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Research paper

Preliminary Analysis of Terrorist Threats Combining Radionuclides and Explosives

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Abstract: The basis for drawing conclusions about the nature of future terrorist threats is the analysis of incidents recorded so far. The paper, based on the analysis of literature reports on terrorist incidents involving CBRNE materials, shows that the available databases do not provide certainty that the data contained in them describe the phenomena analysed representatively. The validity of such an assessment was confirmed by the indication of differences between the number of data published in publicly available global databases and the corresponding numbers given in articles concerning selected geographical areas or types of incidents.
The possibility of releasing nuclear or radiological material into the environment as a result of the stimulation of an explosive charge was analyzed. The paper indicates two possibilities of using an explosive charge for this purpose. The first possibility is to disperse the radioactive material in the environment by means of an explosive method. The second option is to attack an object containing radioactive material with explosives and release this material into the environment.
The paper indicates that the degree of terrorist threat strongly depends on the type of object. Civilian facilities, particularly nuclear power plants, are particularly vulnerable, but military storage facilities are not free of threats, albeit to a lesser extent. It seems certain that terrorists will carry out a spectacular attack with the use of explosives and resulting in contamination with radiological and nuclear materials, but there are still barriers, above all social ones, which prevent them from doing so.

Keywords: terrorist threat, CBRN, radioactive source, nuclear material, explosive, nuclear power plant, trend

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1 Introduction

In a dynamically changing world, extremely anti-human attitudes are becoming more and more common. Terrorism is such a thing, especially one that works mainly by carrying out attacks calculated on the largest possible number of victims. For this reason, analyses, such as [1], on the correlation between the goals of a given terrorist group and the possibility of its use of weapons of mass destruction (WMD) are particularly important. Typically, WMD hazards are considered as use cases for materials belonging to the group of chemical (C), biological (B), radiological (R) or nuclear (N) materials, usually collectively referred to as CBRN.

The terrorist threat caused by the use of CBRN material is an example of a "low-probability, high-impact event". This means that, given the experience of terrorists and the ease of obtaining and using, it can be expected that in attacks aimed at a local effect, CBRN materials will be used much less often in attacks than explosives ("low-probability"). This is primarily due to the comparison of costs. According to [2], the cost of the explosives used in the Madrid attacks on March 11, 2004 was estimated at USD 10,000, while the cost incurred by the Aum Shinrikyo sect to develop the technology for the production of chemical weapons is millions of dollars. On the other hand, more frequent use of WMD can be expected in a situation where terrorists want to take advantage of the fact that the use of WMD can easily lead to enormous and irreparable damage, especially if they want to achieve a global effect ("high-impact event").

Ultimately, it seems realistic for terrorists to use both any CBRN agent and explosives in a single attack. Such a strategy would allow terrorists to create an impression of their power, even if they do not actually possess significant amounts of WMD. Countering this requires explosives researchers to pay particular attention to the problem of how to counter terrorist threats resulting from the simultaneous use of CBRN and explosive (CBRNE) material. In the literature on the subject, the possibility of combining the threats from radioactive

and explosive materials is most often discussed, therefore the presented work focuses on this issue.

In the literature on the subject, it is often indicated that neither terrorists nor their supporters will seek an attack involving a nuclear explosion. It is pointed out that terrorists and their supporters, especially governments, that their use of nuclear weapons will backfire on them [3]. In addition, terrorists lack theoretical knowledge and knowledge of closely guarded technologies, which are a prerequisite for carrying out an attack in a controlled manner leading to a radioactive threat. The argument that "it would go out of control" determined that al Qaeda abandoned the use of the plane to strike the nuclear power plant in planning the attacks on September 11, 2001 [4, 5].

The question therefore arises whether it is possible for terrorists to cause a radioactive threat in such a way as not to condemn themselves to worldwide condemnation. In this light, technologies, equipment and processes related to radioactive materials for civil purposes seem to be particularly threatened. It should be emphasized that, contrary to popular belief, the civilian target of a terrorist attack resulting in a radioactive threat does not have to be the reactor of a nuclear power plant. Enrichment facilities, reprocessing facilities, transporting and storing nuclear and radioactive waste materials [6] may also be involved. Transport and storage issues are of particular concern, as they are much more vulnerable to attack than energy production in a nuclear power plant. In this case, terrorists can act in at least two ways. First of all, terrorists or pirates supporting them can attack a ship and seize radioactive materials during their transport by sea or ocean. In this case, according to [7], the threat of terrorists taking over a ship dedicated to the transport of nuclear materials seems unlikely, but the takeover of a merchant ship carrying, among other things, radioactive cargo is already a real threat. The second possible aspect of terrorist activities within the maritime infrastructure is the smuggling of an unsophisticated nuclear or radiological device into a ship or transport it by container and detonate it in a port [8].

An important aspect of assessing the risks posed by radioactive materials is the effects of their theft and smuggling. As a result of these actions, if terrorists or their supporters have inadequately secured the radioactive material being transported, a radioactive threat can arise anywhere and at any time in public space. The scale of smuggling of radioactive materials is relatively large, which will be shown later in the paper.

