Figure 6. Radioactive material trail in nature [30]

In contrast to the absorption on materials, absorption by living tissue is no longer followed by desorption (Fig. 7). Due to the fact that the CWA enters the bloodstream and is circulated throughout the whole body, it has the possibility to interact with vital substances from the cells, producing characteristic toxic phenomena. When the skin is contaminated with CWA (Sarine, Soman, Vx) there are no traces at the contact area, which increases the insidious character of the contamination process. Other toxic chemicals such as Sulfur mustard and Nitrogen mustard produce hard-healing injuries on the skin. CWA pose a wide range of health hazards because of their high toxicity, therefore it is necessary that the skin decontamination be performed first, before other types of decontamination.

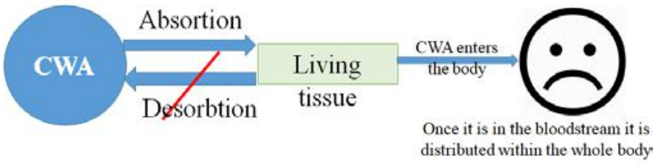

Figure 7. CWA pathway through body

RWA accumulates in the body in the form of a absorbed dose, which can be:

- a very low dose and in time the body will regenerate,
- a higher dose that, in time, can cause cancer, birth defects or genetic defects, or
- a high enough dose to cause death on the spot or within a few days.

IV. Decontamination Process

Decontamination is the process of making any person, object or area safe by absorbing, destroying, neutralizing, making harmless or removing chemical or biological agents or by removing radioactive material clinging to or around it. [31]

Toxic agents lose their toxic properties as time passes. Thus, CWA can be decontaminated by environmental conditions such as precipitation, wind and sunlight, but at the same time the wind can recontaminate the environment by aerosolization. RWA activity decreases in time, but environmental factors do not interfere in their toxicity reduction. The type of decontamination in which weathering is used to create a non-toxic environment is called passive decontamination and is a time consuming process which requires no resources. Figure 8 shows a categorization of decontamination types depending on the methods that are used in a certain situation.

Active decontamination consists in the use of combined physical and chemical methods, so that after the decontamination activities are completed, the decontamination coefficient must be over 99.9% for CWA and over 90% for RWA, so that the environment will be safe again.

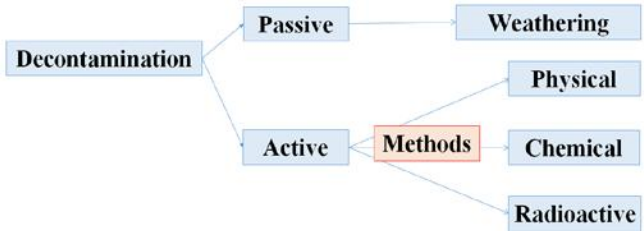

Figure 8. Types of decontamination

Radioactive methods for decontamination are treated separately even though they are also physical or chemical methods, because the result obtained from decontamination is different. If in the case of CWA decontamination the agents can be converted into substances with low toxicity, in the case of RWA this result cannot be obtained, because the activity of radionuclide decreases in time and is not influenced by external factors. Therefore, RWA can only be removed, isolated, encapsulated and stored in places where they do not affect the environment and the population.

Physical methods used simply, and not in combination with chemical methods, can merely relocate the contaminant. Physical decontamination is considered a partial method, even if by removing the contaminants it can still achieve the main objective: to limit the spread and reduce the potential exposure. To obtain complete decontamination, the relocated agent will always require treatment to make it less toxic.

Examples of physical decontamination methods are:

- Rinsing with water, organic solvents and mixtures,
- Washing with surfactants,
- Scrubbing with brush or abrasive material,
- Vacuum cleaning,
- Burying or sealing contamination,
- Adsorption and removal with solid adsorbents,
- Removal of protective layers applied prior to contamination.

For chemical decontamination methods to function it is necessary that CWA be transformed into less or non-toxic compounds. These results are obtained if suitable chemical compounds, irradiation with UV/VIS or plasma are used.

The main chemical methods are based on the use of nucleophilic or electrophilic reagents. Neutrophilic reagents produce hydrolysis reactions that are positively influenced if the reaction medium is basic (e.g. water, hydroxides, aqueous-

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alcoholic solutions, basic nitrogen-ammonia combinations). Electrophilic reagents change the structure of CWA and reduce its toxic properties (e.g. hypochlorites, chloramines, sulfuryl chloride, peroxides, hydrogen peroxide).

