Radiological Terrorism.
Problems of prevention and minimization of consequences

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Abstract. This paper gives a review of the key factors defining the extent of potential hazard caused by ionizing radiation sources for the purpose of radiological terrorism and the key areas of activities in the field of counteractions and minimization of possible consequences of such acts. The importance of carrying out system analysis of the practical experience of response to radiation accidents and elimination of their consequences is emphasized. The need to develop scientific approaches, methods and software to realistically analyze possible scenarios and predict the scale of consequences of the acts of terrorism involving radioactive materials is pointed out. The importance of improvement of radioactive materials accounting, control and monitoring systems, especially in non-nuclear areas, as well as improvement of the legal and regulatory framework governing all aspects of radiation source application in the national economy is of particular importance.

KEYWORDS: Radiological terrorism, RDD, radioactive sources, direct and indirect consequences, scenarios, radiophobia.

According to the IAEA data, millions of ionizing radiation sources (IRS) have been manufactured and used over the last 50 years. Hundreds of thousands of sources find their use in medicine, metallurgy, agriculture, mining, industry, etc. There are obvious advantages in using the IRS, but the positive experience of their use is obscured by lack of control over the increasingly large number of decommissioned sources.

The risks connected with radiation sources security and the possible radiation accidents have been in the focus of international attention for several years. The importance of these issues has especially increased following September 11, 2001, when the potential danger of malicious or terrorist use of radiation sources to expose the population or make elements of radioactive weapons was clearly demonstrated. These events urged the international community to increase the efforts on ensuring the IRS security.

All the countries of the world are currently paying special attention to the problem of terrorism on the whole and, in particular, to nuclear and radiation terrorism [1-3]. The concept of "dirty bomb", identified as a low-technology nuclear weapon or a device combining conventional explosives with radioactive materials, has been widely discussed. The non-proliferation measures, special nuclear materials accounting and control systems initiate the situation when the use of radioactive materials extracted from widely spread IRS for terrorist purposes is of higher possibility.

Radiological terrorism (RT) is identified as intentional dispersion of radioactive substances or placing IRS in residential areas or infrastructure facilities, and sabotage at radiation hazardous facilities aimed at creating radiation impact on the population, environment and destabilizing the social life and economy [4,5].

The key factors affecting the potential danger of IRS use for the purposes of RT include: wide use of such sources in various fields (industry, agriculture, medicine, stand-alone power sources); the unresolved problems of their accounting, licensing, regulating, control and suppression of their unauthorized movement, especially in non-nuclear industries; the relative simplicity of design of "dirty radiological bomb" and its delivery means [6]. There is also a need to remember that, in addition to the gamma-emitting sources, the much-more-difficult-to-detect alpha- and beta-emitting ones are also widely used in industrial applications. From this point of view, theft and unauthorized transfer of beta-

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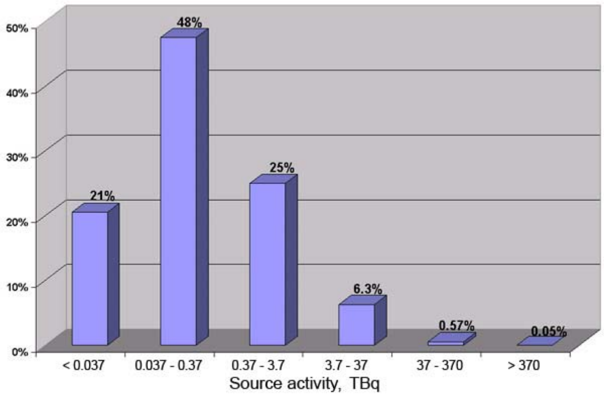
and alpha-emitting sources is a much easier task for potential terrorists. Also a question remains if it is easier for terrorists to obtain a single powerful, but well-secured source, or several sources with smaller activity. There are known examples when several hundred sources with the activity of about 10 Curies are used at a single mine.

