Scientific Journal of the Military University of Land Forces
ISSN: 2544-7122 - print, 2545-0719 - online
2018, Volume 50, Number 2(188), Pages 88-104
DOI: 10.5604/01.3001.0012.2493

Original article

Analysis of means of personal protection for rescuers during incidents involving radioactive materials

Bozena Kukfisz**, *Marzena Polka
Main School of Fire Service (SGSP), Warsaw, Poland,
bkukfisz@sgsp.edu.pl, mpolka@sgsp.edu.pl

INFORMATIONS

Article history:
Submited: 11 November 2017
Accepted: 21 February 2018
Published: 30 June 2018

ABSTRACT

During firefighting and rescue operations there is a high probability that rescuers will come into contact with ionizing radiation and radiation contamination. The firemen of the State Fire Service and the Volunteer Fire Service perform a number of tasks during the action [Obwieszczenie Marszałka Sejmu… 2009], for which they are prepared during exercises and theoretical sessions. A significant reduction in the probability of radiation or radiation contamination risk can be achieved by taking appropriate precautions and following certain rules and procedures. The actions at which ionizing radiation occurs take place very rarely and procedures are regulated by the "Rules of conduct in the event of radiation risk" [Komenda Główna… 2009] annexed to the "Rules of the organization of chemical and environmental rescue in the National Firefighting and Rescue System" [Komenda Główna… 2013]. The aim of this article is to present the possibilities of protecting the rescue team during fire and rescue operations associated with the potential presence of radioactive materials at the scene.

* Corresponding author

KEYWORDS

radiological protection, fire safety

1. Radiation hazards and effects

The issue of occupational safety related to nuclear research and technology is not typical and differs in each field. Hazards connected with radiation can be less obvious and completely imperceptible. Radiation that may have lethal effects can be unnoticeable to a person exposed to it. When relatively small doses are received over a long period of time the first symptoms in the form of irreversible pathological changes can occur after many years.

At present, no nuclear power plant has been built in Poland, but around our borders (within a radius of up to 310 km) ten power plants operate on the basis of nuclear fuel. The only research reactor in Poland, water-cooled, pool-type, with the power of 30 MW, operates in Narodowe Centrum Badań Jądrowych (National Centre for Nuclear

Research) in Świerk. The “MARIA” reactor is used for material irradiation to produce radioactive preparations, for physical tests, crystal exposure and silica doping, and for training purposes. Two centres are related to the reactor, Ośrodek Badawczo-Rozwojowy Izotopów (OBRI, Research and Development Centre for Radioisotopes) in Świerk, dealing with the production and distribution of radioactive materials, and Zakład Unieszkodliwiania Odpadów Promieniotwórczych (ZUOP, Radioactive Waste Disposal Plant), dealing with the disposal of radioactive materials. Krajowa Składnica Odpadów Promieniotwórczych (KSOP, National Storage of Radioactive Waste) in Różan is a subordinate unit of ZUOP.

Table 1. Organisational units whose activity involves exposure to ionising radiation (as at 31 December 2014) [Panstwowa Agencja…]

Organisational units (by type of activity)	Number of units and symbol of activity	
Laboratory class I	1	I
Laboratory class II	92	II
Laboratory class III	115	III
Laboratory class Z	100	Z
Fitter of radioisotope detectors	373	UIC
Fitter of equipment	162	UIA
Isotopic equipment	552	AKP
Production of radioisotope sources and equipment	27	PRO
Trading in radioisotope sources and equipment	67	DYS
Accelerator	72	AKC
Radioisotope applicators	35	APL
Telegamma therapy	5	TLG
Radiation equipment	36	URD
Gamma ray projector	112	DEF
Storage of radioisotope sources	50	MAG
Works with the sources in the field	47	TER
Transport of sources or waste	475	TRN
Chromatograph	228	CHR
Veterinary X-ray machine	868	RTW
X-ray scanner	416	RTS
X-ray flaw detector	207	RTD
Other X-ray equipment	360	RTG

In Poland many institutions make use of radioactive materials (Table 1 presents their organisational units by type of activity). A wide use of radioisotopes causes that there is a probability of incidents involving radioactive materials. It can be exemplified by visits of the dosimetry team which comes into play when radiation has been detected by dosimetry instruments or a radioactive source has been found.

Table 2. Visits of the dosimetry team of the PAA (National Atomic Energy Agency) President to the sites of radiation incidents in 2014 [Panstwowa Agencja…]

Visits of the dosimetry team concerned:	Number of visits
activation of a radiological gate at the border crossing	7
finding a radioactive source in a place accessible to the public	1
presence of radioactive substances in the metal scrap	3
identification of a device that shows increased radioactivity	1
Total	12

A considerably high number of units whose activity involves exposure to ionising radiation and the fact that interventions concerning radioactive materials take place from time to time do not mean that people should feel more at risk. However, if the basic safety rules are not observed, radiation, although apparently invisible and imperceptible, may have certain consequences. In the situation where radionuclides penetrate into the environment the effects can be very harmful and the forms of life exposed to radioactive contamination may even be destroyed.