Although it is still unconfirmed whether "follower of bin Laden in al Qaeda had in 1993 attempted to purchases enriched uranium in hope of attempting to fabricate a nuclear weapon" [9], in the late 1990s scenarios of attacks with the use of nuclear weapons had to be seriously considered. As a result, nowadays, experts

and senior officials frequently state that this scenario is a matter of "When?," not "If?" [3]. The logical consequence of the question "When?" are the questions "Who?" and "How?". In the literature on the subject, the question of "Who?" has been discussed for many years, *e.g.* [1]. However, when it comes to the "How?" issue, researchers are still at the stage of speculation. This is due to the fact that there are only single cases of the use of radioactive materials, *e.g.* in relation to the so-called dirty bombs, only one case has been identified [10]. On the other hand, in considering other scenarios, there is not a single empirical clue. In the light of the analysis of previous attacks, nuclear energy comes to the first place on the list of possible prospective terrorist activities. This direction is confirmed by the analysis [11], according to which the probability of an attack in the area:

– radiological dispersion bomb: is "medium" to "low, but not nonexistent",
– attacks on nuclear facilities: is "very low",
– nuclear bombs: is „extremely low".

The high degree of complexity of the issue posed in the title of this work, described above, poses the question of whether it is possible to effectively prepare for an attack with the use of CBRNE materials. The basic method of assessing prospective terrorist threats is to analyse data on previous incidents. Many organizations provide databases on terrorist attacks free of charge. While appreciating the contribution of work in maintaining such databases, it should be noted, however, that usually this type of data sets do not meet the expectations of researchers as to the completeness of data. The reason is, among other things, that:

– the database operators generally rely on publicly available reports, mainly press reports, and these are selective and may also be mutually contradictory,
– in databases, in many cases, neither the perpetrators nor their motives are known, so it is impossible to distinguish terrorist activities from criminal activities committed by organized groups, or from acts of sabotage committed by individuals for personal reasons,
– in any country there could have been an incident about which it was not possible to inform the public, *e.g.* due to the secret nature of the activities of state services,
– a serious dilemma is always to what extent the published data can help terrorists in preparing the next attack,
– because these databases collect data from all over the world, it is beyond the financial capabilities of the organizations running these databases to verify information about all incidents.

The aim of the presented paper is to provide an initial discussion of issues important in the analysis of terrorist threats and radioactive materials. The main area of analysis are incidents combining radioactive hazards and the use of explosives.

2. Reliability of data sources

2.1 Primary data source

2.1.1 General characteristics of the Nuclear Facilities Attack Database (NuFAD)

In order to select the most appropriate primary source, data published in the database dedicated to incidents occurring in relation to civilian and military facilities, NuFAD [12], were compared with data published in other sources. As of July 30, 2024, 80 entries were registered in the NuFAD database. One of these entries referred to 13 incidents, so 93 incidents were identified in the years 1961-2014 based on the NuFAD database. These incidents consisted of:

- planning or carrying out an external attack on a nuclear power facility, usually not on the reactor building, but on other facilities located in the nuclear power plant complex,
- entering nuclear power facilities without the intention of carrying out an armed attack,
- violation of the airspace of nuclear power facilities with the use of a drone.
- carrying out an attack on military facilities related to the expected or actual presence of nuclear weapons, such as ballistic missiles or nuclear warheads,
- sabotage that could lead to a serious accident of a nuclear power plant,
- theft and/or smuggling of radioactive materials.

Most of the incidents described in the database concerned civilian objects, which is why the presented work focuses on this data set.

2.1.2 Chronological distribution of incidents

The NuFAD database [12] identified 93 incidents that had or, if the plans were implemented, could be related to unauthorized access to radioactive materials or facilities where these materials could be located. The database covers incidents that occurred over a period of 53 years (1961-2014). The average for the analyzed period is almost 2 incidents per year (1.75). While the NuFAD database showed only 1 incident in the years 1960-1969 (1961, sabotage), in subsequent periods it was from 12 to 28 incidents over a period of 10 years, *i.e.* in the years:

- 1970-1979: 13 incidents,
- 1980-1989: 12 incidents,
- 1990-1999: 26 incidents,
- 2000-2009: 13 incidents,
- 2010-2014: 28 incidents.

2.1.3 Perpetrators of incidents

The percentage share of individual groups of perpetrators of incidents related to nuclear and radiological materials is presented in Figure 1. From the point of view of assessing the usefulness of the data contained in the NuFAD database, attention should be paid to:

– less than half of the incidents (around 42%) were caused by identified or identified as alleged terrorist and anti-nuclear organisations,
– a high percentage (approx. 22%) of incidents in which the origin of the perpetrators has not been identified,
– a significant share (approx. 25%) of incidents related to theft and/or smuggling of radioactive materials.

