Investigation of the possibilities for the use of new items in the equipment for fire extinguishing in critical infrastructure sites

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Summary: *The report examines the possibilities for using new modern elements, materials and their combination in the equipment for personal protective equipment of employees from fire safety and civil protection, part of the unified rescue system, in case of accidents in critical infrastructure.*
KEY WORDS*: FIRE SAFETY, PERSONAL PROTECTIVE EQUIPMENT*

1. Introduction

With the development of technologies, the production, storage and use of substances with different physical and chemical properties, leads immensely to higher requirements for the protection of fire safety personnel involved in the reduction and elimination of accidents caused by fires [1-4].
The world's leading and economically developed countries have specific requirements for the equipment of fire safety officers depending on the nature of the incident.

For example, in the National Fire Protection Association (NFPA) in the United States as a global self-funded non-profit organization, established in 1896, dedicated to preventing death, injury, property and economic loss due to fires, electrical and associated hazards, has introduced a series of standards in the field. Regarding the personal protective equipment of the firefighter, the classification NFPA 1994, Standard for protective ensembles for the first response to the events for the fight against terrorism of the chemical, biological, radioactive and nuclear (CBRN) has been introduced.

It sets out design, certification and minimum requirements for the implementation of CBRN safeguards for the first response to CBRN incidents. Terrorism agents and first responders exposed to victims or materials during assessment, eviction, rescue, triage, decontamination, treatment, site security, crowd management and incident protection operations involving terrorism agents. Within the NFPA protective clothing project, protective equipment is designed to provide full body protection; torso, hands, legs, head, arms and feet. All NFPA 1994 clothing is worn with air breathing apparatus.

Despite the variety of personal protective clothing determined depending on the specifics of each case of fire or disaster, this report will conduct a theoretical study of the possibilities of using new modern elements, materials and their combination. Equipment consisting of personal protective equipment and clothing is classified into four levels, namely protective clothing for firefighters used in general firefighting activities to protect against heat, pollution, wetting, wind and other harmful effects.

A problem addressed in this report is the lack of a unified model of protective clothing depending on the type of protection, the shape of the clothing, so as to provide versatile protection of the body and to be comfortable to use.

Table № 1 presents the NFPA protection class of the firefighter's personal protective equipment.

Protective clothing for firefighters must provide the highest possible level of protection. In their design, in addition to the level of protection, the comfort of wearing must be taken into account, there must be freedom of movement when performing the relevant fire-fighting and rescue activities under the foreseeable conditions of use [5-7].
Protective clothing for firefighters must be designed and manufactured in such a way as to exclude the possibility of risks and other undesirable effects under the foreseeable conditions of use.

The materials from which protective clothing for firefighters and their parts are made, including decomposition products, must not have a detrimental effect on the hygiene and health of the firefighter.

NFPA Protective Ensemble Class	Level of Skin Protection	Level of Respiratory Protection	Notes Concerning Use
1 Class (most protective) Level A equivalent	Protective ensemble totally encapsulates wearer **and** respiratory protective equipment	Mandatory use of NIOSH-certified CBRN self-contained breathing apparatus (SCBA)	Establishes minimum level of protection for first responders against: • Toxic vapors, liquids, and particulates during hazardous materials incidents • Specific chemical and biological terrorism agents in vapor, liquid-splash, and particulate environments during CBRN terrorism incidents
2 Class Level B equivalent		Requires use of NIOSH-certified CBRN self-contained breathing apparatus (SCBA)	For use in terrorism incidents involving vapor or liquid chemical or particulate hazards where concentrations are **at or above** levels immediately dangerous to life or health
3 Class - Level C equivalent		Requires use of NIOSH-certified CBRN air-purifying respirators (APRs) or NIOSH-certified CBRN powered air-purifying respirators (PAPRs)	For use in terrorism incidents involving low levels of vapor or liquid chemical hazards where concentrations are **below** levels immediately dangerous to life or health