Situations in which radiological protection cannot be easily ensured include fires or other emergencies. As a result, rescuers taking part in fire and rescue operations are exposed to the hazard to the greatest extent. Firemen working in the area of radiological exposure are subject to two types of direct hazard: irradiation hazard and radioactive contamination. The phenomenon of irradiation can be external or internal. External irradiation consists in absorbing ionising radiation by the human body or its part. Such hazard occurs when the source of radiation is located outside the human organism, at a certain distance or behind the shield. Under normal operating conditions of strong sources, even shielded, an external hazard occurs as well. Preventive activities, being a part of radiological protection, aim at reducing this exposure to the minimum level, however, in the case of a failure it is not simple.

Internal irradiation is related to the issue of radioactive contamination and it occurs when a radioisotope is absorbed by the organism. Under normal operating conditions open sources can release radioactive substances. In such cases the operating conditions are strictly determined, whereas in emergency situations the dimensions and quantity of contaminating substance are significantly exceeded in comparison to normal conditions. Such contamination can be transferred in the form of dust, vapour or aerosol and then it is deposited on different surfaces. Superficial contamination, as the name itself suggests, concerns surfaces and, thus, also the rescue equipment, protective clothing, shoes, room furnishing and the skin. When it is released outside the contained space, also soil and underground water will become contaminated. Depending on the surface and substance properties, the resulting contamination may be:

– non-fixed – contamination can be eliminated with the use of simple methods and measures (e.g. washing),
– fixed – contaminating substance is permanently bound to the substrate, as a result of a reaction taking place between them or as a result of soaking, which makes it necessary to remove the contaminated layer mechanically (e.g. hacking).

In practice, complex cases are most often encountered. A certain amount of substance is removed by washing, whereas the rest remains in the form of fixed contamination. Air contamination caused by the release of vapours, aerosols and dusts and formed in the products of combustion of such materials can be another example. When a radioisotope has been absorbed, it is deposited in the organism and produces adverse effects.

In cellular structures penetrated by radioactive particles or energy quanta there occur atom ionisation, water radiolysis and changes in the permeability of cell membranes. Furthermore, the DNA chain is subject to damage, which leads to chromosome mutations. Biological consequences of radiation are related to the size of the received dose and its distribution over time and to the sensitivity of tissues to irradiation. Lymphatic and haematopoietic tissues, gametes and intestinal mucosa are most sensitive, and the effects can occur after several or several dozen years.

Table 3. Equivalent dose thresholds for some deterministic effects [Politechnika Warszawska…]

Tissue	Effect	Dose threshold [Sv]
Testicles	temporary sterility	0.15
	permanent sterility	3.5-6
Ovaries	sterility	2.5-6
Eye lens	detectable cloudiness	0.5-2
	vision impairment (cataract)	5
Bone marrow	impaired haematopoiesis	5
Skin	erythema, dry desquamation	3-5
	moist desquamation	20
	necrosis of epidermis and dermis	50

When the whole body has been irradiated with a dose higher than 1 Sv the following pathological syndromes may develop:

– encephalic syndrome – the effect of a dose exceeding 10 Sv. It results in death and its signs resemble meningitis,
– radiation-induced haematopoietic system damage – irradiation of the whole body with a dose of approx. 4 Sv. At first, vomiting and nausea occur and after several days of well-being the bone marrow and the lymphatic system fail. Painful ulceration occurs on the skin and after about three weeks the hair starts to come out. The loss of immunity results in infections that accelerate

the occurrence of death. In the case of lower doses the regeneration of bone marrow is possible, up to complete recovery,

– gastrointestinal syndrome – induced by lower doses. As a result of very serious dehydration and acute peripheral circulatory failure the irradiated person may die.

Furthermore, irradiation can cause damage to the eye lens, the consequence of which is a cataract. The effects of radiation on the gonads include possible infertility and irradiation during the early months of pregnancy may cause miscarriages and subsequent damage to a foetus. The absorption of radioactive substances by inhalation results in interstitial pulmonary fibrosis and even in the development of bronchial carcinoma. Radioactive substances penetrating to the bones result in necrosis and problems in the process of bone regeneration, which, in consequence, is conducive to the occurrence of fractures. If during the rescue operations that concern incidents involving radioactive materials the basic rules are not followed, the effects may be observed only in the future generations.

