A comparative analysis of the selected properties of protective filtering masks

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Abstract

The results of comparative experimental testing of different filtering masks are presented in this study. Some of the most important functional properties have been tested on available models of Italian, French, British, Canadian, Swiss, American, and three models of Serbian military protective masks (M3 of the latest generation, as well as M2, and M2FV models of the previous generation). The mask models have been tested on protection factor, dynamic resistance of the exhaust valve and its static permeability, the overall inhalation resistance of protective masks, field of view and optical properties, by standardized testing methods. Based on the experimental results obtained, it can be concluded that the Serbian mask M3 is approximately at the same quality level as tested foreign masks, and above Serbian protective masks of the previous generation marked as M2F and M2FV.

Keywords: respiratory protection, filtrating masks, quality characteristics, inner permeability, field of vision.

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A soldier's personal protective equipment for radiological, chemical and biological (RCB) agents comprises devices that serve to protect his body and respiratory organs [1]. These protective devices, together with other weaponry devices and military equipment, need to be mutually compatible [2]. Respiratory protection is maintained by wearing different types of protective masks, half masks and respirators. A military protective mask is a filtering device which protects the respiratory system, eyes and face of a user from RCB contamination in form of gases, vapour, as well as solid and liquid aerosols [3]. It is also designed to protect a soldier from industrial toxic substances, if used with an appropriate filter.

It is known from experience that manufacturers of weaponry devices and military equipment very often exaggerate the properties of their products for marketing purpose, and it is the same in case of protective masks. Their real properties can be proved only by experimental check of the declared data. Serbian new protective mask M3 (Fig. 1) is expected to be at approximately the same level with the modern armies' IV generation protective masks, in terms of tactical and technical properties.

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This hypothesis can only be proved by comparative experimental testing of its relevant properties in relation to military protective masks of other manufacturers. With this aim, this paper offers results of comparative experimental testing of the most important properties of available models of Italian, French, British, Canadian, Swiss, American and Serbian protective mask.

Figure 1. Serbian military protective mask M3, a product of Trayal Corporation, Kruševac, Serbia.

One of the most important properties of a protective mask is the inner permeability on the face piece's fitting line. Often, instead of the term inner permeability, its reciprocal term – protection factor, is being used. Measured value of inner permeability (protection factor) of a protective mask also involves the exhaust valve permeability. Through values of protection factor, the quality of construction of protective mask is being checked, as well as face piece's airtightness and the quality of its integral elements, thus this property is considered as one of the most important ones.

In this paper, in addition to protection factor, the comparative analysis of the following properties of protective masks and their subsystems has been carried out:

– overall resistance of the mask during exhalation;
– dynamic resistance of the mask's exhaust valve;
– static permeability of the exhaust valve;
– field of view and the most important optical properties.

The aim of this paper is to determine the state of the quality through experimental comparative analysis of the most important properties of the domestic protective mask M3, in relation to available foreign masks, as well as Serbian masks of the previous generation, marked as M2F (phonic) and M2FV (phonic with a subsystem for drinking water) which are in Serbian army's equipment for years.

TEST METHODS

Inner permeability level of protective mask

One of the key parameters for testing the efficacy of the protection mask is monitoring the RBC contaminant aerosol penetration, *i.e.*, determining the inner permeability level of the protective mask. Since the testing with real RBC contaminants in laboratory conditions is a high risk activity, the method of testing with generated aerosols of a non-toxic agents such as sodium chloride, paraffin mist, etc., which simulate the presence of contamination in the air is being used [4–6]. The apparatus, shown schematically in Figure 2, which consists of bellow listed devices and tools, is being applied for testing filtration efficacy of the mask in conditions of contamination:

Inner permeability of the face piece is tested by the method described in literature [7]. Value of inner permeability of face piece, tested by sodium chloride aerosols, for each testing activity must not be more than 2×10^{-2}% per a tester [7]. The mean value of inner permeability of face piece, tested by sodium chloride aerosols, for each testing activity must not be more than 1×10^{-2}% per an examinee [8]. The mean value of face piece's inner permeability, tested on 10 face pieces and 10 examinees according to a defined matrix, using sodium chloride aerosol, must not be more than 4×10^{-2}% [8]. During the comparative quality testing of different protective masks, the protective factor has been measured on: Italian protective mask IMMD (size S), Canadian protective mask C4 (size S), American protective mask M40A1 (size S), Swiss protective mask SM3 (size S), Serbian protective mask M2FV (size S) and Serbian protective mask M3 (size S).

Examinees have been volunteers from the Military Technical Institute. The selection of examinees has been conditioned by the specific head measurement: gnathion-nation (measurement A) and frontal bizygomatic width (measurement B). The protection factor of protective masks has been measured by a standard test [7]. The test comprises seven activities which simulate actions from real life conditions:

– Normal breathing without head movement;
– energetic head movements to the left;
– energetic head movements to the right;
– energetic head movements upward;
– energetic head movements downward (towards the chest);

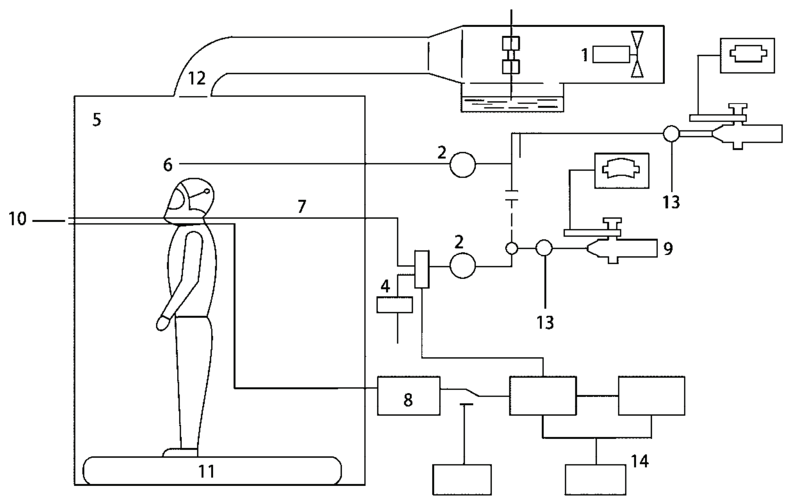

Figure 2. Sodium chloride inner leakage test apparatus. 1. Aerosol generator; 2. pump; 3. valve for sample selection; 4. air filtration filter; 5. testing chamber; 6. aerosol sample from testing chamber C_o; 7. aerosol sample under the mask C_m; 8. pressure sensor; 9. flame photometer; 10. universal filter simulator; 11. treadmill; 12. aerosol inlet; 13. extra air for aerosol dilution; 14. sampling impulse interface.

– Opening and closing the mouth with a deep inhale when the mouth is open to the maximum (hereinafter deep breathing);

– Normal breathing without head movement.

For each test activity the measurement of protective mask factors has been carried out separately and the mean value has been calculated for all examinees.

Total resistance of the protective mask during inhalation has been measured according to the method described in [7]. For measuring total resistance of the protective mask during inhalation, a standard method has been applied, the method which uses a vacuum pump (provides sub-pressure at the flow of 120 dm^3/ /min), flow meter (Rota meter) 0–120 dm^3/min, resistance meter 0–1500 Pa and artificial head with anthropometric dimensions which correspond to the size of the tested protective mask. Before testing the resistance of each protective mask, it is necessary to carefully seal the mask along the fitting line onto the artificial head. Due to the lack of the original filters for all tested protective masks, and thanks to compatibility of the filters of all the mentioned masks, the measurement of resistance of the foreign masks has been carried out by using the American and domestic filters, whereas the Italian protective mask has been tested only with the original filter.

