10th INTERNATIONAL SCIENTIFIC CONFERENCE ON DEFENSIVE TECHNOLOGIES
OTEH 2022
Belgrade, Serbia, 13 – 14 October 2022

ASSESSMENT OF THE EFFECTIVENES OF PERSONAL PROTECTION AGAINST THE EFFECTS OF RADIOLOGICAL CONTAMINANTS

SRETEN ILIĆ
Military Tehnical Institute, Belgrade, Belgrade, sreten.iz@orion.rs

NATAŠA PAJIĆ
Military Tehnical Institute, Belgrade, natasa.pajic969@gmail.com

ŽELJKO SENIĆ
Military Tehnical Institute, Belgrade, Belgrade, zsenic1@gmail.com

TATJANA GOLUBOVIĆ
Faculty of Occupational Safety, University of Niš, Niš, acinos2002@gmail.com

Abstract: *The study displays results of examining decontamination efficiency of 1% detergent solution as a formation agent and efficiency of DECON gel decontamination on samples of materials used in manufacture of formation and non-formation means of personal protection. The examination showed that applied radioactive contaminant alters physical properties of the materials used in manufacture of the light protective coat M4 and that radioactive decontamination thereof is not purposeful. It also indicated that DECON GEL decontamination reaches the highest efficiency on samples of rubber located on cheeks of protective mask M3 (95.4%) and rubber of protective boots M4 (95%). Lower percentage of decontamination efficiency was achieved by the 1% detergent solution, and it reached the best results on samples of rubber. DECON GEL can be used more efficiently in radioactive decontamination of protective mask M3 than the formation 1% detergent solution.*

Keywords: *means of protection, contamination, decontamination efficiency*

1. INTRODUCTION

The Earth has been constantly exposed to natural radiation from cosmic sources, as well as the widespread natural active radionuclides. Natural radiation has existed from the very beginning of the Earth. This group includes cosmic radiation, as well as cosmogenous radionuclides resulting from the interaction of cosmic radiation with the atmosphere.

Technological sources are the result of human activity [1]:

– in industry (coal combustion, mining and construction activities, radionuclides in artificial fertilizers...),
– in medicine (for diagnostics and therapy),
– in public use (lightning rods, fire detectors),
– in nuclear facilities.

Radioactive contamination is the undesirable presence of radioactive substances in quantities that may be harmful to the health and dangerous to the life of people. Means of personal protection are intended to protect people against radioactive, chemical and biological contamination. They can be either formation (those present among the Serbian Army weapons) or non-formation (those not present among the SA formation, but with the same purpose). Radioactive decontamination is the procedure of removing radioactive substances from contaminated surfaces. Internal contamination implies entry of the contaminant into human organism through inhalation, ingestion, or through human skin and mucosa, and chemical matter called radioprotectors is used in such cases. Radioactive material, removed from the contaminated surface by decontamination, is being treated as radioactive waste, and is being processed further, stored and kept in places where it will not represent hazard.

2. PERSONAL PROTECTION

In order to reduce the the impact of radioactive contamination on man it is necessary for individuals, as well as entire companies, to undertake protective measures that can be active or passive [1]. Radioactive protection may be said to represent a series of measures undertaken in order to avoid the consequences of radioactive contamination. Personal protection implies use of formation and non-formation means of protection. Means and equipment for personal protection at work, in terms of Rule Book on preventive measures for safe and healthy work using means and equipment for personal protection at work, includes all means and equipment that an employee wears, holds or otherwise uses at work, for the purpose of protecting themselves from one or more simultaneously arising hazards or damages, that is, to eliminate the risk of injury occurrence and health damage. Means of personal protection play a very important part, and can be divided into general (belonging to each individual) and specific (intended for protection of personnel performing tasks under increased contamination conditions). General means of protection consist of means of respiratory organs' protection and means of body protection. Respiratory organs' protection employs formation protective masks operating on the principle of filtration or insulation and various non/formation means [1].

2.1. Formation personal protection means

Formation means of personal protection include: Protective mask M3, Protective gloves M4, Light protective coat M4, Protective socks M3, Protective overalls M5, Protective filtering suit M2 and Protective boots M4.