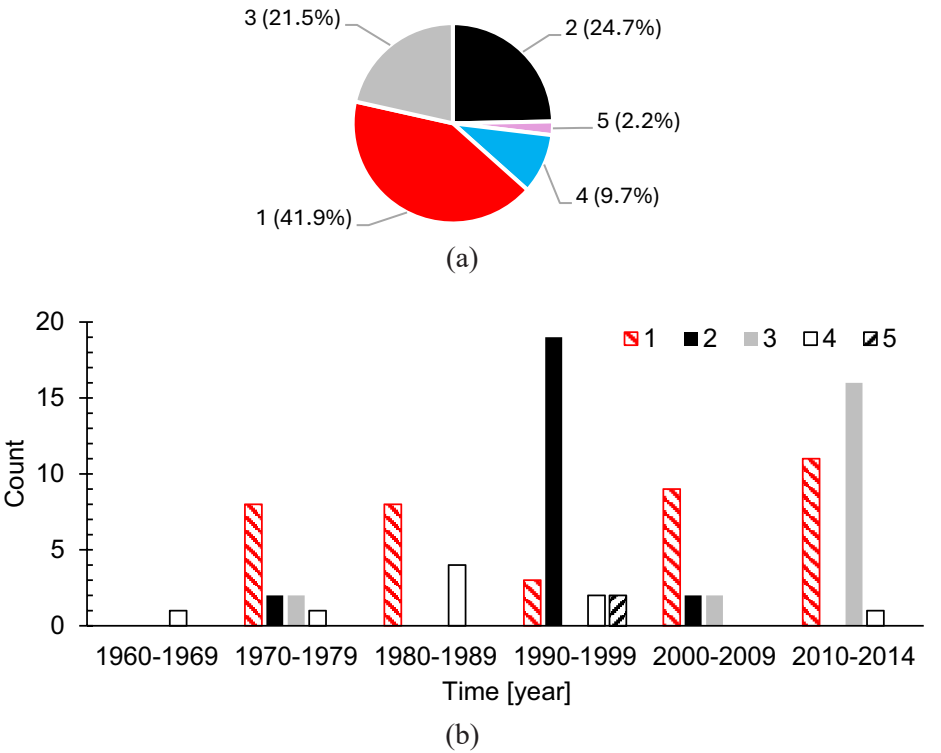

Figure 1. Percentage share of the main groups of perpetrators of incidents in the years 1961-2014 (a) and the activity of individual groups in chronological order (b): 1 – terrorist or anti-nuclear organization, 2 – thief or smuggler, 3 – unknown, 4 – sabotage, 5 – individual; own study based on [12]

Figure 1(a) shows that between 1961 and 2014, organized groups (terrorists and anti-nuclear activists) were the most common group of perpetrators of incidents resulting in a real or potential threat of radioactive material contamination (42%). The organizations operated practically throughout the analyzed period, with the maximum of their activity (11 incidents) falling on the years 2010-2014 (Figure 1(b)). The organizations acted for the following reasons:

– political (mainly separatist): 8 organizations and 12 incidents with a maximum in the 1970s,
– anti-nuclear: 10 organizations and 19 incidents with a maximum in 2010-2014,
– terrorist crimes: 7 organizations and 8 incidents with a maximum in the years 2000-2009.

Due to the scale of the threat to the operation of nuclear power plants, the sheer number of incidents is not a reliable parameter. Protests by anti-nuclear organizations, such as Greenpeace, although numerous, did not pose a significant threat. They mainly consisted of crossing the fence and hanging banners on the buildings. Despite the generally peaceful form of protests by anti-nuclear organizations, attention should be paid to the possible additional threat caused by this type of action. The activities of the anti-nuclear organization can help terrorists get to the power plant. The possibility of a terrorist entering together with activists of an anti-nuclear organization is real, because it is possible that not all participants of such a protest know each other personally. Between 20 and 150 people took part in the Greenpeace protests. In addition, there were international protests, *e.g.* in the Fessenheim Nuclear Power Plant (18.03.2014) 60 activists from 14 countries took part [12]. On the other hand, the security of the facility, observing the development of the incident, cannot immediately step in very decisively, due to the possible negative public perception of taking forceful action.

In most cases, the database [12] assigned individual incidents to individual organizations. Criminal activity (theft and smuggling) peaked in the 1990s (19 incidents). No criminal activity related to radioactive materials in the years 2010-2014 was found in [12]. Throughout the period analyzed, there were sabotages at nuclear power plants, and in no period did these incidents account for more than 5 incidents – the maximum was 4 incidents in the 1980s.

It should be emphasized that the database [12] cites data on acts of sabotage. The relatively small number of such incidents does not mean that it is a minor factor. Since the perpetrator of sabotage may be primarily an employee of the power plant, *i.e.* a person familiar with the principles of operation of the power plant, if such a person acted in concert with terrorists, he could lead to a serious

failure of the power plant. It is worth noting that there have been acts of sabotage as a protest against insufficient security measures, *i.e.* the perpetrators of sabotage did not have hostile intentions and wanted to prove the existence of gaps in the power plant's safety system.

The dominant share of incidents caused by unknown perpetrators in the period 2010-2014 (16 incidents) is due to the intensification of incidents involving drone intrusion into the airspace of a nuclear power plant.