The complexity of the task of organizing effective accounting and control of radiation sources in Russia can be illustrated by a large number of constantly found "orphan" sources (38 cases in 1997-2001) and a large number of IRS thefts – 50 cases over these five years. The situation has not improved. According to Rospotrebnadzor, there were 91 cases of ionizing radiation source detection in scrap metal only in the first half of 2007. The situation is the same in other industrial countries (e.g. up to 200 radioactive sources are lost annually in the USA).

It should be noted that the majority of IRS used in Russia has minor activity (see Fig. 1).

Figure 1. Activity distribution of IRS used in Russia



Naturally, the efforts aimed at securing the ionizing radiation sources should take all these factors into account. The Russian Law on the use of nuclear energy requires the development of a system for state accounting and control of both the nuclear materials and radioactive substances and radioactive waste (RS and RW). The special Resolution of the Government has established the corresponding federal system and entitled Rosatom to be in charge. The objectives of the system include:

- Identifying the quantity of RS and RW, i.e. carrying out inventories of locations of their storage, use or disposal;
- Preventing RS and RW loss, unauthorized use and theft;
- Keeping the executive authorities informed about the location and transfer of RS and RW;
- Informational support of decision-making process.

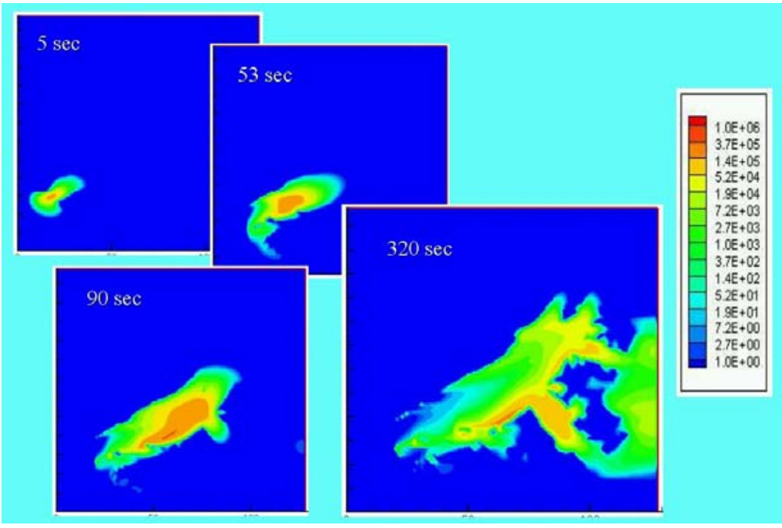
At the local level, availability of information and analytical centers is to be maintained by the local authorities. The system is practically used to monitor the handling of RS and RW. It is, of course, desirable to develop the system of RS and RW accounting and control with the aim of bringing it closer to the in-force system of accounting and control of nuclear materials in Russia and other industrially developed countries.

Technical means revealing IRS and radioactive materials in major transport infrastructure elements and special radiation monitoring systems located in population settlements shall become an important part of safety and security assurance systems. It is necessary to develop principally new and effective methods and devices to reveal radiation sources and potentially hazardous components of radiological weapons in areas of critical infrastructure facilities, crowded places, traffic centers, big cities [7]. Measures to prevent the possibility of preparing radiological terrorist act are required. In this context modernization of the existing state systems regulating radiation safety issues could be required.

It should also be stressed, that the existing systems of response, which are developed and effectively operated in case of radiation accidents and incidents, are not adapted for adequate response to radiological terrorist acts or their simulation. For example, the existing methods and computer codes, successfully describing the contaminant behavior in the vicinity of a release source in the open territory and in elevated roughness conditions, cannot effectively function for the conditions of urban areas, major industrial facilities and transport junctions. Therefore, more accurate assessments require use of three-dimensional methods of aerodynamic simulation in order to study the processes and develop models adequately describing the spreading of admixtures in complex urban conditions, identification of characteristic stagnant areas and locations with anomaly high levels of contamination.

Examples of calculations performed using one of such software, which is currently developed at IBRAE RAS [8], are given in Fig. 2. Analysis of the results of such calculations, carried out for specific variants of urban areas and various scenarios of malicious radioactive materials use, can be effectively used for improving the system of organizational arrangements for collective population protection, especially sheltering the population and evacuation to the uncontaminated areas.