Protective mask M3 (PM M3) is intended for protection of respiratory organs, face and eyes against radioactive particles, poisonous gas (hereinafter as: PGa) and biological agents, as well as other harmful matter in the atmosphere where the percentage of oxigen is not lower than 17%.

Protective overalls M5 (PO M5) is intended for personal protection under considerable droplet contamination (e.g. during decontamination procedure). Provides a high level of protection, but represents a considerable heat burden to the wearer. Apart from chemical protection, PO also protects against radioactive and biological effects and, to a certain extent, against effect of thermal impulse of nuclear explosion (TINE) and burning napalm mixture. PO is produced in one-piece option. There used to be a two-piece option of PO (M3). It can be manufactured with a smaller surface mass, representing a physiologically somewhat more convenient option, as well as performing of some longer lasting activities (e.g. scouting in droplet contaminated zone). The hood is an integral part of the PO. The elements of PO manufactured from butyl rubber are sewn, and butyl strips are attached over the seams. The PO is opened and closed by a zipper located in the front. Ends of the sleeves and trouser legs have rings embedded, allowing firm tightness with

PG and PB. The overalls are decontaminated with the purpose of removing and neutralizing the PGa, biological agents and radioactive contaminants.

Light protective coat M4 (LPC M4) is intended for protection against liquid agents of PGa, contact with PGa droplets, as well as dust and other impurities. It also protects against radioactive precipitation, effect of burning napalm mixture and TINE. By placing personal weapons under LPC M4 they are protected against possible radioactive, chemical and biological contamination. LPC M4 can serve as cover or bolster. The hood is an integral part of LPC M4. It is manufactured in the shape of a cape and primarily in the form of a poncho. Construction solution of PC includes „Velcro" strips, zippers and side holes with the purpose of obtaining multifunctionality (improvised tent, canopy, etc.). LPC M-4 is manufactured in forms of lighter and heavier type, that is, with lower and higher surface mass of coated butyl rubber. LPC M4 can be manufactured with one-sided or both-sided coating of butyl rubber. It is made in green colour or multicoloured camouflage option.

Protective gloves M4 (PG M4) are intended for protection of hands against effect of vapours, droplets and aerosols of PGas, radioactive precipitation, effects of burning napalm mixture and TINE. They are manufactured on the basis of butyl rubber. For specific purposes they can be manufactured on the basis of neoprene, natural rubber, nitrorubber, Viton polymers, latex, etc. They are anatomic in shape and fove-fingered. Soldiers of some armies wear cotton pads underneath PG M4 to collect produced sweat and thus enable easy handling. PG M4 are manufactured from butyl rubber by the technological process of dipping (very seldom pressing). Thickness of PG M4 of 0,7 mm is customary with the mass of 170 t per pair. Specific tasks and special units require thinner or thicker PG, and they are therefore manufactured in material thickness of 0.5 mm to 0.9 mm. PG M4 have solid flexibility even at low temperatures. PG are decontaminated. PG M4 are decontaminated by dry and wet tampons (tampon soaked in soap or detergent solution).

Protective boots M4 (PB M4) are based on butyl rubber with the purpose of protecting the users' feet, primarily against effects of droplet contamination by PGa. PB M4 also protect against radioactive precipitation, effects of burning napalm mixture and TINE. They are used when performing RCB decontamination, RCB scouting, or another activity on contaminated ground.

Protective socks M3 (PS M3) are intended for protection of feet from radioactive, biological and chemical (CBR) contamination. They can decontaminate by the same method as the protective overalls, and can be disposed of and destroyed after use.