2.1.4 Incidents related to the plan of use or the use of explosives

De Cauwer *et al.* [13] identified in the Global Terrorism Database™ 97 incidents against the nuclear industry in the period 1970-2020. After verification, they left 91 incidents, *e.g.* they rejected an attack on a politician who had been a nuclear physicist before starting his political career. On the basis of 91 incidents, with regard to civilian and military aspects, De Cauwer *et al.* [13] concluded that bombings and explosions were the most frequently identified attack type (n = 40; 44.0%), followed by facility/infrastructure damage (n = 24; 26.4%) and armed assaults and assassinations (both n = 7; 7.7%).

In our own research on the use of explosives against nuclear power facilities only, it was determined that 14 incidents were recorded at the NuFAD base between 1973 and 2000, with an operating nuclear reactor being the target in only 4 incidents. In 8 incidents, the target was a reactor under construction. The largest number of incidents (10) took place in the years 1973-1978. In the 1980s, only 4 incidents were recorded (2 each in 1982 and 1985). Only 1 incident in the year 2000 was described, and it is assumed that it was an attack for criminal reasons. The attacks used:

– explosive devices: 12 incidents,
– missile weapons: 1 incident,
– firearms: 2 incidents.

In 12 incidents, the perpetrators were identified. The Basque nationalist separatists group (ETA) was responsible for 4 incidents and the communist guerrillas in the Philippines for 2 incidents. After one attack, they made:

– Breton Separatists (1975),
– Red Army Faction (RAF),
– Environmental Assault Unit of the NWLF,
– Do-It-Yourself Group 007,
– Pacifist and Ecologist Committee Chaim Nissim (subsequent Geneva Green Party MP),
– uMkhonto weSizwe (MK) wing of the African National Congress.

In the above list, it is worth noting the participation of pacifist and pro-

ecological organizations by force. More specifically, Pacifist and Ecologist Committee Chaim Nissim carried out the coup using five Russian-made anti-tank rockets.

2.2 Discrepancies

The first reference point for assessing the data in the NuFAD database was the Global Terrorism Database™ (GTD). It should be noted that although the NuFAD and GTD databases come from the same source, *i.e.* the National Consortium for the Study of Terrorism and Responses to Terrorism (START), the data sets obtained for the studied topic in both databases were different. In the GDT database, an additional 21 incidents were recorded. These incidents were not related to attacks on objects related to radioactive materials, but on, for example, employees or politicians seeking to build nuclear power plants.

The NuFAD database lists 3 terrorist attacks on nuclear power plants in Europe in the years 1961-1977, while [6] states that 10 terrorist attacks of this type took place in Europe during this period. Further, the NuFAD database in 1979 did not mention any incident, while [6] reported that a terrorist attack had taken place in 1979 resulting in serious damage. Between 1969 and 1975, only 2 incidents at nuclear power plants related to the use of explosives were mentioned to the NuFAD base. Meanwhile, according to [6], during this period there were 14 actual and attemped bombings of U.S. nuclear facilities and 240 bomb threats.

For outsiders, serious repercussions may be caused by the illegal – and probably also improperly secured – transport of stolen radioactive materials. According to The International Atomic Energy Agency's (IAEA) Incident and Trafficking Database [14], between 2010 and 2014 there were 160 cases of theft and therefore illegal transport of radioactive materials. This is almost twice the number of all incidents described in the NuFAD database, which also includes cases of theft. According to [15], over the period of 1992-2009, a total of 24 incidents involving nuclear material thefts and smuggling have been recorded in all three Baltic states, including 14 in Lithuania. On the other hand, there are no data for Estonia and Latvia in the NuFAD database, while there are 2 incidents for Lithuania, both in 1992, with only 1 of them involving the theft of radioactive material. In turn, [16] states that in the period 1991-2012, 630 incidents with radioactive materials were recorded in 10 countries located in the Black Sea region, 5 of which involved highly enriched uranium (HEU). Ursu [17] cites data from the Database on Nuclear Smuggling, Theft, and Orphan Radiation Sources (DSTO), according to which 90 nuclear material incidents were registered in Russia between 1992 and 2012, including 15 cases of HEU, 13 cases with low enriched uranium, and 62 cases of radiological material involvement. Ursu also

lists 5 incidents with HEU in other countries:
– 1999: Bulgarian-Romanian border, 10 g 75% HEU,
– 2003: Georgia-Armenia border, 170 g 89% HEU,
– 2006: Tbilisi, Georgia, 80 g sample from a batch of 2-3 kg of 89% HEU,
– 2010: Tbilisi, Georgia, sample 18 g of 89% HEU,
– 2011: Chisinau, Moldova, 4.4 kg HEU.

There are no incidents occurring in Bulgaria, Romania and Georgia in NuFAD database, however, there is only 1 incident from 1992 in Moldova.

It is known from [18] that in the U.S., members of the Evan Mecham Eco-Terrorist International Conspiracy (EMETIC) were arrested in May 1989 on charges relating to planned incidents at several nuclear power plants in the U.S. Information about these plans has not been made public in the NuFAD database, although this database includes data on incidents involving planning an attack.