Figure 2. Dynamics of change of ^{241}Am concentration in the air for the case of blasting the explosive with the radioactive source in a given urban area, rel.un.



While addressing the problem of RT act feasibility, it is necessary to bear in mind that generally these are different means for dispersion of radiation substances to harm human health, environment, public or economy (directly or indirectly).

The so-called "dirty bombs" attracted serious attention of the specialists, media and the public in the recent years. It should be kept in mind that the quantity of radioactive stuffing in the "dirty bomb" can be as small as fractions of a gram (Table 1) and conversion of conventional explosive device into a "dirty bomb" does not require any complex technical solutions.

Table 1. Quantity of Radioactive Material, which, if Used in a "Dirty Bomb", May Require Population Protection Actions at a Distance of over 100 m, grams

Weather Category	Radionuclide				
	^{60}Co	^{90}Sr	^{137}Cs	^{226}Ra	^{239}Pu
A	0.020	0.11	1.0	2.6	0.82
D	0.052	0.28	2.8	6.9	2.6
F	0.021	0.11	1.0	2.8	0.88

This fact, along with the low weight of such devices, lack of any complexities in their delivery, difficulties in their detection, and the possible simulation of radiological terrorism make it a very topical problem due the attractive qualities of the "dirty bombs" for terrorist groups as a tool of radiological blackmailing. The relative complexity of detecting small quantities of β- and α-emitters

(Sr, Pu and other isotopes) combined with a highly acute perception of their real or supposed danger may lead to serious consequences even if only the probability of such radiological terrorism events is announced. Low levels of contamination - when exposure doses do not exceed the threshold of radiation harmful impact - do not mean low level of damage to the society. Indirect damage may appear to be rather significant in this case.

Summarizing the available information, it can be stated that a terrorist act utilizing radioactive substances (IRS or RW) can lead to the following consequences:

- Direct effect of the terrorist actions, which is connected with the possible loss of life, injuries, damage of the infrastructure and loss of property;
- Costs associated with mitigation of the terrorist act consequences, the forced enhancement of radiation monitoring, carrying out population protection actions and remediation of the contaminated territories;
- Deterioration of social and psychological situation not only in the affected areas, but also in large territories practically unaffected by radiological contamination;
- Indirect losses connected with inability to use some of the territories, possible closure of agricultural and industrial facilities, reduction of purchasing the products produced in affected areas, termination of tourism, drop of prices for apartments and capital assets;
- Hidden expenses connected with increased negative attitude of the community towards radiation and nuclear power, in particular.

Specialists of IBRAE RAS have been working for several years together with specialists of various Russian ministries and departments on systematic analysis of the possible consequences of terrorist acts involving radioactive materials and IRS. An important task of such system analysis is to develop the approaches to identification of priorities for measures on prevention, suppression and minimization of RT act consequences. It should also be stressed that the existing approaches to development of measures and priorities are generally based on independent analysis of separate factors dependent on the given design of a dispersion device (DD) and its "radiological" component, limited number of scenarios for DD and its fragment illicit trafficking, means of its delivery as well as the extent of potential effect of consequences of such terrorist acts on population and infrastructure. Unfortunately, these assessments do not take full account of possible interconnection between the consequences of such incidents for the human health and the scale of social and economic consequences for the public with the design of DD and the scenario of RT act.

We believe that the probability of RT acts involving a specific radioactive material is largely dependent on:

- Availability of RS and the extent of security measures preventing their unauthorized (illicit) acquisition;
- The means of their transfer and delivery to the supposed place of RT act;
- Presence and effectiveness of detectors at various stages of transfer and delivery of RS, DD and their components taking into account the possible disguise measures;
- Effectiveness of special measures aimed at revealing and suppression of RT acts preparation.