For efficient decontamination hydrolysis and oxidation are the principle reaction mechanisms used, because of the specific nature of most CWA. G-type and V-type CWA are sensitive to hydrolysis at the phosphorus atom, whereas both H-type and V-type CWA have a sulphur atom that is very susceptible to oxidation.

Examples of chemical decontamination methods are:

- Electrophilic methods (oxidation, chlorination),
- Nucleophilic methods (hydrolysis or other nucleophilic attack, e.g. with oximate),
- Complete destruction (full oxidation, thermal degradation, plasma-induced radical reactions).

Radioactive methods of decontamination are a separate chapter, but they are simple and consist of removing radioactive dust by repeated washing. To enhance the process, complexing agents are used that have the capacity to form stable chelates with the radionuclide which later on will be disposed (Fig. 9).

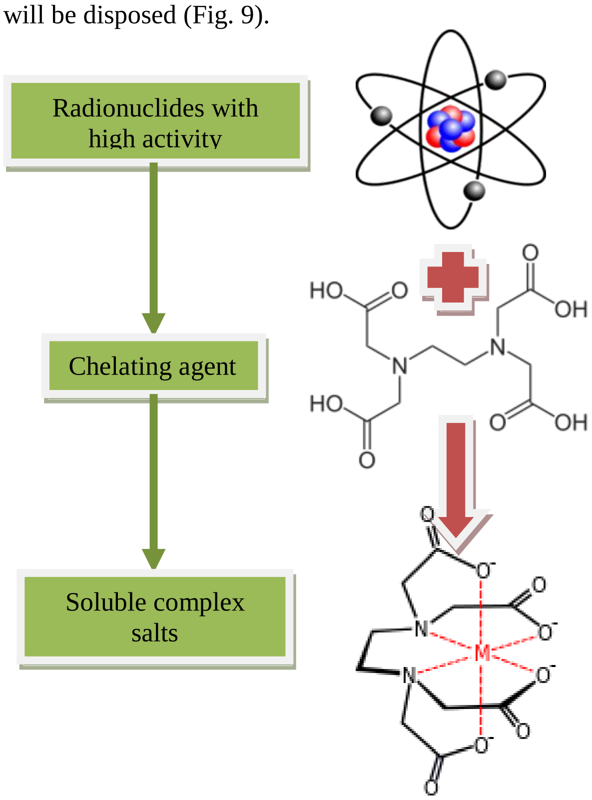


Figure 9. Simplified chelating mechanism

The principles for selecting the appropriate decontamination methods according to field factors can be:

- The quantity and the physical form of the contaminant (aerosols, liquid or solid particles),
- Climatic conditions,
- The type of materials that will be decontaminated (porous / non-porous, cement, wood, glass, electronics, human skin),
- The extent to which staff and surroundings were affected,
- For what purpose will the area be used after decontamination, to anticipate eventual staff exposure,
- Means and resources that are available.

In order for a solution to be included in the class of decontaminants it must fulfill the following characteristics:

- Neutralize a broad spectrum of CWA and remove radioactive agents,
- Compatible with skin and all types of surfaces,
- Non-corrosive, non-toxic, non-flammable and with low impact on the environment,
- May not soften or destroy paint, films or polymeric seals,
- May not interfere with the detection and monitoring equipment system of the contaminated area,
- Easy to prepare, apply, remove and to remain stable for a longer period of time,
- May adhere to vertical surfaces for a certain time for acquiring surface desorption and neutralization of CWA, but at the same time to be easy to remove by rinsing,
- Decontaminants should be in solution with a solvent capable of solubilising CWA, supporting neutralization of CWA and degrading thickening agents in which CWA are mixed (usually thickening agents are harder to remove than CWA),
- For the training of troops to be carried out as often as possible with real substances, the decontaminant must not be toxic in all manner of ways,
- In order to reduce the storage and transport of large quantities, it should be kept as a concentrated solution, where possible, and to make the decontamination mixture on site,
- From an economic point of view, it must consist of easily procured, low-cost and long-lasting substances,
- The ideal solvent is water or seawater, which is found on site and does not require transportation.