4 Class (least protective) Gallery - Level D equivalent	Ensembles not tested for protection against chemical vapor or liquid permeability, gas-tightness, liquid integrity	Permits use of NIOSH-certified CBRN air-purifying respirators (APRs) or NIOSH-certified CBRN powered air-purifying respirators (PAPRs)	For use in terrorism incidents involving biological or radiological particulate hazards only where the concentrations are **below** levels immediately dangerous to life or health

The surfaces of any part of the protective clothing for firefighters which are or may come into contact with the firefighter during use must not be rough or have sharp edges and protrusions which could cause severe irritation or injury to the firefighter during of operation of clothing

Protective clothing for firefighters must, to the least extent, impede movement, occupy various positions of the body and must not cause movements that would endanger the firefighter using the clothing or his colleague working near him.

Protective clothing for firefighters must be designed and manufactured in such a way that:

- be placed as very easily and tightly as possible on the body of the firefighter and remain in place throughout the period of work them, taking into account the high temperature, adverse environmental conditions, movements and positions of the body of the firefighter.
- allow possibilities for their adaptation to the morphology of the firefighter by all appropriate means, such as adjustment and fastening devices or by a sufficient variety of sizes.

Protective clothing for firefighters must be as light as possible without affecting the strength of their construction and their effectiveness when working in or around places with high temperatures and humidity. They must also be strong enough to withstand the harmful effects of direct fire and work in areas with high temperature levels, as well as to meet the additional requirements associated with specific risks. In addition, protective clothing for firefighters must have high-visibility reflective strips.

The main current normative act for determining the requirements for protective clothing for firefighters is the Bulgarian State Standard (BDS) Euronorm (EN) 469 [8]. This European Standard specifies minimum levels of requirements for the performance of protective clothing used in firefighting operations and related activities, such as rescue and disaster relief operations. This clothing does not provide sufficient protection during operational actions related to cleaning of released chemical products and gases

This European Standard includes general requirements for the performance of clothing, minimum performance levels of the materials used, as well as test methods to be used in determining these performance levels. The required levels of performance can be achieved by using one or more garments.

Protective clothing for firefighters must be made of waterproof products and heat-resistant materials, providing protection against penetration of water, heat, flame, sparks and cold to the body of the firefighter. It (on the inside) must bear the pictograms required by the standard, including the CE marking, proving its intended use as a personal protective equipment for firefighters.

Protective clothing for firefighters must be able to remove moisture from the body of the firefighter, because under intense stress a person's body reaches a state of profuse sweating. They must also allow easy and quick dressing and undressing, given the nature of the work and the fact that every second lost is valuable. It should not be forgotten, however, that they must also have a level of protection under current legislation [8].

As garments are directly exposed to all kinds of dirt, they must be designed to be washed in washing machines at a certain water temperature and/or by dry cleaning, without damaging their protective functions, reflective strips or in general to damage the integrity of protective clothing for firefighters.

The tensile strength of the outer material of the garment when tested in the longitudinal and transverse directions must not exceed that specified in the Standard "Protective clothing for firefighters. Requirements for the implementation of protective clothing for firefighting "[8]. Respectively, the tensile strength of the seams of the main connecting seams of the outer material of the garment must not be less than that specified in the same standard. Torn resistance of the outer material of the garment in the longitudinal and transverse direction must also comply with the standard

Protective clothing for firefighters must not change their dimensions (longitudinally and transversely), regardless of the number of cleanings, with a coefficient clearly specified in the standard [8]. They must have good abrasion resistance, which does not allow rapid disintegration of the outer tissue and fibrous balls on the surface of the outer fabric. All materials used and clothing in general must have the necessary durability, be easy to clean and wash (by hand and in washing machines).

Protective clothing for firefighters must be multi-layered and consist of:

- Outer layer - must be made of materials with high thermal protection and antistatic fibers in proportions specified again in the standard [8].
- Intermediate layer - flame retardant breathable membrane, protecting from the penetration of liquids.
- Lining - insulation of flame retardant stitched material. [9-11].