2. Radiological protection

According to the National Atomic Energy Agency, radiological protection includes all issues related to the protection of people and the environment from harmful effects of ionising radiation. Radiological protection consists of legal regulations, inspection system, methodology for emergency management, training and prevention. The beginning of research on the properties of ionising radiation led to the conclusion that the lack of proper control and protection may pose a huge threat to human health. Subsequent research showed the rules of protection from radiation to be followed. All rules, procedures and regulations for the safety whilst handling radioisotopes have been collected by radiological protection. Radiological protection comprises actions and measures aimed at preventing exposure of people and the environment to ionising radiation, and in the situation where there are no solutions to protect from this exposure, actions aimed at limiting the adverse effects of such radiation on the health of future generations. ALARA (As Low As Reasonably Achievable) is the basic rule, i.e. “the further you stay, the safer you are and the shorter the exposure is, the lower dose of radiation is delivered, use shields”.

Radiological protection covers only these types of sources and situations that can be subject to regulation. Protection from ionising radiation may not restrict the effects of radiation from such sources as natural radionuclides contained in the human organism or cosmic radiation. In the human environment there are many sources of ionising radiation, which induce constant irradiation of live organisms. The current radiological protection is based on two systems:

– licensing and supervision,

– dose reduction.

In line with the requirements of the licensing system the acquisition, possession, use and disposal of radioactive substances are allowed only for strictly defined purposes, at the appropriately protected places and by authorised persons exclusively. The dose reduction system involves the following: limiting the use of ionising radiation sources to justified cases only, improving protection from radiation and observing the regulations concerning the so-called dose limits.

The measures used by radiological protection include: permanent shields with the thickness satisfying the requirements of radiological protection (additionally confirmed by the measurements taken by the National Atomic Energy Agency or Wojewódzka Stacja Sanitarno-Epidemiologiczna (Provincial Unit of State Sanitary Inspection)), personal protection equipment, dosimetric instruments, dosimetry in the work environment, personal dosimetry, equipment acceptance tests, and quality control tests of diagnostic and therapeutic equipment. Furthermore, the measures of radiological protection comprise: marking of the laboratories that use ionising radiation with warnings signs, designating and marking controlled areas and allocating employees to relevant categories of exposure.

To designate the zones with dose limits radiological protection most often makes use of ionising radiation measure in the form of an absorbed dose and an equivalent dose, and the levels of these doses, and an effective dose.

To ensure the appropriate level of protection from ionising radiation the dose limits are used, determined by the Regulation of the Council of Ministers on ionising radiation dose limits of 18 January 2005 [Rozporzadzenie Rady Ministrow… 2005]. The regulation on dose limits determines the ionising radiation dose limits, indicators making it possible to establish the doses used for the assessment of exposure and the way and frequency of making exposure assessments. The assessment of exposure for employees and general public is made on the basis of effective doses and equivalent doses received by them. It should be emphasised that effective doses are reduced by the doses that result from the natural background ionising radiation occurring within a given area, taking account of the actual time of exposure. If the natural background value is not known, the value of 2.4 mSv over a calendar year is adopted. Dose limits, being the highest doses of ionising radiation that may not be exceeded, have been established for three categories of people:

a) people working under conditions of exposure to ionising radiation, and in this case firefighters, who are listed among people exposed to radiation:
   - – 20 mSv – for the whole body (effective dose) – it can be exceeded up to the value of 50 mSv in a given calendar year, provided that for five consecutive years the aggregate value does not exceed 100 mSv,
   - – 150 mSv – in the eye lenses (equivalent dose),
   - – 500 mSv – in the skin, in the form of an average value for any surface area of 1 cm^2 of the irradiated part of the skin (equivalent dose), 500 mSv – for the hands, forearms, feet and shanks (equivalent dose),

b) people who are exposed because they live or stay close to the sources of radiation or radioactive contamination of the environment:

- 1 mSv – for the whole body (effective dose) – it can be exceeded in a given calendar year, provided that for five consecutive years the aggregate value does not exceed 5 mSv,
- 15 mSv – in the eye lenses (equivalent dose),
- 50 mSv – in the skin, in the form of an average value for any surface area of 1 cm^2 of the irradiated part of the skin (equivalent dose),

c) pupils, students, trainees (16-18 years):

- 6 mSv – for the whole body (effective dose),
- 50 mSv – in the eye lenses (equivalent dose),
- 150 mSv – in the skin, in the form of an average value for any surface area of 1 cm^2 of the irradiated part of the skin (equivalent dose),
- 150 mSv – for the hands, forearms, feet and shanks.

Giving at least three values of dose limits in each of the categories of people results from the fact that the human organs are characterised by a highly different sensitivity to different types of radionuclides. In some cases radioisotopes can induce irradiation of one organ or tissue [Rozporzadzenie Rady Ministrow… 2005].