2.2. Non-pharmaceutical means of personal protection

Non-pharmaceutical means are not included among weapons of Serbian Army, but can be used for protection. The overalls based on TychemR F is similar in construction to PO M5 based on butyl rubber, with certain specifics concerning this material. Protective overalls based on TychemR F can be decontaminated, but also disposed of due to more accessible price. The suit weighs 450 g. [2]. All the modern armies of the worls are equipped with protective coat, more precisely, the light type with the mass range of approximately 600 g. Lower mass enables easy movement, also providing lower thermal load. Protection by the coat of lighter type is lower than the protection by coat of heavier type. Generally speaking, protective coat is decontaminated, and the multicoloured camouflage PC unilaterally coated on the interior side is not. Almost all of the world armies are equipped with PS, but there is no such diversity in construction of any other protective means as there is in PS, which clearly indicates that concept solutions differ from army to army. PS are manufactured from very light and simple material of polyethylene type with slight protection, up to PS of heavy type from butyl rubber with high degree of protection against the effect of PGa. Construction solutions also differ. PS can also be coated with layers of various thisknesses, and the degree of achieved protection depends on the type of material and applied protective layer. They can be monochrome or camouflage multicoloured.

3.MATERIALS USED IN MANUFACTURE OF PERSONAL PROTECTION MEANS

3.1. Insulating materials

Insulating materials are based on elastomer or plastomer. They are manufactured as relatively thick films, applied to the basic textile material based on polyamide, polyester or cotton. These materials are used to manufacture the protective overall, coat, gloves, socks and boots. Generally speaking, there are two basic types of material [2]:
a) multilayer sandwich and
b) coated textile material.

Du Pont has projected TychemR F army material with excellent protective features against the contaminating effect. TyvekR F base is TychemR C (TyvecR, non-woven fibres manufactured from high density polyethylene and polymer layers). The result is TychemR C (Figure 1), with firstly the barrier and then the polymer film applied to it, in order to obtain TychemR F (Figure 2).

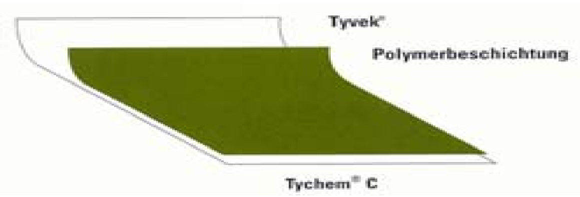

Figure 1. Tychem^R C material [2]

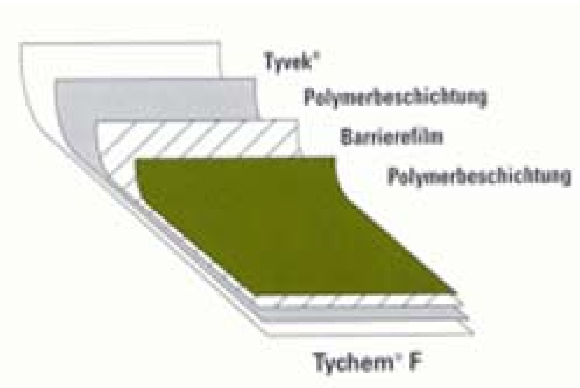

Figure 2. Tychem^R F material [2]

The overalls manufactured from TychemR F material protects extremely well against effect of many chemicals, which is very important in certain incident situations. Protection time while under effect of chemical and biological agents is higher than 48 hours. After contamination TychemR F either decontaminates or is rejected and destroyed. TyrhemR F is not resistant to effect of thermal impulse of nuclear explosion (TINE) and effect of napalm mixture, does not have camouflage features and is coloured green or white.

3.2. Filtering materials

Filtering materials are primarily used in manufacture of protective filtering suits (PFS) [2], consisting of inner and outer layer (Figure 3).

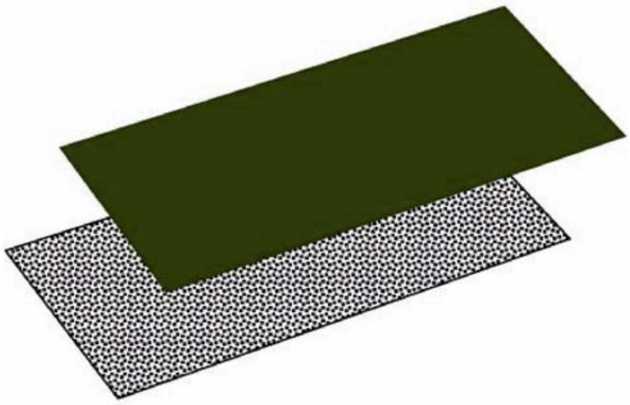

Figure 3. Construction of permeable CBR protective material [2]