The exhaust valve resistance has been measured according to the method described in [7]. For measuring dynamic resistance of the exhaust valve a standard method has been applied, the method which uses the source of the airflow, flow meter, tray subassembly of the exhaust valve and instruments for measuring the resistance.

The method of static permeability of the subassembly of the exhaust valve is described in the literature [7].

Field of view and optical properties

The field of view means the total spatial extent of stationary sources of visual information that causes irritation of the stationary eye. Total field of view is the field which is obtained by looking with both eyes. Folded or stereoscopic field of view is part of the total field of view which can be seen by one eye. Viewing angle is the angle that is formed by peripheral and central visible beam [7]. The average values of visual angles in the main directions are:

– on the temple: 85°;
– above the temple: 55°;
– above: 45°;
– up on the nose: 55°;
– on the nose: 60°;
– down on the nose: 50°;
– down: 65°;
– down on the temple: 85°.

The flow of the process with the order of activities is described in the literature [9]. Equipment for measuring the field of view comprises apertometer, apertogram and planimeter. The required optical characteristics of protective masks are defined through their tactical and technical requirements, a check is given to the criteria [5,7–10]. Due to the unavailability of these data for the foreign protective mask, tactical and technical requirements for protective mask M3 are to be referred to on this occasion [8]. Ocular transparency to visible light wavelength of 420 to 780 nm must be at least 85%. Spectral transmissions through the oculars in the field of visible light must not deviate more than 5% compared to the average value of the transmission in entire range. Distortion of figure, by passing of visible light through the oculars, must not be greater than ±2%.

The oculars should not have an optical intensity, whereas the following deviations are allowed:

– spherical intensity: ±0.25 Dpt;
– astigmatism: ±0.25 Dpt;
– prismatic effect: ±0.25 PrDpt.

The optical characteristics were studied on the optical bench Salvadoris Firence, Officcine Galileo, Italy manufacturer, with collimator f = 1781 mm, except for the integral transparency in the visible part of spectrum, which was measured on the device "Odeltron", Old Deft USA manufacturer, with photocathode S 20 and green filter for correction of the spectrum to the human eye.

RESULTS AND DISCUSSION

Inner permeability (P) is calculated from aerosol concentration average values in the last 100 s of every test session. Inner permeability expressed in percentage is calculated by using the formula (1):

$$P = \frac{100C_m}{C_o}\frac{t_{\text{in}} + t_{\text{ex}}}{t_{\text{in}}} \qquad (1)$$

C_m – NaCl aerosol concentration under the mask, determinate in the inhalation phase (mg/m^3); C_o – average NaCl aerosol value in the testing chamber (mg/m^3); t_{in} – overall inhalation time (s); t_{ex} – overall exhalation (s).

Results of the calculated mean values of the protection factor for all tested protective masks are shown in Table 1 and Figure 3, where: *PF* (1) – protection factor mean value for normal breathing at the beginning of the testing, *PF* (2) – protection factor mean value for head movements to the left, *PF* (3) – protection factor mean value for head movements to the right, *PF* (4) – protection factor mean value for the upward head movements, *PF* (5) – protection factor mean value for the downward head movements, *PF* (6) – protection factor mean value for deep breathing, *PF* (7) – pro-

Table 1. Protection factor mean values of the tested protective masks

Protection factor	IMMD (S)	M2FV (S)	C4 (S)	SM3 (S)	M40A1 (S)	M3 (S)
PF (1)	141024	43228	96960	58630	≥100000	109213
PF (2)	147911	59832	99550	62725	≥100000	250318
PF (3)	234526	53004	82567	67215	≥100000	92590
PF (4)	216836	52643	86687	67065	≥100000	101349
PF (5)	167453	53613	85247	67930	≥100000	109645
PF (6)	165753	44564	70003	62690	74820	109325
PF (7)	119903	50852	68490	59960	≥100000	89650
PFm	170487	51105	84215	63744	95930	123156

tection factor mean value for normal breathing at the end of testing and *PFm* – protection factor mean value for all test activities of all the examinees.