At the same time, radiological terrorism acts may be carried out in major settlements, large cities first of all, social and economic centers, critical infrastructure facilities (airports, railway stations, underground), crowded places, waters sources (wells, rivers). There is also a possibility of deliberate contamination of food, clothes, agricultural lands, residential and industrial buildings, transport communications. Radioactive substance or an ionizing radiation source may be concealed in crowded places. Radioactive substance can be dispersed either by blasting an explosive or by thermal or chemical mechanisms. Dispersion of radioactive liquids, solution and other methods of contaminating water are also possible. Unfortunately, there is an abundance of such scenarios available in open sources including blockbusters and books, which are described both by those having a scientific point of view on the issue and those who consider these possibilities as a threat. The deliberate criminal can also easily use one of such "recipes" from the Internet.
Can such scenarios be prevented? What will be the real consequences for the public?

If we speak of RS dispersion in crowded places, this can be a serious problem, especially taking into account the need to make a prompt decision for tens of thousands of people in the affected area. A clear logical structure of decision-making process based on understanding of the consequences of each specific action in this situation should be available in order to assure effective assistance to the public. If there would be acute radiation injuries, they would be dealt to not more than several tens of people. Remote consequences of exposure might be forecasted for another several hundreds of people. These are the direct radiological consequences. Doses for the rest of the people affected by the incident would be much lower than the practical threshold of harmful radiation effect. Still, these people would percept the radioactive contamination situation as a dangerous one. Consequently, the population will try to avoid the contaminated areas, and the authorities currently have no remedies to correct this situation. There are no tools or legislation demonstrating that such additional exposure is absolutely safe for human health. Therefore, the indirect consequences of a terrorist act carried out, for example, at an underground station in a rush hour, will include:

- Inability for the public to use the station or even a subway line for a considerable period of time. Simultaneous closure of several stations and interchange terminals will virtually paralyze the transport activity and lead to great transport problems in a large city;
- Compensations to the citizens who lost property as a result of radioactive contamination,
- The need to organize long-term medical care for a large group of people who were affected by the terrorist act or took part in the mitigation of its consequences.

If we consider a scenario of dispersion of ^{137}Cs in an urban area (see Fig. 3), several tens of square kilometers of city territory may be contaminated with a density of over 37 kBq/m^2. It was well known that - during the analysis of Chernobyl accident consequences - the soil contamination by ^{137}Cs exceeding the level of 37 kBq/m^2 was the reason to give such territories favorable social and economic status. This meant that the state acknowledged the fact that these areas were dangerous for living.

Figure 3. Forecasted density of urban territory contamination in case of blasting an explosive device stiffed with ^{137}Cs, kBq/m^2

Analysis of data given in Table II, which are based on real characteristics of one of the districts of Moscow, demonstrate that direct application of this standard in the city may lead to the need to carry out deactivation of the area populated with several tens of thousands of people, while the losses of residential and commercial estate may amount several hundreds of thousands square meters.

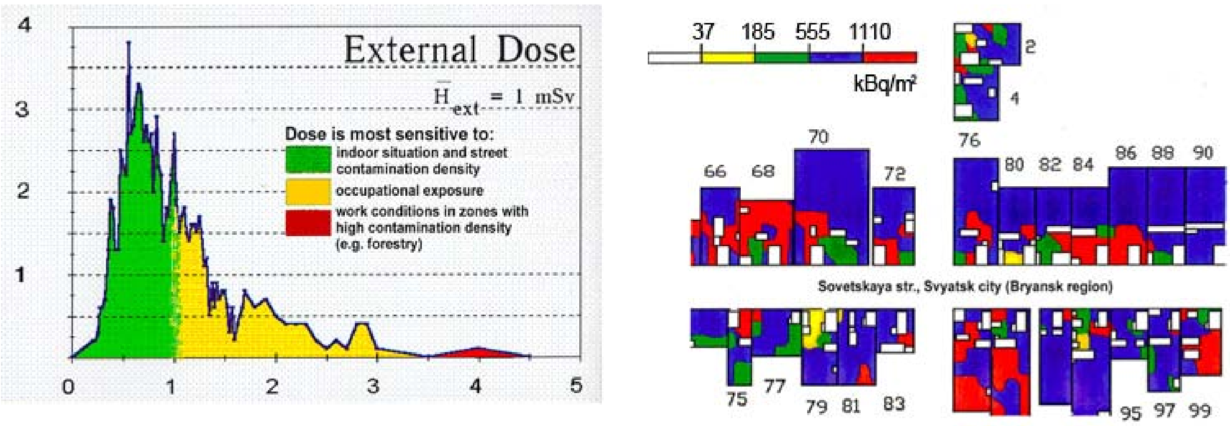
The methodology applied for RODOS and MACCS software was used to assess the extent of economic losses. Social and economic Moscow-specific data were used for calculations made for concrete scenarios (dispersed radioactivity in a megapolis). The calculation results have shown that the extent of economic loss can amount to several billions of US dollars and can alter for an order of magnitude depending on adopted criteria for resettlement and territory decontamination.