Some examples can be given of yearly doses (in mSv) received by people exposed to ionising radiation for medical purposes: stomach X-ray – 3.5 mSv, chest X-ray – 0.05 mSv, sinuses X-ray – 0.3 m and teeth X-ray – 0.02 mSv. There are also some areas with a significantly increased value of the natural background, located in Italy, Brazil, France, India, China and Iran. For the sake of comparison, the yearly dose of radiation from natural sources totals 2.4 mSv for Poland and 5 mSv for Brazil. Despite the fact that inhabitants of these regions are exposed to such values of radiation, the incidence of cancers or genetic diseases is not higher. Moreover, there is cosmic radiation, increasing with altitude, which varies between 0.2 and 0.5 mSv per year. And on the top of Mount Everest it amounts to approx. 40 mSv/year.

In the places marked with a sign informing about the presence of radioactive substances and exposure to ionising radiation it is required to observe strictly the safety rules and to exercise special caution. Radiological protection applies one important rule, i.e. ALARA (As Low As Reasonably Achievable). The application of this rule consists in restricting any work with radioactive sources, so that the people exposed receive the lowest possible doses. To achieve this aim the optimisation of technological processes is applied, among others, and the basic rules ensuring protection from radiation are observed:

- distance – the further from the source of radiation, the safer,
- time – the shorter the exposure, the lower the dose,
- shield – appropriate shield reduces radiation.

3. Measures protecting firefighters from radiation

In accordance with the "Rules of the organization of chemical and environmental rescue in the National Firefighting and Rescue System (KSRG)" [Komenda Glowna… 2013] chemical and environmental rescue operations have been divided into basic and specialist scopes. The basic scope is applicable to all Firefighting and Rescue Units of the State Fire Service, fire protection units and other entities that confirm, being in readiness, their capability of performing tasks, taking account of their organisation and equipment potential and training [Rozporzadzenie Ministra… 2011]. The above-mentioned units first undertake these firefighting and rescue operations for which there is a possibility of occurrence of radioactive materials. The "Rules", referred to hereinabove, provide for equipping them with the following devices to measure radiation and protective equipment for firefighters and rescuers:

- device for detecting ionising radiation,
- personal protection equipment including: specialist clothes, firefighter rubber boots, specialist gloves and firefighter helmet,
- special chemical protective clothing, type 3 at a minimum, according to the standard [PN-EN 14605+A1:2010… 2010], including chemical resistant gloves and shoes,
- respiratory protection equipment (respirators) and filter masks.

The devices and firefighter protection equipment listed above are the accessories used by firefighters in the actions concerning incidents with radioactive materials at the basic level.

3.1. Devices for measuring radiation

As mentioned above, fire protection units which are the first ones to take firefighting and rescue actions, even during incidents involving radioactive materials, should be equipped with a device for detecting ionising radiation. In the case of the Volunteer Fire Service units this device is not mandatorily required. However, there are situations in which volunteer firefighters are the first ones to arrive at the scene and they have to act on their own for some time. Therefore, even the Volunteer Fire Service units should have on hand the devices for measuring ionising radiation. Particularly these ones on whose area there is a high number of potential sources of radiation hazard.

During the firefighting and rescue action the incident manager should use relevant equipment to protect firefighters from ionising radiation. The dosimetric equipment, used for detection and measurement of radiation, can be allocated to one of three groups, with respect to the function it performs: dose measurement, dose rate measurement and radioactive contamination measurement. It can also be divided into stationary or portable equipment. Depending on the application of detectors and the energy of measured radiation the dosimetric instruments can be divided into alfa, beta and gamma radiation meters. A dosimeter consists of a detector, measuring circuit and power unit. The main element of a dosimetric instrument is the detector, which makes use of the phenomenon of ionisation occurring as a result of radiation in gases, liquids and solids. Detectors can be divided into two types: impulse-based and current-based. The operating mechanism of the first type of detectors is based on the phenomenon of gas ionisation, where an energy quantum or particle passing through its gaseous medium causes ionisation. Current-based detectors make use of the phenomenon of a change of electric conductivity in crystals [Rozporzadzenie Rady Ministrow… 2002].

At present, there is a wide range of equipment for measuring doses and radioactive contamination, but firefighters from fire protection units most often use radiometers and radioactive contamination monitors.

The radiometer RK-100 is the most popular device among fire protection units for detecting the presence of radiation in space. The presented radiometer is used as a measuring instrument to detect radiation sources and to assess the level of contamination. The radiometer RK-100 is used mainly to measure:

- surface contamination with alpha radioactive substances,
- surface contamination with beta radioactive substances,
- dose and spatial equivalent dose of X and gamma radiation,
- spatial equivalent dose rate of X and gamma radiation,
- dose rate of X and gamma radiation.

Fig. 1. Radiometer RK-100
Source: own work.