3. Terrorists and the Warfare of Mass Destruction (WMD)

3.1 The reality of the threat of WMD being used by terrorists

The question of the reality of the threat was posed and resolved, in the only reasonable way, in the 1990s. It was considered that there were no grounds to conclude that the issue of the threat to the use of radioactive materials by terrorists could be omitted. The basis was the recognition that terrorists aim for as many victims as possible. Today, terrorists are usually not interested in escalating the number of victims, but at the time, the general feeling indicated that they were striving to achieve this goal. As is well known, only the use of WMD ensured that terrorists achieved this goal at that time. According to [9], the RAND Chronology of International Terrorism database has registered 481 attacks in 1991. Although in 1996 only 250 attacks were recorded in this database, it was the year with one of the highest numbers of fatalities in the history of attacks so far (510 killed). On the other hand, at that time there were reports of threats to the use of WMD by terrorists, *i.e*. measures to obtain as many victims as possible. In the literature, m.in are mentioned such actions as those proving the will to use WMD as:
– 1993: It was determined that the bombers who planned the first attack on the World Trade Center (1993) planned for their bomb to release cyanide in the explosion [4],
– 1999: It was reviled that the arrest of an Algerian terrorist on the U.S.-Canadian border foiled a plan to detonate a large bomb at Los Angeles International Airport. The same terrorist had studied how to place lethal chemicals in air-conditioning intakes [4],

– 2001: In the U.S., after the September 2001 attacks, it was noted [19] that at that point the most catastrophic consequences for Washington D.C. could have been caused by hitting a water treatment facility located roughly a mile away from the Capitol or the White House. Chlorine gas was stored there in rail cars, unprotected and unguarded. It was estimated that the rupture of just one rail car with chlorine, out of more than 400 such tanks located in that place at that time, could have placed 1.7 million people at risk,
– 2003: al Qaeda planned to release hydrogen cyanide on New York's subways [4],
– 2005: British authorities say that they thwarted a plot begun in 2004 to release deadly gas or chemicals at the Houses of Parliament in London; plotters reportedly were also considering the London subway system as a target [4].

To complete the picture, it should be added that the situation has not changed today. In addition to the well-known issues related to chemical weapons in Iraq, the use of chemical weapons in the Russian-Ukrainian war is suspected [20]. The use of chemical weapons in this war may translate into an analogous retaliatory action of a terrorist nature.

Figure 2, based on data from 1990 to 2024, published in the CBRN Event Database [21], illustrates the frequency of incidents with CBRN materials. At the end of 2024, the CBRN Event Database collected information on several hundred different types of activities related to CBRN materials – from planning, through preparations, to incidents. This is a negligible number compared to the total number of terrorist attacks, even in relation to individual years. According to [22], in 2023, 3350 attacks were carried out worldwide, and in 2022 there were 4321. In the Global Terrorism Database™ (GTD) [23] one can find data on over 200000 terrorist events around the world from 1970 through 2020. On the other hand, according to [23], there were 88000 bombings in this period (44%).

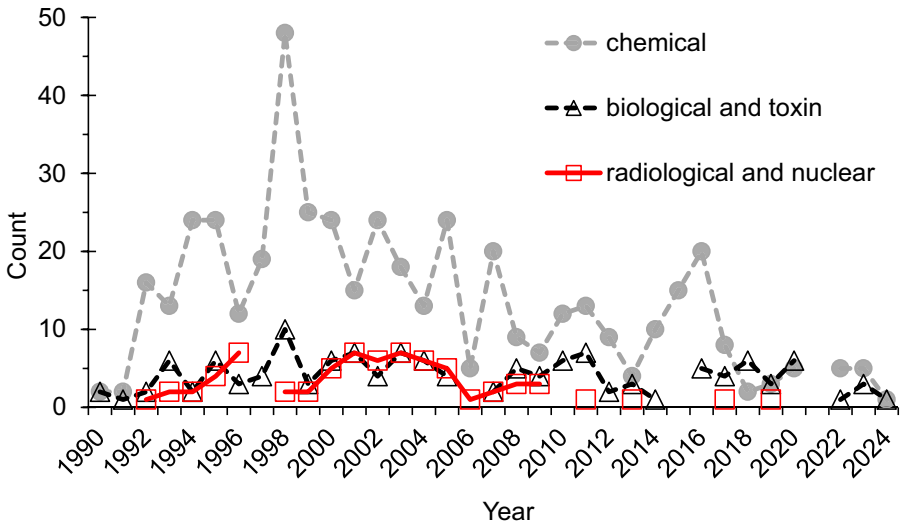

Figure 2. Number of incidents involving CBRN materials; own study based on [21]

Figure 2 shows a clear variation in the number of events depending on the type of CBRN material. Historical data indicate that terrorists were much more interested in chemical substances than biological weapons or radioactive materials (both in the form of nuclear warheads and industrial or military radioactive materials). The special importance of chemical hazards is also confirmed in many other sources. However, no one advocates the complete exclusion of the threat of an attack with the use of radioactive materials, as negligible compared to the threat posed by chemical weapons or by toxic substances or industrial materials.

For the reasons presented above, the available databases leave much to be desired, *e.g.* they do not clearly distinguish between a terrorist attack and a common criminal act. Nevertheless, it can be assumed that the proportions presented in Figure 2 reflect the trends in the scale of the threat of WMD use by terrorists and the proportions between individual types of WMD. Between 1990 and 2024, the use of radiological and nuclear materials, *e.g.* HEU, was sporadic. Since around 2010, biological weapons have become more important than radioactive materials, but the use of chemical weapons and chemicals is still more common in terrorist attacks than other types of WMD.