The type and cut of the models must be consistent so as to ensure a higher degree of protection from more harmful factors and to provide good freedom and comfort when moving. The garments must be service-resistant and reusable. Which in turn requires new engineering solutions regarding the type of materials used to make the garments.

The development of technologies, respectively, affects the materials from which the clothes of firefighters are made, as there is a tendency to increase the use of technical textiles, due to the possibility of "property management".

The use of technical textiles is growing from year to year and the companies of the highly developed countries are entering the production of technical textiles more and more intensively.

A very important property of technical textiles, especially for fire-resistant clothing, is its limited oxygen index (LOI) - the percentage of oxygen in the environment than the flame. This property is very important for organic textiles, which are used near a source of flame - clothing for firefighters. The LOI has been introduced into the international standardization organization ISO through the ISO 4598-2 Limited Oxygen Index.

Fibers with a LOI of more than 23 are fire-resistant in a normal environment (after elimination of the flame source they are extinguished). On the other hand, the LOI of paraaramide and metaaramide are the same, but the flammability of the tissues of these fibers is different and depends not only on the nature of the fibers of the stock, but also on the parameters of the tissue structure (weaving, linear densities and thread set) also [12].

The most important of the mechanical properties of fabrics for protective clothing against heat and fire are tear strength, air permeability and surface density. There are many fabric structures that are used to make fireproof clothing. These fabrics differ in the percentage of meta- and para-aramid fibers, in the linear density of the yarns, in groups, in the surface density, and so on.Thus, they are produced not only from different meta-aramid yarns ("Nomex", "Kermel", "Conex"), but also have different fabrics - each company "Du Pont", "Akzo Nobel", "Rhone - Poulenc", "Teijin" and others) for fire-resistant clothing for the production of proposed own fabrics. Table №2 shows the main characteristics of various meta-aramid fabrics used to make protective for firefighters.

***Table №2** - some characteristics of metaaramid tissues*

Property	Nomex III twill 3/1	Nomex Delta TA twill 3/1	Kermel HTA ripstop	Teijinconex Xfireplain
Percent compositio n,%	Nomex – 95 paraaramid–5	Nomex – 75 paraaramid– 23 carbon – 2	Kermel–64 paraaramid–36	Conex – 90 paraaramid–10
Superficial density, g / m^2	**265**	**205**	**200**	**210**
Tensile strength N Based on On the fabric	1440 1250	1080 1045	2000 2000	1400 1200
Tear strength, N Based on On the fabric	56 60	46 49	200 200	140 120
Thread length, mm	10	13	5	10
LOI [%]	28	28	30-32	30

The fabric characteristics presented in Table 2 suggest that the fabrics used differ not only in structure but also in end-use properties. Protective clothing for firefighters according to standard EN 469 is designed to protect the body by excluding the head, arms and legs from the effects of heat and flame, as well as to prevent the ingress of water from the outside, but must also be breathable.

Studies have shown that various attempts have been made to prove the fire-retardant properties of metaaramid tissues, Fig.1

***Fig.1** Mannequins dressed with "Nomex" for test in a camera*

For example, the company "DU PONT" publishes the following results:

The experiment was performed in a chamber, on a male mannequin, equipped with 122 heat sensors located over the entire surface. The manikin was exposed to an abundant flame (intensity of thermal radiation 2 cal / cm2 / s, corresponding to 84kW / m2) on all sides for 4 seconds (simulation of an explosion in an airfield).

On the first attempt, the mannequin was dressed:

- outerwear - flying overalls made of cotton fabric with an area of 335 g / m2;
- underwear - summer type cotton underwear (T-shirts with short sleeves and shorts with short legs) made of fabric with an area of 170 g / m2.

As a result of the impact of the flame on the mannequin, the sensors have detected temperatures that cause the following damage:

- 2nd degree of burning - on 57% of the total area of the mannequin;
- 3rd degree of burning - 16% of the total area of the mannequin.