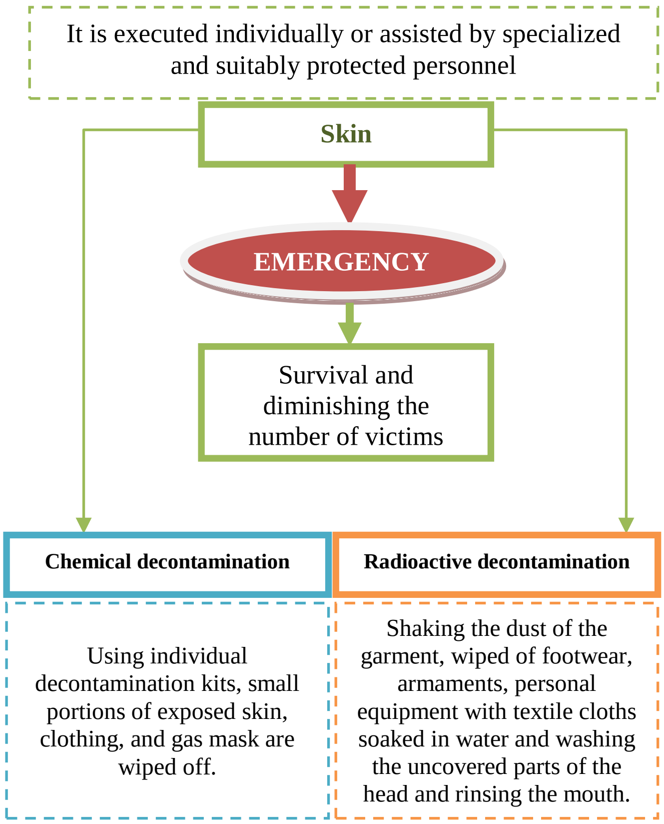


Figure 10. Skin decontamination assumptions

If we refer to a general composition that a universal decontamination solution should have, that will consists of:

- One or more reagents that can neutralize or destroy CWA
- Detergent
- Additives like: buffer solutions (to maintain pH between 8-8.5), anti-foaming and degassing agent (glycerin, silicates), chelating agents or/and agents for maintaining oxidation power (peracetic acid)
- Water

Military personnel must be trained and equipped to operate in a CBRN environment and must be able to sustain operations during and after a CBRN incident. However, if the staff was contaminated, their decontamination is representing Emergency 0 and it is primarily executed before all other types of decontamination. Skin decontamination is based on assumptions briefly described in Figure 10.

V. Decontamination Equipment of Romanian Army

In order to understand the current trends in the decontamination field, the procedures used in the Romanian Armed Forces should be exemplified and establish why it is necessary to improve them.

In the following tables (Table I, Table II and Table III) are listed equipment, materials and decontamination solutions used in the Romanian Army.

TABLE I. WEAPONS, VEHICLES AND TERRAIN DECONTAMINATION

Chemical decontamination of weapons and vehicles	**Chemical decontamination of the terrain**
Aqueous decontamination solution	*Suspension of basic calcium hypochlorite*
sodium hydroxide NaOH sodium thiosulfate $Na_2S_2O_3$ detergent	calcium hypochlorite $Ca(ClO)_2$ sodium silicate Na_2SiO_3 emulsifier

ADTT-4

Weapons, vehicles and terrain decontamination system

[32]

TABLE II. EQUIPMENT DECONTAMINATION

Chemical decontamination of the equipment	
Decontamination solution 1	*Decontamination solution 2*
sodium carbonate Na_2CO_3 detergent water	sodium carbonate Na_2CO_3 ethylene glycol $C_2H_6O_2$ detergent water

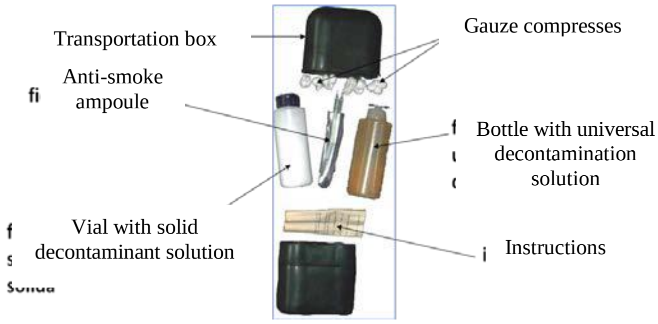
ADE-84

Equipment decontamination system

[32]

TABLE III. PERSONNEL DECONTAMINATION

Chemical decontamination of the personnel
Universal decontamination solution
sodium hydroxide NaOH dimethylsulfoxide $(CH_3)_2SO$ monoethanolamine $NH_2CH_2CH_2OH$ ethylene glycol monoethyl ether $CH_3OCH_2CH_2OH$
PDI Individual decontamination kit



To achieve radioactive decontamination, the same systems are used, but chemical decontamination solutions are replaced with radioactive solutions as those listed in Table IV.