The following versions of the radiometer RK-100 are available:

- with an internal probe, to measure the equivalent dose rate, the absorbed dose rate, the equivalent dose and the absorbed dose of gamma radiation, and after connecting an external probe, to measure the surface contamination with α, β and γ radioactive substances,
- with an internal probe and an external probe to measure the equivalent dose rate and surface contamination with α, β and γ radioactive substances.

On the front part of the radiometer an LCD and a membrane keypad are located. In its bottom part the radiometer has a connector for an external probe and a transmitter and a receiver for infrared communication, located under the shielding. At the top and back walls detectors of the internal probe are installed. An acoustic signalling device has been installed inside the casing.

The external probe makes it possible to measure:

- surface contamination with $\alpha + \beta + \gamma$, when the α or β shields are not placed,

– surface contamination β + γ, when the α shield is placed (the purpose of this shield is to attenuate α radiation),
– surface contamination γ, when the β shield is placed (the purpose of this shield is to attenuate β and α radiation),
– equivalent dose rate when the γ filter is placed.

The purpose of the gamma filter is to enable the detector to measure the equivalent dose rate in Sievert per hour units (Sv/h). The detector is not shielded with the γ filter in the case of alfa and beta radiation. If it is necessary, a filter with the β or α shield can be placed.

The functions of the radiometer make it possible to measure contamination in three modes: relative mode which shows measurement data in (s-1), absolute mode which shows measurement data in (Bq/cm^2), and absolute differential mode which shows measurement data in (Bq/cm^2).

The results of measurements taken by the radiometer RK-100 can be recorded in its internal non-volatile memory. By means of an infrared connection (IrDA communication interface) incorporated into the radiometer the contents of the memory can be downloaded to a PC. Data sent to the computer can be read in the form of tables with measurement data, dose rate graphs or in the form of a "tree". Moreover, the software of the RK-100 device provides the possibility of its full configuration. Thus, its operating functions can be adjusted to user requirements, for example by setting alarm thresholds.

Fig. 2. Radioactive contamination monitor of the EKO-C type
Source: own work.

A radioactive contamination monitor of the EKO-C type is another piece of equipment for measuring ionising radiation, detecting and measuring ionising radiation from radioactive contamination with alfa and beta radioisotopes, and also from roentgen and gamma radiation sources. The instrument shows the measurement data in three respective units:

– Bq/cm^2 – measurement of surface contamination with alpha radioactive isotopes,

– cps (pulse frequency) – measurement of contamination with beta radioactive isotopes,
– μSv/h – measurement of the spatial equivalent dose rate of X and γ radiation.

The measuring circuit has the following measuring ranges: 0.01-1000 μSv/h (dose rate), 0.1-10,000 Bq/cm^2 (surface contamination) and 0.1-10,000 cps (number of counts per second).

The detection element in the said device is represented by a mica window Geiger-Mueller tube. A thin mica window of the detector, with a density of 2-3 mg/cm^2, makes it possible to detect gamma and X and also alpha and beta radiation. A slidable window shield performs the function of a filter for measuring X and gamma radiation.

Radiation is detected in the following energy ranges:
– X and gamma radiation: 50 keV - 1.5 MeV,
– beta radiation: above 100 keV,
– alpha radiation: above 4 MeV.

The power supply of the monitor enables it to operate continuously for at least 30 h in the environment with a temperature from -10 to 40°C and a relative humidity of up to 80% at 30°C. The radioactive contamination monitor operates in two modes: measurement with an automatic deduction of the background and measurement in the radiation detection mode. In the first mode the function of storing the background values is switched on, owing to which the level of radiation after an automatic deduction of the level of background is shown. The measurement with the "radiation detection" mode switched on makes it possible to move with the monitor towards the expected source of ionising radiation. When an increased level of radiation is detected, a sound signal will be heard.

3.2. Protective equipment for firefighters

Pursuant to the regulation [Rozporzadzenie Ministra… 2008], the firefighter personal protection equipment is defined as equipment or outfit designed for wearing or holding, aimed at protecting the firefighter from hazards that might exert an impact on his safety and health. In accordance with the above-mentioned regulation the hazardous zone is described as an area where a hazard to life or health occurs. In such situation a firefighter taking part in the action involving radioactive materials should use personal protection equipment in the form of equipment or outfit.

During firefighting and rescue operations specialist clothes represent the main protection for firefighters. A specialist uniform, US-05, can serve as an example of the above-mentioned personal protection equipment. Specialist clothes are used during firefighting actions, but also in other emergency situations. Owing to their structure they protect from mechanical and surface factors, chemical agents, weather conditions, steam or thermal radiation.

The firefighter uniform consists of a jacket and trousers which should be made of materials with the same parameters. The structure of the firefighter clothing consists of outer fabric, inner insert (membrane) and a thermal insulation layer quilted with fleece. The outer layer is formed by the combination of 99% aramid fibres and 1% antistatic fibres, and the inner part is formed by lining made of 100% PTFE laminated aramid fibres. Because of this laminate water vapour is not carried off easily, but, instead, it is highly resistant to mechanical impacts. The combination of the thermal insulation insert and fleece produces a layer protecting from a high temperature. This property is achieved owing to the mix of 50% aramid fibres and 50% viscose.