The total area of lesions in this experiment was 73%, Fig.2

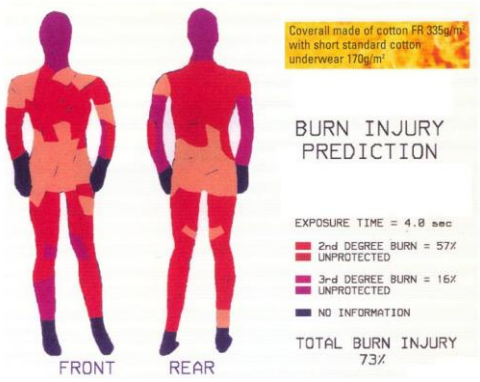

***Fig.2** First attempt, burn rate*

On the second attempt, the mannequin was dressed:

- outerwear - flying overalls made of cotton fabric with an area of 335 g / m2;
- underwear - winter type cotton underwear (T-shirts with long sleeves and long leg pants) made of fabric with an area of 170 g / m2.

As a result of the impact of the flame on the mannequin, the sensors have detected temperatures at which the following damage is caused:

- 2nd degree of burning - on 48% of the total area of the manikin;
- 3rd degree of burning - 8% of the total area of the manikin.

The total area of lesions in this experiment was **57%**, Fig.3

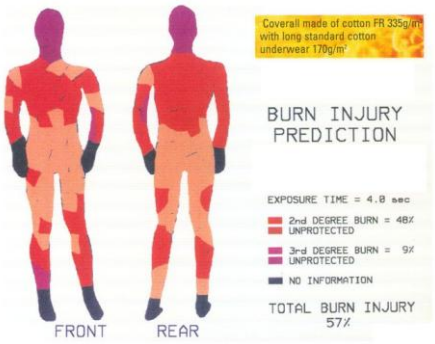

***Fig.3** Second attempt, burn rate*

On the third attempt, the mannequin was dressed:

- outerwear - flying non-combustible overalls made of metaaramid fabric with an area of 150 g / m2;
- underwear - non-combustible winter type underwear made of a mixture of meta-aramid fabric and viscose FR (long-sleeved T-shirts and long-legged pants) made of non-combustible fabric with an area of 170 g / m^2.

As a result of the impact of the flame on the manikin, the sensors have detected temperatures at which the following damage is caused:

- 2nd degree of burning - on 6% of the total area of the manikin;

- 3rd degree of burning - 7% of the total area of the manikin. The total area of lesions in this experiment is 13%, Fig.4

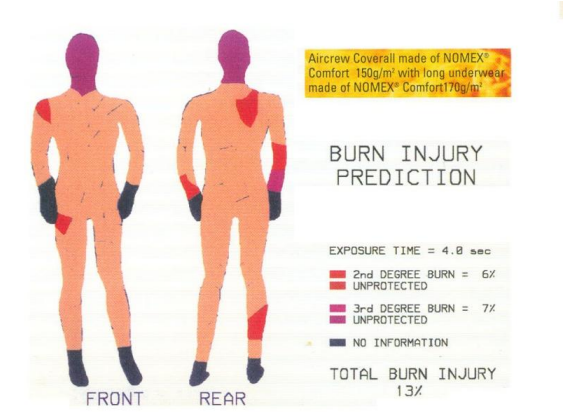

Fig. 4. *Third attempt, burn rate*

Other experiments were performed with a thermo-mannequin wearing only clothing made of fabric, which has a composition of a mixture of metaaramide and viscose "FR" with an area of 220 g / m^2. It is placed in a chamber in which the occurrence of a fire explosion is simulated. The mannequin was exposed to fire for 4 seconds.

The result showed that a human body placed under these conditions would receive 33% 2nd degree burns and 5% 3rd degree burns. The total affected areas of the human body can reach up to 38%.

The obtained results refer to used metaaramid fabrics with an area mass of 170-220 g / m^2. The same properties are possessed by the non-flammable jersey from a mixture of metaaramide and viscose FR, which provides greater comfort and a better feeling of softness. Studies have shown that it is more comfortable to make underwear. Its surface mass is about 280 g / m^2.