3.2 Terrorists' interest in radioactive materials

The literature on the subject describes many arguments justifying the need to both prevent and prepare for a large-scale terrorist attack with the use of radioactive

materials. The most famous reason is the so-called 1% doctrine, also known as the Cheney doctrine. This doctrine was propagated in Suskind's book [24]. Other arguments are, for example, in chronological order:

- 1985: The Liberation Tiger of Tamil Eelam (LTTE, Tamil Tigers), Sri Lanka, planned to obtain radioactive material from a nuclear power plant or medical equipment and spray it from a small aircraft over a government military base. Although the terrorists abandoned this plan, this course of action remained in the sphere of interest of the heads of the LTTE [9],
- 1987: It was stated in [6] that while being held by the Italian Red Brigades, General Dozier was interrogated about NATO and U.S. nuclear weapon locations, and members of Germany's Red Army Faction have been apprehended with maps and drawings of nuclear storage sites and security patrol routes. Ponadto, podano że The efforts of Libya, a supporter of terrorism, to obtain nuclear weapons have been documented.
- 1998: Osama bin Laden's December 23 interview with Time Magazine said that Osama bin Laden considered it his duty to acquire such weapons and to resign from possession of them as a sin [2, 4, 25].
- 2004: A dirty bomb (Semtex, thermite and caesium-137) detonated at Oxford Street in London [10].
- 2015: President of U.S. said that "No threat poses as grave a danger to our security and well-being as the potential use of nuclear weapons and materials by irresponsible states or terrorists." [26].
- 2009: In the opinion of the U.S. Department of State [27], serious treatment of the threat of attacks with the use of m.in. radioactive materials results from, for example:
  - *(i)* the fall of the former Soviet Union and the existence of other failed or weakened states have increased the probability that terrorists or their facilitators will seek to steal or smuggle – among others WMD – also to nuclear weapons stocks,
  - *(ii)* the Internet – most recently, particularly Darknet [28] – and the development of digital and mobile communications, and the onset of globalization and other technological advances have enabled terrorist groups to acquire quickly the expertise and coordinate the delivery of WMD through extended, transnational networks. It is worth noting that even generally respected organizations can be a source of at least basic knowledge about the principles of radioactive material production, including not only knowledge of historical significance [29, 30], but also more recent knowledge [31].

- 2016: several institutions in Slovakia, including the Ministry of Justice, district courts, and a regional police office received suspicious envelopes containing the radioactive material americium-241 [28],
- 2015: In Belgium during a house search of a suspect linked to the November Paris attacks, a video was found containing surveillance footage of a senior executive of a nuclear research site. However, there is no evidence that the terrorist's intention was to actually steal nuclear material. [28],
- 2017: Indonesian police arrested five suspects who were members of the Jamaah Ansharut Daulah (JAD), an IS-linked group. The suspects were trying to transform low-grade radioactive thorium 232 into uranium 233, as instructed by *Nuclear for Dummies*, a forty-seven page Indonesian-language bomb manual written by JAD leader Bahrun Naim. This was a work of fantasy, as the required transformation needed a nuclear reactor and therefore was clearly an impossible task for terrorists working in a domestic environment. Nevertheless, the case highlights continued efforts by jihadist terrorists to acquire a device of mass destruction, as claimed on IS's social media [28].
- 2019: terrorists were willing to buy 40 g of U-238 for $2.8 million [28], indicating that terrorists do not care about the cost if they can obtain radioactive materials.

It should also be remembered that the opinion that terrorists want to provoke those they consider enemies to such actions that will radicalize the hitherto moderate Muslims to such an extent that they will be accepted – one might add an "apocalyptic" – lose-lose scenario [32]. In addition, the "catalytic" effect of the attack in the US on September 11, 2001 seems to have worked. On the one hand, there was the knowledge that in the 1990s the number of international terrorist attacks was several hundred per year. There was also an awareness that radioactive materials were available on the black market – *i.e.* also within the reach of terrorists [33-35], and that these could be significant quantities. For example, according to [15], in 1992 there were attempts to sell in Lithuania a nuclear fuel rod weighing around 270 kg (2% HEU) stolen from a nuclear power plant, and in 1996 – 100 kg of uranium-238 stolen from a company responsible for nuclear waste management. In 1996, there were also attempts to sell 13 kg of U-238.

At the beginning of the 21st century, a factor increasing the threat of nuclear terrorism on a global scale was the activity of Pakistani nuclear scientist, Khan, had developed a transnational nuclear proliferation network reaching from Southeast Asia to Europe, and was making available sensitive technology and WMD-related materials to rogue nations willing to pay [36-39].