Table 2. Possible Scale of Contamination of Urban Territory in Case of a RT Act Involving a Given Quantity of ^{137}Cs

Parameter	Over 37 MBq/m^2	0.037- 37 MBq/m^2	Under 0.037 MBq/m^2
Total area of contamination, km^2	1	51	36
Number of residential buildings	37	1900	1000
Their area, thos. m^2.	170	9600	12000
Population, thous. people	6	490	650
Children	1	60	150
Working population	3	320	350
Pensioners	2	110	150
Number of facilities	3000	9600	10000
Number of people employed at the facilities	39000	91000	99000
School students	420	39000	54000
Nursery attendants	160	10000	32000
Number of beds in hospitals	730	4200	5500

The actual measurement data demonstrate the high heterogeneity of surface contamination and gamma-radiation dose rate values for the settlements in the Chernobyl area (Fig. 4 - right). There are also high variations of individual exposure doses for various professional and age groups of the population (Fig. 4 – left). All of this adds to the difficulties experienced in zoning the area, causes negative attitude of the population to the carried out protective measures and causes socials stress of the society. The results of the analysis of the RT scenarios demonstrate that the same problems would be much more difficult to solve in the conditions of a large city.

Figure 4. Left – distribution of external exposure of the population of the settlement in Chernobyl area after the accident at ChNPP depending on living and work conditions; Right – heterogeneity of yards contamination in the street of a town (Svyatsk, Bryansk Region of the RF, 1986)



Indeed, it would be very difficult to explain the population where the hazardous and safe areas are and what doses they receive if the contamination density varies for several orders of magnitude and the dose rate for one order of magnitude and more within one street. There are no reliable algorithms for decision-making in this situation today. And this is an important task, which requires immediate solution. New hardware needs to be developed for on-line radiation monitoring and mapping to enable new level of decision-making on urgent protection measures.

Thus, working out effective measures for prevention, suppression and minimization of consequences of RT events requires a system approach based on multi-factor analysis of:

- Various scenarios of unauthorized withdrawal, methods of RS transfer taking into account the possible disguise measures and the technical capabilities of their detection, especially for α and β-emitters;
- Possible designs of delivery means, methods and targets of possible terrorist acts;
- All the possible consequences (including radiological, environmental, sanitary, hygienic, economic, social, etc.) taking into account the features of radiation situation characteristic for various scenarios of radiological terrorism events in a large city (fast contamination, spatial heterogeneity of urban areas contamination, multi-component infrastructure);
- The requirements to the methods and hardware for radiation surveillance and monitoring (taking into account peculiarities of radiation situation in large cities in case of radiological terrorism events, and the detectable levels of α, β and γ emissions for the cases of RS unauthorized transfer (taking into account possible disguise measures and the means and methods of their delivery;
- The existing legislative and regulatory framework in the field of radiation safety and its influence on the decision-making process when admissible and monitored levels of human exposure and contamination of personal belongings as well as the environment widely vary in normal situations and emergencies;
- Practical application of population radiation protection criteria with account for high heterogeneity of radioactive contamination, complex distribution of individual exposure doses and the multiple interconnected elements of city infrastructure;
- Causes of the inadequate public perception of radiation risks.

The above given facts demonstrate that the international community faces a complex task of effectively counteracting the threats of radiation terrorism. However, an equally important task is establishment of a response system capable of minimizing the threat of radioactive substance involvement for the purposes of terrorism. Experience of past accidents and incidents demonstrates that errors in the response systems lead to severe consequences for the public. The real data show that the indirect consequences of inadequate management of radiation risk have a much larger scale than the direct losses caused by the radiation effect.