Outer layer of filtering material represents woven textile material based on polyamide, polyester, cotton or polyacrylonitrile, which, depending on the required degree and selected mechanism of protection against the effect of PGa, can be processed or unprocessed. The processing refers to obtaining the quality of oleophobicity and fire resistance. Inner layer of filtering materials consists of the filtering layer, constituting of the holding fabric, and the sorption layer of active carbon material. Nowadays active coal is the basic component of permeable PFS. It is used in three basic forms [2]: granules or powder, spheres and carbon fibrous material. The active coal powder is applied to the woven textile material or thrown into the structure of non-woven textile material and polyurethane foam and is used in manufacture of the inner layer of PFS.

4. BASIC TERMS OF RADIOACTIVE CONTAMINATION AND DECONTAMINATION

4.1. Radioactive contamination

Radioactive contamination is defined as undesirable presence of radioactive materials in quantities exceeding permissible limits [3]. A radioactive contaminant that a surface can come in touch with may appear in solid, liquid or gaseous states. A contaminant dissolved in water can have an ionic or neutral form, while those that are not dissolved in water comprise a wide range of disperse states, form molecular aggregates, colloidal particles, and particles ranging from submicron to macroskopic in dimensions.

The strength of an established bond between contaminants and a surface depends of the nature of the conataminants and nature of the force surface established in contaminating can be of [3]:

– electrostatic nature;
– physical nature, excluding electrical;
– chemical, with the reaction between the contaminants and the surface producing new chemical compounds, and
– mechanical.

Depending on the character of forces acting in the contamination process, there is a possibility of occurrence of equivalent (molecule) adsorption, ion exchange adsorption and specific adsorption, also chemisorption and action of physical forces, as well as mechanical process.

Equivalent or molecule adsorption is based on equivalent action of cations and anions, with the electrolyte molecules adsorbing as a unity in such cases. If surface of the adsorbent, which had previously adsorbed an ion, contains an ion of the same charge, exchange between these two ions may occurr, such form of adsorption being the ionic exchange adsorption. Specific adsorption occurs in case an adsorbent more strongly adsorbs one ion in the solution than the other, with resulting difference in potential between the bordering surfaces of the adsorbent and the solution. If a new chemical compound is created during the contamination process of a surface, such form of adsorption is named chemisorption. Mechanical procedure results from capturing of minute particles of the contaminant by a surface which is not ideal in the actual case and contains various defects, pores and cavities that the contaminant can penetrate.

Contamination also occurs through activation of the given material, if it entered a field of the corresponding radiation and thus got contaminated by their isotopes [4].

4.2. Radioactive decontamination

The term radioactive decontamination indicates a series of actions or processes eliminating contamination from surfaces. Decontamination of people, devices, technical instruments, facilities and land ought to stop spreading of contamination and reduce it to a permissible level where it had already occurred. Processes and procedures of decontamination include washing, heating, chemical or electrochemical action, as well as mechanical removing of contamination from certain surfaces. Generally speaking, multiple diversified methods or combination thereof, are necessary in each decontaminating procedure.

While implementing decontamination procedures one can encounter a problem of detecting low concentrations of contaminants and verifying reduction of their concentration to a permissible level, that is, determining of decontamination efficiency.

4.3. Radioactive decontamination methods

Methods of radioactive decontamination can be divided into dry and wet ones. The term wet methods imply that the procedures are based on chemical and physicochemical processes of eliminating radioactive contaminants from contaminated surfaces using water, detergents, solutions and solvents. The decontamination process itself occurs in the liquid stage, with particles of a contaminant separating from the surfaces on account of reduction in adhesion force [3].