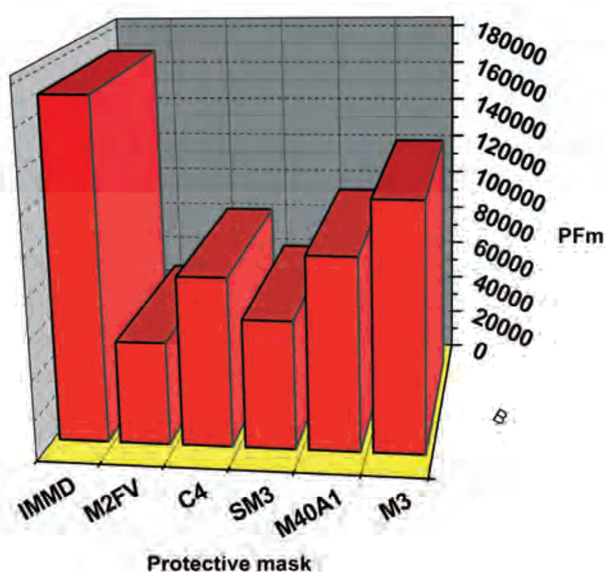

Figure 3. Protection factor mean values of the tested protective masks.

It needs to be pointed out that the number of foreign masks have been limited to one sample per each of the listed, except for the Italian and American (two samples), and number of filters from 1 to 5 pieces. For a valid Quality Score of protective masks in relation to the protection factor, it is needed to have at least 10 protective masks and 30 examinees. Despite the number of foreign masks being insufficient as well as number of measuring, it can still be concluded from the results shown in Table 1 and Figure 3 that the tested protective masks completely fulfil protection factor requirements [8].

During the testing of mask resistance, mostly 4 different airflows have been applied: 30, 60, 90 and 120 dm^3/min, and given results are shown in Figure 4.

By analyzing given results of the total resistance of protective masks during inhaling, it can be concluded that the lowest resistance during inhaling, in complete applied flow range of 30 to 120 dm^3/min, gives Serbian protective mask M3, then Swiss protective mask SM3, and a slightly higher and mutually almost equal, American M40A1 and English AVON S10. The highest level of resistance has been measured in Serbian mask M2FV. It can also be concluded that the resistance during inhalation in all three types of the tested foreign protective masks is higher with domestic than with American filter, which is logical, since the Serbian filter provides higher resistance than the American in total monitored airflow range.

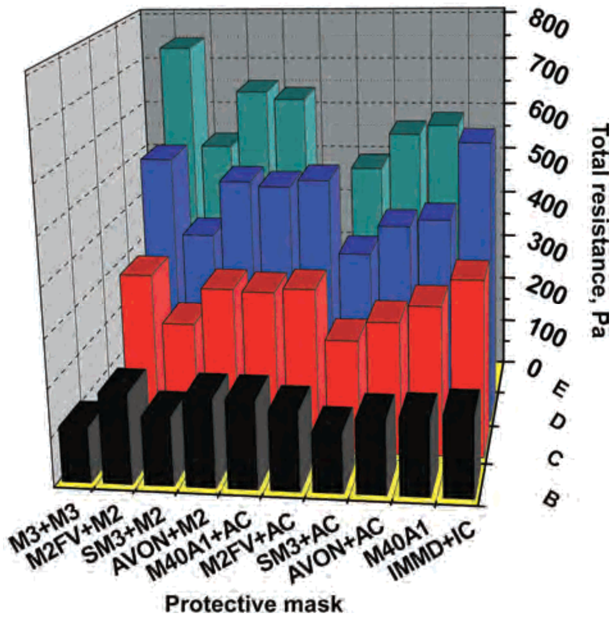

Figure 4. Total resistance during inhalation in tested protective masks IMMD, C4, SM3, M40A1, AVON, M2FV and M3 in combination with different filters at different airflows. B bars: 30 l/min, C bars: 60 l/min, D bars: 90 l/min and E bars: 120 l/min.