TABLE IV. RADIOACTIVE DECONTAMINATION SOLUTIONS

Radioactive decontamination solution for weapons and vehicles	• Detergent and water
Radioactive decontamination of terrain	• Decontamination suspension with hot water and hot gas • Compositions for fixing radioactive dust to the ground (cement, asphalt, plastics, resins, etc.)
Radioactive decontamination of the equipment	• hexametaphosphate $(NaPO_3)_6$ • sodium carbonate Na_2CO_3 • detergent and water
Radioactive decontamination of the personnel	• Liquid soap solution • Ethersulfate solution

Listed below are the issues that can be improved in the decontamination process:

- Fast intervention in case of an attack with chemical and radioactive substances,
- The use of substances that can decontaminate large areas, because inside buildings and in small areas the danger of spreading the agents is much smaller,
- For solid particles, especially radioactive dust, the problem consists in generating aerosols during the cleaning of contaminated areas
- Use of readily available and inexpensive substances
- Materials and techniques easy to put into operation, used and trained for military personnel.

VI. New Directions in Decontamination

Conventional decontamination processes generally consist of applying a decontaminant solution to a contaminated surface, followed by a physical removal of the reaction products which can be partially toxic or non-toxic, action that is performed after a pre-determined time that is necessary to complete the neutralization reactions.

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Procedures currently used have disadvantages such as:

- High consumption of materials, energy and time,
- Complex logistics,
- Trained and qualified staff,
- Negative ecological EFFECTS.

Due to these shortcomings, decontamination specialists have researched new procedures on completely different principles, eliminating - at least partially - the disadvantages of classical processes.

Modern decontamination technologies approved by NATO stand out from classical technologies based on:

- Wet procedures in which decontamination solution are sprayed and friction is used or
- Dry procedures in which superheated steam and hot gases ARE USED.

New technologies aim to increase the efficiency and productivity of the decontamination process by:

- Improving mass and heat transfer phenomenon,
- Increasing the contact time between toxic and decontaminant due to the viscosity and higher adherence of the decontaminant compositions to the surfaces that need to be treated,
- Using surfactants and pressurized decontaminant fluid that ensure desorption and hydrolysis of toxic agents THAT PENETRATED THE PORES OF THE SURFACES.

For backing up the above statements Table V gives examples of new decontamination materials and methods.

TABLE V. EXAMPLE OF DECONTAMINATION MATERIALS AND METHODS

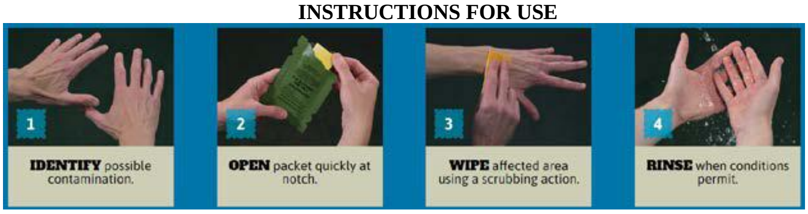
DECONGEL

- First Line Technology product.
- Decontaminates a wide range of materials (concrete, painted or unpainted steel, aluminum, plexiglass, linoleum, sandstone and mortar).
- Mode of action: capture and encapsulate a broad spectrum of radioisotopes and chemicals, allowing easy and safe disposal.
- Hydrogel, safe and environmentally friendly, with an almost neutral pH.
- Does not require preparation before use.
- Does not require the use of water.
- Efficient against radioactive isotopes, industrial toxic substances, heavy metals and methamphetamine.
- It can be used simply by brush or spraying, thus penetrating into the finest cracks of the surface, followed by a drying and decontamination period.
- Drying time depends on a combination of humidity, temperature, surface type, and film thickness applied.
- Drying can take place from less than one hour to 24 hours.[33]

RSDL

- Patented and made by Canadian specialists and produced by E-Z-EM, Inc., Lake Success, USA.
- Decontaminates the contaminated skin with tabacco (GA), sarine (GB), soman (GD), cyclohexyl sarine (GF), VX, iperite (HD) and T-2 toxin.
- It is composed of Dekon 139 (an unknown potassium salt) and a small amount of 2,3 butadiene monoxime (DAM), dissolved in a solvent composed of polyethylene glycol monomethyl ether (MPEG) and water.
- Decontamination is accomplished by removal, hydrolysis and nucleophilic substitution. It is not used for prophylactic purposes.
- The lotion is pre-impregnated in a sponge applicator, each applicator being packed in a sealed package.[34]

INSTRUCTIONS FOR USE



[35]