Inveterate fear of radiation is frequently spurred on via various information channels. Practically each year media informs the population about requisitioning large quantities of "radioactive" berries, mushrooms, vegetables at the city markets. Muscovites are regularly informed via radio of a large volume of "contaminated" bilberry confiscated and disposed of. According to the standards in force in Russia, the maximum allowed concentration of ^{137}Cs in fruit, berries and grapes is 40 Bq/kg (SanPiN-96). Specialists in the field of radiation hygiene know that even if this overly harsh standard is exceeded by tens of times, there is still no risk for the health, but there are parties who use this for advertising purposes.

The populist policy prevailing in the post-Chernobyl period has caused legal adoption of excessively harsh sanitary standards, which cannot be economically justified even in more developed countries. Such radiation criteria make Russian population to be alerted even in case of a minor standard exceeding, which is safe and acceptable for most of the western countries. The Chernobyl legislation, guaranteeing compensation for loss of health for population living in the territories with additional exposure (much below the natural background oscillations) also makes its contribution. At the same time, such doses are believed to be absolutely safe for human health from the point of view of scientific community.

It should be remembered that the excessively harsh radiation standards are one of the most influential factors for the public. If radiation materials will be used by terrorists, the people will first of all refer to the existing standards and will demand the authorities to keep to these standards. There are no special regulations for the cases of radiological terrorist acts. So, if the allowed exposure level is 1 mSv/year, the dose of 1.1 mSv/year will be considered a dangerous one. Thus, the existing regulatory framework will largely determine indirect losses and social tension in case of radiation terrorism events.

Therefore, the modernization of the regular and legal framework applied at all the stages of IRS lifecycle, starting from production to disposal (the IAEA "cradle-to-grave" control concept) and the responsibility for inobservance of such laws and regulations are all very urgent issues. It should be kept in mind, that direct transfer of the regulatory framework effectively assuring radiation safety of personnel and population in case of radiation accidents to the radiation events connected with potential local contamination caused by terrorism acts involving radiation sources is incorrect and requires development of additional criteria to support the appropriate regulations.

It is obvious that intensive efforts are needed to provide the community with the explanations of real risks associated with possible use of radiation-hazardous devices by terrorists. Consolidation of the efforts of different countries and the international organizations is essential.

Inadequate perception of radiation risks exists not only at the level of a common mind. Prejudice against radiation exists in nearly all professional, social and economic groups of the society, including the representatives of legislative and executive powers involved in development of population protection measures and environmental regulations. Efforts to assure the adequate perception of the threat and the possible consequences of radiological terrorism by the society require a varied approach to each of the target groups. For example, information for decision makers should not be limited to the data on the levels of radiation risks and population protection measures, but also include information about economic effectiveness of these measures, their social acceptability and adequacy [6].

Fear of radiation, the tough and intricate regulations in the field of radiation safety and radiation protection make the society highly vulnerable to the radiological terrorism threat. This fear and the wide availability of instruments for detection of minor radiation background elevation make the system highly unstable: the mechanisms of social augmentation of risk are triggered by the slightest threat of use of radiation sources by the terrorist groups [9]. In this case the indirect damage caused by fear and inadequate reaction will inevitably surpass all the consequences of the radiation exposure itself. The fear epidemic can spread very fast, especially in densely populated areas with developed communication systems, threatening all public activities [10].

Non-routine event without nuclear substance release at one of the Russian nuclear power plants (Balakovo NPP) can be used as an example demonstrating the power of public response and rumoring. Accidental coincidence of emergency response exercise conducted in the town and a zero level event according to INES scale (i.e. an accident without radioactivity release) at adjacent NPP happened on November 4, 2004. Lack of adequate official information had given raise to rumors about the release of radioactivity (Fig. 5). The population of nearby town of Balakovo started to inform the relatives and friends about the accident and recommended each other to take iodine pills and wine and leave the place as soon as possible. In 30 hours millions of people living in the European part of Russia were alarmed.