Dry decontamination methods include the procedures of collecting and eliminating radioactivity by mechanical actions in absence of liquid environment (using lasers, vacuum and ultrasound, scraping, wiping, brushing, peeling and other procedures). Loosely bound contamination is subjected to use of vacuum decontamination instruments, equipped with filters absorbing and retaining the radioactive material. Loosely bound and extensive contamination (thick layer of radioactive dust) is subjected to special varnishes that are applied to a contaminated surface, that dry very quickly and thus firmly bind the contaminant. After a while the varnish layer is peeled off together with the contaminant, after which additional decontamination procedures are implemented. Relatively bound contamination is mostly eliminated by wet methods. The most difficult contaminant to remove is the one bound to the surface by adsorbing chemical forces. The first level of decontamination includes removing of loosely bound contaminants. The remaining contamination is removed in the next step by decontaminating solutions containing complexing agents with the purpose of preventing resedimentation of the contaminants. If there is residual contamination after completing decontamination, abrasive agents are used.

4.4. Radioactive decontamination efficiency

The decontamination process comes down to breaking up the bond between the contaminant and the surface. The capacity of a surface to bind to itself and retain a certain contaminant is called contaminability, and its capacity to loosen and break up the bond between the contaminant and the surface under an influence (decontamination agent) – decontaminability. At the same time, contaminability also serves to compare different materials in terms of their susceptibility to contamination, as well as compare efficiency of different means of decontamination in relation to the same contaminated surface. Contaminability of a surface, relative to the given radionuclide, is expressed in percentages of residual activity at a surface ZA (%), representing the raltio between residual activity A after decontamination and initial activity A_0 [5]:

$$ZA\ (\%) = A/A_0 * 100 \qquad (1)$$

The percentage of withdrawn activity SA (%) can be reached through the ratio between the withdrawn activity A_0-A and initial activity A_0 [5]:

$$ZA\ (\%) = ((A_0 - A)/\ A_0) * 100 \qquad (2)$$

The measure of decontamination efficiency is the decontamination factor F_d, defined as the ratio between initial activity Ao and residual activity A after completion of decontamination, an can be expressed in equation:

$$F_d = A_0/A \qquad (3)$$

It is evident that, the higher the decontamination factor, the more efficient will the decontamination process be, the higher the percentage of withdrawn activity, and the lower the percentage of the residual activity.

Decontamination efficiency represents the ratio between the decontamination factor (F_d) and the percentage of removed activity (% R), as defined in the following equations:

$$\% R = (1 - A / A_0) * 100 \quad (4)$$

$$F_d = A_0 / A$$

where Ao is radioactive activity off the surface prior to application of decontaminating technologies, and A is the radioactive activity off the surface after decontamination.

$$\% R = (1 - 1 / Fd) * 100$$

Decontamination factor of 10 results in 90% of removed radionuclides from a surface:

$$90\% = (1 - 1/10) * 100.$$

5. SAMPLING AND MEASURING METHODOLOGY

In the period from the beginning of January until the end of July 2021 a number of 10 material samples were obtained and used to manufacture formation and non-formation means of personal protection (Figure 4a and 4b).

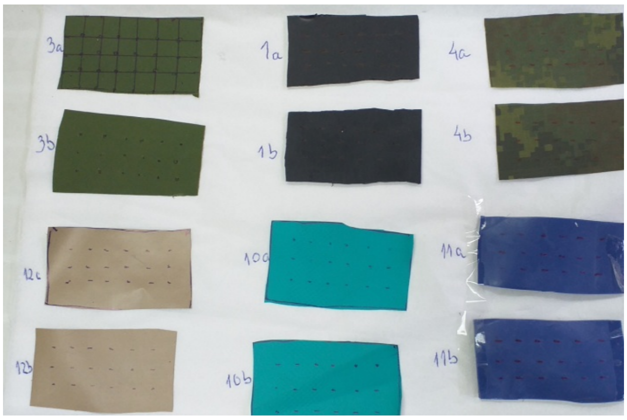

Figure 4a. Protective means material samples (Photo: N. Pajic)

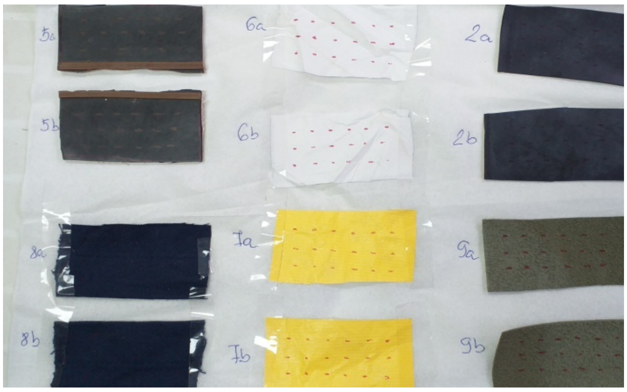

Figure 4b. Protective means material samples (Photo: N. Pajic)