The specialist uniform US-05 has received an EC certificate and an approval certificate issued by Centrum Naukowo-Badawcze Ochrony Przeciwpożarowej – Państwowy Instytut Badawczy (CNBOP-PIB, Fire Protection Research Centre – State Research Institute), which confirm the effectiveness of protection at level 2. The firefighter specialist clothing is used during many different incidents, but its properties have not been tested with regard to the ability to protect from ionising radiation and radioactive particles.

The firefighter boots are the second inseparable element protecting the firefighter during the rescue operations and with respect to their outer side they can be divided into two types: leather or rubber boots. During the actions firefighters most often use rubber boots, which are made of rubber, cotton and synthetic lining, and an insert of non-woven woollen fabric. The firefighter rubber boots protect the feet from mechanical factors (steel toe caps protect toes and steel mid-soles protect from puncture), current voltage of up to 1000 V, thermal factors (soles resistant to temperatures of up to 250°C, legs resistant to flame and thermal radiation), chemical factors (boots are made of materials resistant to sodium hydroxide, sulphuric acid at low concentrations, and mineral and plant oils), slippery and uneven surfaces (appropriate sole tread pattern, energy absorbing heel ensuring comfort when walking on uneven surfaces), cold and a high temperature (thermal insulation insert) and humidity. They have been designed in accordance with the recommendations contained in Directive 89/686 EEC and approved for use for fire protection units on the basis of an approval certificate issued by CNBOP-PIB.

Since rubber boots are designed to protect from so many hazards, they have to be rather massive, but, thus, they are highly resistant to dangerous factors. However, they have not been tested with regard to their ability to protect from ionising radiation or from penetration of radioactive substances.

Protective gloves of different types are another form of protection used by firefighters. The specialist uniform is completed with specialist five-finger firefighter gloves, e.g. specialist gloves GSP/BC PLUS. They are made of cowhide having fire resistance properties and equipped with a knit wristband made of para-aramid fibres. The inner layer of the gloves is made of special para-aramid fleece which protects the hands from cuts and abrasion. Between the outer layer and the fleece there is a waterproof insert protecting the hand against penetration of humidity, viruses and chemical substances. The specialist gloves GSP/BC PLUS have been approved for use on the basis of the relevant certificate issued by CNBOP-PIB.

A firefighter helmet with a visor, and with additional goggles in some models, is a very important element of firefighter personal protection equipment. Because of the sensitivity of the human head to any impacts, the helmet is an important part of the firefighter uniform.

A specialist firefighter helmet, F1 SF type, commonly called GALLET, is a helmet model with two forms of face protection. The helmet taken as an example has an incorporated visor with a metallised layer protecting against thermal radiation, moulded as the human face. The helmet shell is made of polyamide resistant to high temperatures and equipped with a reinforced system for absorbing energy from impacts. In addition, a neck protection is provided, made of aluminised material or Nomex.

The metallised visor serves as eye protection, ensuring comfort during high intensity fires, but during the rescue operations it considerably darkens the view at the scene. The transparent goggles incorporated in the above-mentioned visor can also be used as protection. The disadvantage of this design is that the mouth and chin remain uncovered and are not protected from dangerous factors.

Specialist clothes protecting against chemical factors, type 3 at a minimum, made in compliance with standard PN-EN 14605+A1:2009 [PN-EN 14605+A1:2010… 2010] are an additional piece of equipment for the national firefighting and rescue system units. Full protection should include also chemical resistant gloves and boots. The type 3 clothes protecting against chemical factors cover the whole body and prevent from penetration by a jet of liquid. Such clothes consist of overalls with a hood or visor, or without them, special rubber boots or boot protectors and gloves. There are also models of clothes consisting of trousers with a raised front and a matching tunic. Clothes protecting against liquid sprays or jets are made of materials with plastic coating on non-woven fabric carriers, on fabrics and knitwear. The physical and mechanical properties as well as the chemical resistance of these materials are designated by means of classes. The so-called breakthrough time is the main parameter which determines the resistance to chemical substances (determined in accordance with PN-EN ISO 6529:2005 [PN-EN ISO 6529:2005… 2005]).

The overalls Tychem C can serve as an example of such specialist clothes. They are made of a light and very strong material: Tyvek – type C, i.e. laminated non-woven polyethylene fabric. These overalls have also seams sealed with tape, which ensures that they are completely liquid-proof.