Radioactive materials are a potential tool in the hands of terrorists in attacks involving nuclear explosion or dispersion in the vicinity of radioactive material. This type of attack may consist of, for example:

– initiation of military nuclear explosive devices, *e.g.* nuclear warheads,
– dispersion of radioactive material in the environment, without leading to a nuclear explosion, which may result from the use of a radiological dispersal device, RDD. A well-known example of RDD is the so-called dirty bomb [28, 40-43].
– in a non-explosive manner, spraying in the air (*e.g.* using an airplane) or introducing into the aquatic environment, or placing in a public place, the so-called radiation exposure devices (REDs), also called a "hidden sealed source," that can expose civilians to lethal or debilitating doses of radiation. REDs, constructed from partially or fully unshielded radioactive material, can be hidden from sight in a public place. [28]
– causing a failure of an industrial installation, primarily a nuclear power plant, resulting in the emission of radioactive material.

Other sources of fissile material include weapons, such as ballistic missile warheads, and military materials, such as fuel for nuclear submarines. As in nuclear energy, also in this case, procedures and technical measures have been implemented to prevent any hostile action, including a terrorist attack. For terrorists, medical and industrial devices are a potentially important source of materials that pose a radiation threat, without resorting to attacks on energy or military facilities.

3.3 Nuclear power

The more sources of radioactive materials, the easier it is for terrorists to gain access to them [3]. However, in Europe, although in some countries energy production in nuclear power plants is being liquidated (Germany), in others investments are being made in nuclear energy, also at the level of uranium mining (Romania [44]). It is estimated that in 1997 more than 700 tons of plutonium were stored in highly radioactive spent nuclear reactor fuel [45]. In 2001, it was estimated [46] that there were a total of 450 tons of military and civilian plutonium and over 1700 tons of HEU in 32 countries, of which 1306 kg of civil HEU were in 27 countries. In 2014, on the other hand, [47] a total of significantly more plutonium (2627 tonnes) and significantly less HEU (1377 tonnes) were stored worldwide.

In the US, a drastic change in the approach to nuclear threats, as in many other areas, took place after the attacks in September 2001. According to [19], immediately after these attacks, it was feared that the next target would be one

of the 103 commercial nuclear power plants. A heightened state of alert at all nuclear plants was immediately decreed and legislative initiatives were taken regarding security requirements for nuclear facilities. The aim of the actions taken was to prevent terrorists from doing things like [19]:

– deliberate crashes of airliners,
– use of truck bombs,
– sabotage by plant "insiders,"
– military-style assaults by groups of armed individuals,
– attacks using biological and chemical agents, and
– cyber attacks.

On the other hand, due to the risks associated with the energy production technology of nuclear power plants (high pressures and temperatures, radiative radiation) and the required resistance to environmental factors (hurricanes, fires, droughts, earthquakes), nuclear power facilities are designed, built and controlled in such a way that they appear to be probably the strongest, most secure industrial facilities ever constructed. Also, the destruction of a system in a nuclear power plant will not cause its immobilization or destruction, because all its important systems must be completely redundant and independent of each other. In addition, tests are carried out to withstand the hazards of nuclear power plant components, *e.g.* in 1988 a test was carried out in the USA simulating a direct collision of an F-4 fighter with a wall simulating a structural element of the power plant [19]. In the context of the 1987 study considering this type of threat [6], attention should be paid to the lack of information in the results of the strike of a military aircraft, but which is a carrier of explosives. There is also an opinion [46] that the impact of a passenger plane with full fuel tanks could lead to a failure of the reactor cooling system of the nuclear power plant, and consequently to Chernobyl-like contamination. In the study cited in [19], the aircraft shattered into pieces and only penetrated about 5 cm into the reinforced concrete wall. Nuclear power plants are also required to protect against the effective use of truck bombs like the one used in Oklahoma City (1995). These are barriers which, when raised, are to prevent such a vehicle from reaching a place where its explosion could critically harm the power plant. Nuclear power plants are also protected against an effective cyber attack as standard. According to [19], nuclear power plants do not use computers to control their operation. Computers only provide employees with information about the status of devices and the course of processes. Employees control the operation of the power plant using wired networks, without the use of computer systems. Through the legal requirements allowing the power plant to be launched, it is ensured that procedures are in place and verified, through exercises, in the event of attacks from external armed groups and saboteurs

inside the plant [19]. In particular, a nuclear power plant must be prepared for violent external assault, attack by stealth, or deceptive actions, of several persons assumed to have military training, automatic weapons and explosives, a vehicle for transportation, and assistance by an insider within the plant.

The need to maintain close attention to threats to the nuclear power plant infrastructure also results from the fact that regardless of whether the attack is carried out by terrorists or by another group, *e.g.* a criminal group, a local community opposing a given construction, or by a group striving systemically to prevent the operation of nuclear power plants, it – if successful – may bring catastrophic consequences. In addition, most aspects of the attack on the nuclear power plant are well described, but a rarely raised argument is that limiting and hindering energy production in nuclear power plants is profitable for terrorists associated with Arab states. Difficulties in the use of nuclear fuel result in greater interest in fossil fuels, in particular oil, which is the main source of income in Arab countries.