Italian protective mask fulfils tactical and technical requirements, which a new generation of protective masks needs to fulfils when it comes to total resistance of protective mask at the flow of 30 dm^3/min, even though it is significantly higher than in Swiss protective masks with the American filter, and somewhat higher

(6–10 %) than in the remained tested protective masks. However, the highest that the mask has been tested on, at the airflow of 90 dm3/min, was the Italian protective mask with the original filter that provided the highest resistance during inhalation, which is a negative property.

The following masks' exhaust valves have been tested simultaneously: Italian IMMD (panorama with transparent face piece and elastomeric border), French ARFA (panorama), English AVON S10, Canadian C4, domestic M2FV and M3. During testing, mostly two different airflows have been applied: 30 and 90 dm^3/min. The results are shown in Table 2.

Table 2. Results of the testing of the dynamic exhaust valve resistance (Pa) of protective masks

Exhaust valve	Flow, dm^3/min		
	30	60	90
IMMD	49.6	81.3	133.9
ARFA	28.4	–	176.6
AVON S10	46.1	–	106.9
C4	78.5	–	206.0
M2FV	52.0	–	133.4
M3	60.4	96.0	123.9

According to the results given in Table 2, it is concluded that the lowest dynamic exhaust valve resistance provide the valve of the French ARFA (panorama) mask at the flow of 30 dm^3/min and English valve AVON S10 at the flow of 60 dm^3/min, whereas the Canadian mask C4 valve provides the highest dynamic resistance at both applied airflows. Dynamic exhaust valve resistance of the Italian protective mask is at the same level as measured in the protective mask M2FV. Considering that in literature [8] is stated that dynamic resistance which has to fulfil the exhaust valve, at the airflow of 30 dm^3/min, is below 70 Pa, from Table 2. It can be concluded that all tested exhaust valve samples fulfil this criteria, except the Canadian protective mask C4.

Static permeability of the exhaust valve has been measured by a method described in literature [8], on IMMD and domestic protective mask M2F, on original apparatus, and Canadian protective mask C4, after the adjustment of exhaust valve's mount on the apparatus. It has been found out that the tested samples fulfil the criteria from [8]. Also, 10 exhaust valve samples of the protective mask M3 have been tested, and it has been found out that there is no static permeability in the time of 30 and 60 s and that according to this parameter they fulfil tactical and technical requirements [8]. Namely, static permeability of the exhaust valve subassembly has to be less than 15 cm^3, when the valve is exposed to the sub pressure of 250 Pa for 30 s. Measurement of static permeability of the exhaust valve in other foreign protective masks (ARFA, AVON S10, M40A1, SM3) couldn't be conducted due to decision according to which the exhaust valve should not be disassembled.

Total field of view with a protective mask M3 on the model of the head must be at least 80%, compared to the total field of view without protective masks [10]. For foreign protective masks this parameter as a tactical–technical data are not available. Field of view is measured on the following protective masks: Italian (IMMD), French (ARFA), British (AVON S10), Canadian (C4), U.S. (M40A1), Swiss (SM3), Serbian (M2F), (M2FV) and (M3). All measurements and processing of the results were performed according to the standard [9]. Measured values of the field of view are shown in Figure 5.