Their purpose is to protect from: liquid chemicals with a pressure of up to 3 bar, liquid sprays and volatile solid particles of chemical substances, and biological hazards. They also ensure protection against static discharges, provided that the proper grounding is ensured, and protection against contamination with radioactive particles, in accordance with the standard [PN-EN 1073-2:2005… 2005]. In the case of these clothes the protection against radioactive particles is aimed to minimise the penetration of radioactive materials to reduce the probability of their contact with the skin and underwear. Owing to this property these overalls can be used in the potentially contaminated areas and for decontamination of contaminated people.

The material used in the disposable overalls Tychem C, according to standard PN-EN 1073-2:2005 [PN-EN 1073-2:2005… 2005], does not provide a barrier for ionising radiation, i.e. gamma radiation, roentgen radiation and alpha and beta radiation. However, taking into account the ability to penetrate and range of α and β radiation, it can be assumed that the material of the overalls will protect against alpha radiation and partly against beta radiation. Clothes with elements made of lead materials may provide partial protection, however, it happens rarely that overalls with such a high standard of protection against radioactive materials form a part of the equipment of fire protection units that are the first ones to arrive at the scene.

To the specialist clothes protecting against chemical factors chemical resistant footwear is added. Chemical resistant footwear of Rancher 966/984 type can serve as a relevant example. Its basic layer is made of polyvinyl chloride (PVC), outer side and soles are modified with nitrile rubber and a textile material is used as lining. These boots protect against impacts, humidity, mineral oils, whitewash, acids and bases at medium concentrations, brines and sea water. However, there is no information about the possibility of protecting against radioactive contamination or ionising radiation. High leg chemical resistant boot protectors, Tychem C, can ensure protection against radioactive materials for specialist rubber boots. Together with the overalls Tychem C they represent the equipment of type 3 at a minimum, ensuring protection from chemical factors. The boot protectors are knee-high and have anti-slippery soles. Hot-sealed seams ensure that they are liquid-proof, like the material used for the overalls Tychem C. They ensure protection against radioactive particles or liquids by limiting the penetration of radioactive materials to minimise their contact with the skin and the footwear under the protectors, in the same way as the specialist clothing Tychem C. The clothing protects firefighters in the potentially contaminated areas, but it does not block ionising radiation itself.

The outfit protecting against chemicals is completed with chemical resistant gloves. Butoject 898 can be used as an example of gloves protecting against numerous chemical factors. The gloves Butoject are made of 0.7 mm thick butyl rubber by injection moulding, which makes it possible to use them under extreme chemical loads while in contact with esters and ketones. Their properties include: very good elasticity at low temperatures, good resistance to ozone and UV radiation, good mechanical resistance and high level of gas-tightness. The protective gloves Butoject 898 show resistance to numerous chemical substances and gases and ensure protection against radioactive contamination according to standard PN-EN 421:2010 [PN-EN 421:2010… 2010]. The gloves Butoject 898 fulfil the conditions, but they do not provide protection against ionising radiation. To protect against ionising radiation the protective gloves have to contain a specified amount of lead, which is called the lead equivalent.

A respiratory protection device, i.e. the so-called breathing apparatus, is the last element of the protection equipment used by firefighters and rescuers that has been stipulated in the “Rules”. Breathing apparatuses that meet the requirements contained in standard PN-EN 137:2008 [PN-EN 137:2008… 2008] are used by firefighters during firefighting and rescue actions to ensure respiratory protection against hazardous factors. Fenzy Aeris type II is an open circuit apparatus that fulfils the requirements of the above-mentioned standard. It ensures a positive pressure of even 3 bar in the mask. The operating time, depending on the conditions, amounts to approx. 30 min, and a cylinder volume is up to 6.9 dm^3 at a pressure of 300 bar. A full face mask with head-straps and a helmet connection kit ensures face and respiratory protection. The panoramic mask is equipped with a speech diaphragm, half-mask and visor, and it is made of soft plastic, owing to which it adheres tightly to the face. Furthermore, the apparatus is equipped with the second medium pressure outlet to connect the second mask or rescue hood, to evacuate an injured person from the smoke zone or contaminated area.

Acknowledgement

The article has been prepared as part of project DOBR-BIO4/050/13009/2013, contributing to the State's defences and security, entitled "Development of system solutions that support fire investigations, making use of modern technologies, including technical and IT tools" financed by the National Centre for Research and Development.

Conflict of interests

The author declared no conflict of interests.

Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

ORCID

Bozena Kukfisz https://orcid.org/0000-0001-5049-7316

Marzena Polka – The author declared that she has no ORCID ID's

References

Adams, B., Miller, L.A. and International Fire Service Training Association. (2004). *Hazardous materials for first responders*. 3rd ed. Stillwater, Oklahoma: Fire Protection Publications, Oklahoma State University.

Komenda Glowna Panstwowej Strazy Pozarnej, Krajowe Centrum Koordynacji Ratownictwa i Ochrony Ludnosci. (2009). *Zasady postepowania w przypadku mozliwosci wystapienia zagrozenia radiacyjnego* – maj 2009 r. Warszawa.