3. Conclusions

The analysis of fire-resistant fibers shows that the flammability of the fabrics of these fibers is different and depends not only on the nature of the fibers, but also on the parameters of the fabric structure. The end-use properties of the various meta-aramid fabrics used in the world as an exterior fabric by firefighters are also different.

The analysis of the characteristics of various protective clothing intended for firefighters used in the world shows that the most promising are clothing consisting of two layers:

- external fire-resistant fabric and at the same time with an internal breathable layer for protection against water penetration from the outside,

- a second inner tissue with a layer resistant to heat

4 . Literature

1.Petkov SP "Model for the formation of high-speed elongated striking elements" 2008Sp. “Engineering Sciences”, book 3/2008, BAS-IMet, ISSN 1312-5703

2.Petkov SP Mathematical model for the interaction of the cumulative jet in dynamic protection, 2008, Engineering Sciences Magazine, book 4/2008, BAS-IMet, ISSN 1312-5704

3. Baranov VL, Petkov SP, "Modeling the behavior of metals under high-speed shock load" 2005, Magazine. "Engineering Sciences", vol. 3/2005 year XLII, 41-48 pp., Sofia, BAS-IMet, ISSN 1312-5702

4.Petkov SP "Features of the interaction of the cumulative jet with active elements of dynamic protection" 2009 Magazine. “Engineering Sciences”, book 1/2009, BAS-IMet, ISSN 1312-5702.

5. Yaneva S. Ergonomic requirements to the individual equipment of the anti-terrorist, used in critical infrastructure sites. IV International scientific technical conference. Technics. Technologies. Education. Safety'17, Proceedings, Issue 1 (1), Sofia, Bulgaria 2017, Volume 1, Military sciences and national security, Scientific technical union of mechanical engineering “Industry-4.0” June 2017, ISSN 2535-0315 (print), ISSN 2535 -0315 (online), pp.70-71

6. Yaneva S., Materials used in the means for individual ballistic protection. Analysis, advantages and disadvantages, International Scientific Conference "Asymmetric threats, hybrid wars and their impact on national security", March 16, 2018, New Bulgarian University, Department of National and International Security, Proceedings, Publisher: NTS in Mechanical Engineering Industry-4.0, ISBN 978-619-7383-09-6, pp.439-447 15.

7.Vasileva P., M.Sc. eng. Yaneva S. PhD, Analysis and evaluation of the EU action plan to enhance preparedness against chemical, biological, radiological and nuclear security risk and the national program for its implementation, III International Scientific Conference "High Technologies. Business. Society 2018", 12-15.03.2018, winter resort „Borovets”, Bulgaria, Proceedings, Year II, ISSUE 2 (4), Sofia, Bulgaria 2018, Volume II “Business. Society”, ISSN 2535-0005(print), ISSN 2535-0013 (online), Publisher: Scientific Technical Union Of Mechanical Engineering, Industry-4.0, p. 199-201. Published: INTERNATIONAL SCIENTIFIC JOURNAL “SCIENCE. BUSINESS. SOCIETY”, Year 3, Issue 1/2018, ISSN PRINT 2367-8380 и ISSN WEB 2534-8485, p.35-37. Publisher: Scientific Technical Union of Mechanical Engineering, Industry-4.0

8. BDS EN 469: 2005 / A1: 2006. "Protective clothing for firefighters. Requirements for implementation of protective clothing for firefighting ”;

9. Achtsnit, H.-D. Heat Protection Textiles Manufactured from Textile Silica Sliver Technical Textiles 2 1995: pp. 19 – 20.

10. Bristol Uniforms, Dusseldorf, 2001 (in German).

11. Fire Protection “Model Hamburg”, Sachsische Schutzkleidung, Zwenkau, 2001 (in German)

12.ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 9, No. 4. 2003 Investigation of End-use Properties of Fabrics From Metaaramid Yarns .