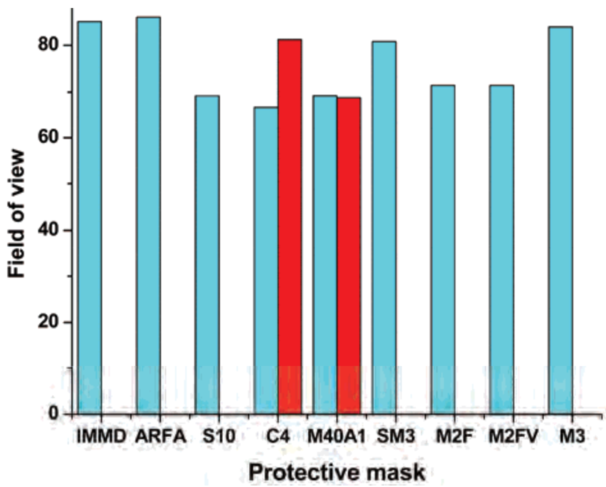

Figure 5. Field of view of tested protective masks. First red bar indicates unclear expanded field of view of C4 mask, and two bars for M40A1 mask represent the results for the basis and protective version of the oculars.

Figure 5 shows that the total field of view of protective mask M3 is 84% and it is greater than the total field of view of protective masks M2F and M2FV, where the value was about 70 %. The value of the total field of view of a protective mask M3 is at approximate level as in some foreign protective masks of IV generation: Swiss mask SM3 (80%), Finish mask M95 (80%), Swedish masks F2 (88%), and better than field of view measured at S10 (69.2%), C4 (66.7 %) and M40A1 (69.2%).

Comparing the results in Fig. 5 it was observed that the protective masks marked IMMD, ARFA and SM3 have bigger fields than others. Protective masks IMMD and ARFA are panorama type, so bigger field of view was expected. Increased field of protective mask SM3 is probably result of its small size, which is incompatible with the size of the artificial head which is used to determine field of view of mid-sized protective mask on the existing apparatus, and from that point the obtained result is unreliable and may be rejected. In C4 protective mask oculars are a specific form of "cup", where in Fig. 5 unclear field of view is indicated (only unclear contours of the characters can be seen from the sides).

In M40A1 protective mask (Fig. 5) clearly shows the result of measuring of field of view with basic and protective ocular which is used for protection against mechanical damages and sunlight. Based on the results obtained from these measurements, it can be concluded that the literature data for the field of view, for some foreign protective masks that are not panorama type (*e.g.*, C4-field of view greater than 90%), are of marketing character and unrealistic.

The results of measuring optical properties of the oculars are shown in Table 3 and include determination of:

– integral transparency in the whole visible spectrum, *T* (%);
– spherical optical intensity, *P* (D_pt);
– astigmatism, *A* (D_pt);
– prismatic or cornering light beam, *D* (P_rD_pt);
– distortion of image, *Dist* (%).

Based on these results we can conclude that the oculars of all tested protective masks have satisfying transparency (except flexible polyurethane mask type panorama (ARFA) and satisfying optical characteristics, except for oculars of the American protective masks, which have a great value for deflecting a light beam, which causes deformation of the image. Comparative study of materials, components and complete foreign and domestic protective masks, enabled to reach quantitative indicators to compare their characteristics and evaluate and fulfil mounted tactical and technical requirements for protective mask M3 (all of this is done under the same experimental conditions). Number of foreign masks was limited to one sample of medium size, except the Italian (two samples). Due to the limited number of samples, obtained results are accepted with some caution. Despite these problems, the results were used to perform certain conclusions. It was found that the Italian and French masks have the largest field of view, which was expected since both are the panorama type. Among binocular protective masks, Swiss SM3 has the largest field of view. These protective masks satisfy mounted tactical and technical requirement for the field of view of protective mask M3.

By construction of protective mask M3 face piece, *i.e.*, by installation of two small valves in the nasal insert, steady flow of air into interior of nasal insert is enabled, as well as better evanescent of oculars by separation of the hot and cold air.