Komenda Glowna Panstwowej Strazy Pozarnej, Krajowe Centrum Koordynacji Ratownictwa i Ochrony Ludnosci. (2013). *Zasady organizacji ratownictwa chemicznego i ekologicznego w Krajowym Systemie Ratowniczo-Gasniczym* – lipiec 2013 r. Warszawa.

National Fire Service Incident Management System Consortium. (2000). *Model procedures guide for hazardous materials incidents*. Stillwater, Oklahoma: Fire Protection Publications, Oklahoma State University.

Obwieszczenie Marszalka Sejmu Rzeczypospolitej Polskiej z dnia 15 pazdziernika 2009 r. w sprawie ogloszenia jednolitego tekstu ustawy o ochronie przeciwpozarowej (Dz. U. 2009 Nr 178, poz. 1380). (2009).

Panstwowa Agencja Atomistyki (website), [online]. Warszawa. Available at: http://www.paa.gov. pl/ [Accessed: 11 February 2016].

PN-EN 137:2008. (2008). *Sprzet ochrony ukladu oddechowego. Aparaty powietrzne butlowe ze sprezonym powietrzem wyposazone w maske. Wymagania, badanie, znakowanie*. Warszawa.

PN-EN 421:2010 (ANG.). (2010). *Rekawice ochronne przed promieniowaniem jonizujacym i skazeniami promieniotworczymi*. Warszawa.

PN-EN 1073-2:2005. (2005). *Odziez chroniaca przed skazeniami promieniotworczymi. Czesc 2: Wymagania i metody badan dotyczace niewentylowanej odziezy chroniacej przed skazeniami czastkami promieniotworczymi*. Warszawa.

PN-EN 14605+A1:2010. (2010). *Odziez chroniaca przed cieklymi chemikaliami. Wymagania dotyczace odziezy ochraniajacej cale cialo, z polaczeniami nieprzepuszczajacymi cieczy w postaci plynnej (Typ 3) lub rozpylonej (Typ 4), lacznie z wyrobami zapewniajacymi tylko czesciowa ochrone ciala (Typy PB[3] i PB[4])*. Warszawa.

PN-EN ISO 6529:2005. (2005). *Odziez ochronna. Ochrona przed substancjami chemicznymi. Wyznaczanie odpornosci materialow na odziez ochronna na przenikanie cieczy i gazow*. Warszawa.

Politechnika Warszawska, Wydzial Fizyki (website), [online]. Warszawa. Available at: http://www.if.pw.edu.pl/ [Accessed: 10 February 2016].

Rozporzadzenie Ministra Spraw Wewnetrznych i Administracji z dnia 16 wrzesnia 2008 r. w sprawie szczegolowych warunkow bezpieczenstwa i higieny sluzby strazakow Panstwowej Strazy Pozarnej (Dz. U. 2008 Nr 180, poz. 1115). (2008).

Rozporzadzenie Ministra Spraw Wewnetrznych i Administracji z dnia 18 lutego 2011 r. w sprawie szczegolowych zasad organizacji krajowego systemu ratowniczo-gasniczego (Dz. U. 2011 Nr 46, poz. 239). (2011).

Rozporzadzenie Rady Ministrow z dnia 18 stycznia 2005 r. w sprawie dawek granicznych promieniowania jonizujacego (Dz. U. 2005 Nr 20, poz. 168). (2005).

Rozporzadzenie Rady Ministrow z dnia 23 grudnia 2002 r. w sprawie wymagan dotyczacych sprzetu dozymetrycznego (Dz. U. 2002 Nr 239, poz. 2032). (2002).

Biographical notes

Senior Captain **Bozena Kukfisz** – Ph.D., Eng., graduated from the Faculty of Fire Safety Engineering at the Main School of Fire Service in Warsaw in 2005, and from the Faculty of New Technologies and Chemistry at the Military University of Technology in Warsaw in 2006. Assistant Professor at the Department of Theory of Combustion and Explosion

Processes at the Main School of Fire Service. Specialising in environmental engineering.

Senior Brigadier **Marzena Polka** – Ph.D., Sc.D., SGSP Professor, graduated from the Faculty of Chemistry at the University of Warsaw in 1992. SGSP Professor at the Department of Theory of Combustion and Explosion Processes at the Main School of Fire Service in Warsaw. Specialising in processes of combustion of polymer materials and their fireproofing modifications.

How to cite this paper

Kukfisz, B. and Polka, M. (2018). Analysis of means of personal protection for rescuers during in-cidents involving radioactive materials. *Scientific Journal of the Military University of Land Forces*, vol. 51, no. 2(188), pp. 88-104, http://dx.doi.org/10.5604/01.3001.0012.2493