Figure 5.Left – Balakovo NPP hosted the exercise which caused rumors of a radiation accident on November 4-6 of 2004; Right – the photograph associated with the incident, which was published in all Russian media.

It should be stated that the so-called social augmentation of risk is present at all levels of response to radiological threat, which leads to multiple increase of both direct and indirect losses. This is confirmed by the experience of past radiation accidents. For example, the protective measures after the accident at Chernobyl NPP could be considered justified for 300 thousands people (based upon the radiation protection criteria being in force at that time), while in reality over 7 million people were affected by the intervention measures. The total economic losses (the direct losses + indirect costs) in Russia, Ukraine, and Belarus for the period of 15 years after the Chernobyl catastrophe are assessed at the level of several tens or hundreds billions of US dollars. If we take the NEA assessments [11], then the social risk augmentation effect increases the losses caused by a hypothetical accident at a modern NPP to 400 billion Euros instead of 10-20 billion.

The extent of protection of the society against the radiation terrorism threat, as well as the severity of the terrorist act consequences is largely dependent on the adequacy of public reaction. The work aimed at forming adequate perception of radiation factor can be considered an effective preventive measure which does not require large expenses. Are there any possibilities for this today? Yes, of course there are. The Russian nuclear industry is one of the biggest corporations in the country, possessing such information resources as "Atom-press" weekly newspaper, "Atomium", "Nuclear Energy Bulletin" and "Nuclear Strategy" magazines, and gradually increasing its informational presence in the Internet. These publications are not distributed only within the industry, they also are read by the politicians, heads of major facilities and organizations, participants of exhibitions and conferences, journalists. This potential can be actively used to form a more adequate perception of the radiation risks by the society to guard the public from mythical threats.

However, the complexity of resolving this task should not also be underestimated. The experience of past radiation accidents shows that informing the population about radiation risk issues requires both professional approach at the merging point of several scientific fields and the features of scientific information perception by non-professional audience. Consolidation of international efforts is of utmost importance for the resolution of this task.

However, this is insufficient. Regulation of man-caused risks and formation of adequate perception cannot be addressed in the framework of industry-related programs for environmental safety and public relations. It is the responsibility of the state for the vulnerability of society to new terrorist threats; in such context the role of the state becomes a primary one. The state functions are not only to block most of the mechanisms causing massed fear and to maintain the responsibility for careless advertising, but also to eliminate the inconsistencies in the environmental legislation as well as to modernize the environmental education system. Committed participation of the state is a required condition for intensification of nuclear industry efforts in this area.

CONCLUSION

Summarizing the above said, we should indicate that according to our opinion, the following are the key efforts in the field of counteracting and minimizing the consequences of potential radiological terrorism events:

- Systematic and inter-discipline analysis of practical experience of response to radiation accidents and mitigation of their consequences aimed at developing recommendations on effective countermeasures in case of radiological terrorist acts;
- Development of scientific approaches, methods and software for realistic analysis of possible scenarios and forecasting the scales of consequences of terrorism acts involving radioactive materials;
- Development of a conception of national and international expert scientific and technical support in response to radiological terrorism;
- Analysis of the causes of inadequate perception of indirect (psychological, social, economic) consequences of radiological terrorism and development of the recommendations for mitigation thereof;

- Analysis of availability of various radioactive materials and ranking them according to the level of potential danger in case of their use for terrorist purposes;
- Development of recommendations for modernization of the system of accounting, control and monitoring of radioactive materials (IRS and RW), especially in non-nuclear industries;
- Improvement of the regulatory and legal framework regulating all aspects of radiation source use in the national economy;
- Development of new technologies for radiation monitoring and survey in large cities and important infrastructure facility zone;
- Development and legal adoption of the clear and efficient criteria of radiation safety and protection to be applied to radiological terrorism.

It should be stressed that this problem is an interdisciplinary one and requires well-coordinated efforts of multiple specialists, experts and decision-makers in different fields. Moreover, close cooperation between scientific and research institutes all over the world is required and we believe that the present IRPA Congress could play an important role in this regard.

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