Out of the formation ones a number of 5 material samples were obtained that are used to manufacture 7 formation means of personal protection, namely: Protective mask M3, Protective gloves, Protective coat light M4, Protective socks M3, Protective overalls M5, Protective filtering suit M2 and Protective boots M4. 4 material samples were also obtained that are used to manufacture non-formation means of personal protection, namely: Tyvek overalls, Tychem overalls, Protective socks heavy type, NITRAS gloves and samples of materials used to manufacture the protective hood (brown colour material from figure 4a). Two rectangles were cut out from each of the material samples of 3x5 cm dimensions, marked, amounting to the total of 20 material samples (Picture 4a and 4b). After that the samples were contaminated by the contaminating solution of specific activity of 1.23×104 Bq/mL and pH = 2.5, representing the diluted mixture of liquid samples of radioactive isotopes ^{60}Co (964.56 Bq/ml) in form of $CoCl_2$, ^{133}Ba (515.79 Bq/ml) in form of $BaCl_2$, ^{152}Eu (9496.12 Bq/ml) in form of $EuCl_3$ and ^{241}Am (1321.47 Bq/ml) $Am(NO_3)_3$. Marked area of sample of 15 cm^2, (50 × 30) mm, was contaminated by applying 18 drops of solution of 10 µl volume in homogenous layout. Contaminated samples were dried in a digestor in standard laboratory conditions.

Thus prepared material samples were measured on a semiconductor HPGe spectrometre, produced by „AMETEK-ORTEC“, of the resolution (FWHM) of 1.78 keV and of relative efficiency of 56.2 % for ^{60}Co at 1332 keV [6,7], thus obtaining the initial activity (A_0).

The detector was placed within a special low-pitched lead protection with 12 cm thick walls and 5 mm thick copper inner layer. All of the samples were measured for 10000 seconds, in order to obtain appropriate statistics of counting speed in the spectre.

Efficiency calibration of the detector was performed by a radioactive standard in a Marineli dish of1000 ml, type MBSS, Inspectorate for ionizing radiation of the Czech metrolorical institute (certificate no: Cert.No: 9031-OL-159/08), the matrix of which is the sylicone resin of density with radionuclides: ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{133}Ba, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{88}Y, ^{54}Mn and ^{60}Co. The spectrum analyses were done on the basis of present gama lines [6]. Software pakage Gamma Vision 32 was used to determine specific activity [7]. Obtained values of countdown below peaks of observed lines were corrected to the fon measured at 250000 s.

6. RESULTS AND DISCUSSION

In all of the 20 material samples, after receiving the initial activity (A_0), decontamination was performed by 1% detergent solution on 10 samples, and decontamination by DECON gel was performed on the remaining 10 samples. Applied radioactive contaminant alters physical properties of materials used in manufacture of Protective coat light M4 (LPC M4) and Tyvek material, that is, it deforms them. After contamination of „b“ samples (displaying deformity), no contamination was performed of the „a“ samples (Table 1). After performed decontamination, the samples were subjected to new measuring and thus obtained sample activity (A). After this, the decontamination factor was calculated, as well as efficiency of decontamination (equations 3 and 4). Obtained results are displayed in Table 1.