CONCLUSION

Serbian protective mask M3 has significant improvements compared to Serbian masks of previous generations, M2F and M2FV, in the field of RCB agent protection, as well as in terms of being comfortable to wear. Protective mask M3 has been improved in terms of material quality by choosing brombuthyl rubber instead of natural rubber for making the face piece and nasal inset, then by choosing the natural rubber for making the inhalation and exhaust valve and transparent single-layered polycarbonate for making the ocular (eyepiece). By inserting new subassemblies, its functions are enriched. For example, by getting a new construction of the subassembly of the exhaust valve and its mount, a more reliable work and better hermetic have been achieved, which can be seen from the given results of measuring the protection factor. System of elastic straps at the top of the head of protective mask M3 provides evenly fitting, which also helps improve the masks hermetic.

The field of view of the protective mask M3 is 84% and it is at the level of the latest protective masks generation IV, and is significantly higher in relation to the protective mask M2F and M2FV, where the value is 70%. Based on the obtained results of optical properties testing, it can be concluded that the protective mask M3 oculars and all other investigated protective masks, have satisfying transparency (except flexible polyurethane mask type panorama ARFA) and satisfying optical characteristics (except oculars of American protective mask which has a great value for deflecting a light beam, which causes deformation of the image).

Table 3. Oculars' optical characteristics of foreign and domestic protective masks

Characteristic	*T* / %	*P* (D_pt)	*A* (D_pt)	*D* (P_rD_pt)	*Dist* / %
M40A1	89	0	0	1.3	0
Protective glass M40A1	91	0	0	0	0
M40A and protective glass M40A1	82	-	-	1,3	0
C4	89	0	0	0.14	0
M2F, M2FV	89	-0.25	0.25	0.20	0
M3	96	≤ 0.1	≤ 0.1	≤ 0-8	0
AVON S10	91	0	0	0.58	0
ARFA	83	0	0	0.29	0

The increase of protective mask M3 total comfort is achieved by a new construction of face piece body and nasal implant, by new constructional solution to tighten the mask's strap system on the users head and by new construction and selection of the oculars position on mask's face piece body. The functions of protective masks M3 have expanded by addition of a new filters carrier subassembly, on the right side, which allows more efficient use of mask for left-handed users with targeting, by addition of correction glasses carrier for users with impaired vision and the addition of auxiliary voice membrane for better voice transmission in the use of means of communication. The possibility of using combined filters on the left and right side, and possibility of correction glasses usage significantly facilitates the performance of users' combat actions, especially left-handed persons' and those with weaker eyesight.

Protective mask M3 fulfils all the requirements of tactical and technical quality and in this sense represents a significant improvement in relation to the Serbian military protective masks of previous generations, marked M2F and M2FV. According to their optical and total characteristics, protective mask M3 is at the level of most modern devices of personal respiratory protection generation IV.

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IZVOD

UPOREDNA ANALIZA ODABRANIH KARAKTERISTIKA ZAŠTITNIH MASKI FILTRIRAJUĆEG TIPA

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(Stručni rad)

U radu su prikazani eksperimentalni rezultati komparativnih ispitivanja određenih modela zaštitnih maski na principu filtracije vazduha. Osnovne funkcionalne karakteristike zaštitnih maski potrebne za ocenjivanje njihovog kvaliteta, testirane su na modelima italijanske, francuske, britanske, švajcarske i američke proizvodnje, kao i na tri modela vojnih zaštitnih maski domaće proizvodnje (model M3 najnovije generacije i modeli M2 i M2FV prethodne generacije). Primenom standardizovanih metoda ispitivanja, dostupni modeli zaštitnih maski testirani su na faktor zaštite, dinamički otpor i statičku propustljivost ventila izdisaja, ukupan otpor pri udisaju, karakteristike vidnog polja i optička svojstva. Na osnovu rezulata ispitivanja, može se zaključiti da je zaštitna maska M3 na približnom nivou kvaliteta sa testiranim modelima sa inostranog tržišta i značajno višeg kvaliteta u odnosu na modele ranije generacije M2 i M2FV.

Ključne reči: Respiratorna zaštita • Filtrirajuće maske • Karakteristike kvaliteta • Unutrašnje propuštanje • Polje vida