BX-24

- Made by Cristanini.
- A chemical and biological detoxification and decontamination product for vehicles, weapons and various materials.
- It is applied as a foam suspension
- can be applied with Sanijet Gun C.921 Apparatus , in three phases:
    - a prewash with cold water at a pressure of 90 bar;
    - a spraying of foam on the contaminated materials (the actual decontamination step in which an aqueous emulsion and hot water at low pressure are produced);
    - a post-wash with hot water (95°C) and pressure of 90 bar or dry steam. [36]

DEFENZ

- DEFENZ products are used for the decontamination of chemical, biological and industrial toxic substances. In collaboration with the United States Army, Genencor developed the DEFENZ range of enzyme decontamination solutions.
- DEFENZ can be used as a self-contained product or embedded in different systems, depending on the purpose of the mission.
- It is a non-toxic product, and does not destroy materials that need to be decontaminated. [37]

ALLDECONT

- Skin decontamination system patented by OWR.
- Decontaminates the skin in less than one minute.
- Decontaminates chemical warfare agents and a wide range of industrial toxic substances.
- Dermatological tests have shown that human skin is not affected by the decontamination solution for a 24-hour period.
- Rinse with clean water is not mandatory but recommended if the mission allows it. [38]

SDF

- Made by Canadian specialists (DRDC and RCMP).
- The aqueous solution for chemical and biological decontamination, CASCAD, was originally developed to decontaminate military equipment: ships, planes and vehicles.
- The solution was subsequently transformed into a decontamination foam (SDF) used for chemical and biological decontamination of buildings and sensitive materials.
- SDF has been further improved to be used in extreme temperature conditions.
- Effectively decontaminates all CBRN agents and a wide range of industrial toxic substances.
- Is stable between 4 and 24 hours after activation.
- The foam adheres well to surfaces and does not require reapplication.[39-40]

M - 7 RAD WIPES

- Product of Radiation Decontamination Solutions LLC,
- Used for the radioactive decontamination of non-porous surfaces, as well as skin and hair.
- Simple to use in emergency situations.
- The substance in which the wipes are soaked is water-based and eco-friendly.
- They are valid for 10 years if stored according to their characteristics.[41]

FAST-ACT

- The FAST-ACT Sorbent, made by NanoScale Materials is effective against a large number of industrial toxicants and chemical agents.
- It is capable of acting on liquid hazardous substances and vapors.
- It is nontoxic, non-flammable, non-corrosive, safe and easy to use.
- Within 90 seconds, it removes over 99.9% of iperite and soman and over 99.6% (detection limit) VX on the surface. After 10 minutes 99% of the soman and 99.9% of the VX are destroyed.
- FAST-ACT destroys toxic agents by hydrolysis and dehydrohalogenation.[42]

FIBERTECH

- Fibertect is a composite material consisting of 3 flexible layers, used for the absorption and adsorption of chemical warfare agents, industrial toxic substances and pesticides.
- FiberTect is effective in decontamination of personnel, weapons and sensitive equipment.
- The three layers of material consist of: two layers of textile material, the first and the last, and a core layer made of activated carbon fibres embedded in a composite material. The first and the last layer provide structural coherence, improving mechanical strength and friction resistance.
- FiberTect can be incorporated into personal decontamination kits and can be used with RSDL for a more effective decontamination (First Line Technology, Responder Decon Kit). [43]
- FiberTect is in various forms: sheets, wipes, rollers or gloves (can be worn over gloves).
- Exterior layers can be made of kevlar, nomex, nylon, raylon, wool, cotton, viscose, polyester, polypropylene as needed.[44-45]

SX34

- SX34 is a system that performs complete decontamination and cleaning of sensitive equipment and the interior of platforms (small individual equipment such as masks, weapons, sighting systems, helmets, etc.), sensible equipment such as electronic, optical, optoelectronic, etc.;)
- Is not corrosive or toxic and meets environmental safety requirements and is suitable for decontamination of CBRN agents on all sensitive materials and surfaces.
- Acts by removing agents from sensitive surfaces without damaging them.
- Acts without extending the contaminated area or carrying contaminants in the fine cracks of the surfaces.
- Is environmentally friendly (no component affects the ozone layer).
- It acts effectively against all CBRN agents. [46]

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VII. CONCLUSION

The global trend is to minimize pollution and environmental contaminants in the field of chemical and radiological decontamination, therefore it is still necessary to improve procedures and, at the same time, decontamination solutions and materials so that decontamination operations will be able to face the new situations encountered on the battlefield.

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