Table 1. Efficiency of decontamination of material used in manufacture of means of personal protection

Sample type	Decontamination by DECON gel – samples **a**			
	A_o $Bqcm^{-2}$	**A** $Bqcm^{-2}$	**F_d**	**%R**
Rubber on cheeks PM M3	9023	418	21.6	95.4
Rubber PG M4	17020	3100	5.49	81.8
Rubberized canvas PO M5	11240	3716	3.02	67
Rubberized canvas LPC M4	11720	2513	4.66	78
Rubber PB M4	11800	633	18.63	95
Tyvek material	6240	1371	4.55	78
Tychem material	21010	1545	13.6	93
Rubber PS M3 heavy type	3485	1901	0.55	83
NITRAS gloves	1870	309	6.05	83
Sample type	Decontamination by 1% detergent solution–samples **b**			
	A_o $Bqcm^{-2}$	**A** $Bqcm^{-2}$	**F_d**	**%R**
Rubber on cheeks PM M3	24000	4002	6	83.3
Rubber PG M4	16660	3144	5.30	81.1
Rubberized canvas PO M5	18600	3710	5.01	80
Rubberized canvas LPC M4	/	/	/	/
Rubber PB M4	21200	3200	6.63	84.9
Tyvek material	/	/	/	/
Tychem material	/	/	/	/
Rubber PS M3 heavy type	/	/	/	/
NITRAS gloves	/	/	/	/
Protective hood material	1990	345	5.77	82.7
Protective hood material	12400	2351	5.27	81

The applied method has proven as successful in assessment of efficiency of decontamination of rubber and textile materials and can as such be applied to other surfaces. Earlier research has shown that retention time of contaminants on surfaces has strong impact on efficiency of decontamination. Much higher decontamination efficiency was observed in rubber material samples as opposed to samples of textile materials. Difference in efficiency of decontamination in the examined materials is increasing almost linearly with the increase of time of retaining contaminants on the samples. Analysis of obtained results, after contamination procedures, and subsequent decontamination of samples leads to the conclusion that the highest efficiency of decontamination is displayed by DECON GEL on samples of rubber in cheeks of the mask, with 95,4% and rubber PB with 95% decontamination efficiency. Lower decontamination percentage was achieved by 1% detergent solution, obtaining best results on samples of rubber in mask cheeks with 95% decontaminaton efficiency. Next lower decontamination percentage was achieved by 1% detergent solution, scoring best on samples of rubber in mask cheeks with 83.3%, as well as rubber in PB M4 with 84.9%.

7. CONCLUSION

After use of radioactive contaminants, the decontamination of people, weapons, technical resources, facilities and land should prevent spreading of contamination and, where it has occurred – to reduce it to a permissible level. While reaching the decision on the resources and methods tu be used in decontamination procedures it is important to determine the level of contamination and define the physicochemical form of the contaminant and the contaminated surface. While implementing decontamination procedures one can encounter a problem of detecting low concentrations of contaminants and verifying reduction of their concentration to a permissible level, that is, determining of decontamination efficiency.

This study has defined procedures of decontamination by modern means of decontamination, as well as the efficiency of decontamination on means of personal protection in use, accentuating the impact of ratio between the contaminants and the contaminated surface.

The study compares results obtained by measurements on the subject means of radioactive decontamination. In the following research we need to consider introduction of new means of radioactive decontamination, as modern technologies and methods have shown that there are much more efficient means in the market, as well as means with a wider scope of impact, both in radioactive and chemical decontamination.

References

[1] Glišović, D., *Protivnuklearno, hemijsko i biološko obezbeđenje*, Beograd: SSNO, 1976.

[2] Dobričanin, D.: *Zaštita tela*, Vojnotehnički institut, 2009.

[3] Lazarević, N.: *Dekontaminacija radne i životne sredine*, Beograd, INN "Vinča", 2017.

[4] INN Vinča, *Radioaktivni izotopi i zračenja, knjiga II-Radne tehnike*, Beograd: Institut za nuklearne nauke "Boris Kidrič", 1985.

[5] Vujošević, S., *Obuka za rad sa otvorenim izvorima i osposobljavanje za sprovodjenje mera zaštite u naučnoistraživačkoj delatnosti,* Beograd: Institut za nuklearne nauke "Vinča", INN "Vinča", 2017.

[6] Slivka, J.: *Gama spektrometrija - specijalne metode i primene*, Novi Sad: Univerzitet u Novom sadu, Prirodno -matematički fakultet, 2000.

[7] ORTEC Gamma Vision - 32, Gamma-Ray Spectrum Analysis and MCA Emulator for Microsoft Windows 95, 98, 2000. s.l. : Software User's Manual, 2002.