Although this is the domain of activities other than terrorist, the possibility of attacking a nuclear power plant during hostilities is also an important aspect. In other words, terrorists can use the fact that military operations are carried out in the vicinity of the power plant for their own purposes. As early as 1992, Stritar and Mavko [48] were considering the possible consequences of a fighter jet hitting a nuclear power plant building during hostilities. In the case of the Russian-Ukrainian war – in view of the fact that it is limited to verbal declarations and the lack of action in this direction – the possibility of including the destruction of the nuclear power plant in military plans may – at least for the time being – be treated only as an element of the information war [49]. Of course, the seizure of an enemy nuclear power plant is an expected goal of tactical operations [49], but warfare is usually about the continued use of the enemy's resources, not their destruction. The issue of the impact of the Russian-Ukrainian war on the level of nuclear threats is an important starting point for further analyses, such as in [13].

4 Discussion of Results

In the literature on the subject, an analysis of two directions of potential terrorist activities is usually undertaken. These are the use of nuclear weapons or the so-called dirty bombs. Since both of these fields of study require specialist knowledge, large financial resources and hard-to-find equipment and materials, it can be expected that the interest of local terrorist organizations, *i.e.* those

pursuing mainly political goals in their country, will always be negligible. This results from the analysis of profits and losses caused by carrying out this type of attack, because killing people is not their ultimate goal. Unfortunately, the situation is not clear-cut. It is different if one considers the possibility of an attack by terrorists aimed at ideological goals, or even – as in the case of the Aum Shinrikyo sect in Japan – to bring about the end of the world. In this case, the goal of a small terrorist organization may also be to achieve as many victims as possible. The decisive question will be whether or not other WMD resources with comparable effects will be much more readily available.

The situation is different with regard to international terrorist organizations. In the literature on the subject, it is stated that terrorist groups dependent on material support from the local community avoid increasing the number of civilian casualties. On the other hand, terrorist organizations with external funding, *i.e.* mainly international ones, more often attack in public places and do not pay attention to minimizing the number of victims. For such organizations, carrying out an attack with the use of radioactive materials is also a signal to their supporters that they are a strong organization and one that is worth supporting.

In the light of the above considerations, it can be assumed that the issue of the terrorist threat in relation to nuclear technologies will never be abandoned. As a result, in Sweden, in 2024, the exercises in response to a terrorist attack on a nuclear power plant were part of training organized by the Swedish Defence University [50].

5 Nuclear Power Plant Safeguards

Nuclear power plants are among the least vulnerable and most resilient critical infrastructure to terrorist attacks [19]. As a result, terrorist attacks on nuclear power facilities have been recorded for more than 50 years, but there are no reports of such destruction of a nuclear power plant during a terrorist attack that it would be necessary to shut it down completely or that there was an environmental threat caused by the release of radioactive materials.

Causing an accident in the field of nuclear energy allows to achieve at least three effects, important for terrorist organizations. The first is to prove that you are a party to be reckoned with. The second reason is the long-term and deadly contamination of a large area, including those beyond the borders of one country. The third reason is that an effective terrorist attack in this area (exclusion from the power grid) may cause an imbalance in the energy balance of a given country. This threat is particularly real for countries that base their

energy sector on a small number of nuclear power plants. Terrorists following this premise may be considered unrealistic in relation to countries with several dozen power plants, *i.e.* it seems unlikely that a dozen or so terrorist attacks on nuclear power plants could be carried out simultaneously and effectively.

In the early 21st century, in India, areas of exploration for technological safeguards in nuclear power plants included [51]:

– in the range of sensors:
  (i) imaging sensors: infrared, multispectral, nonintrusive millimeter wave, and behind wall imaging,
  (ii) intrusion sensors: all-weather and all-terrain, economical sensors with a very low incidence of false and nuisance alarms,
  (iii) contraband detection sensors: personnel, baggage, and vehicles for explosives and metal (*e.g.* weapons), – radiation and nuclear material sensors,
– in the range of surveillance:
  (i) personnel access control: biometrics (positive identification),
  (ii) alarm assessment: – automatic alarm assessment with intruder characteristics,
  (iii) all-weather day-night surveillance: – robotics: automated, remote-controlled vehicles and group intelligent, mobile machines that carry out specific tasks (*e.g.* detection and deactivation of explosives, chemical and biological agents),
– in the range of research in safety: – safety-related technologies, – computer modeling, simulation, and analysis of willful malevolent acts that raise safety concerns,
– in the range of root-cause analysis: design implications and social dynamics. Safety and security culture was also an important research area [51].

In the 1980s, a law was introduced in the USA allowing for detailed control of nuclear power plant employees [6]. On the other hand, not all facilities on the site of a nuclear power plant are equally strongly protected. According to [5], in 2005 it was recognized in the USA that it was possible to contaminate the environment with radioactive materials in the event of a terrorist attack on spent nuclear fuel depots. This resulted in the 2006 budget providing $21 million for the Nuclear Regulatory Commission to carry out the site-specific analyses recommended by the National Academy of Sciences [5]. As far as the fuel used is concerned, it should be emphasized that there are different technical conditions in different countries. In some countries, landfills for spent fuel are relatively few, *e.g.* in France and the USA. In other countries, there are relatively many more landfills and they are scattered throughout the country, *e.g.* in India. The

advantage of the latter solution is that there are smaller amounts of fuel used in a given place, while the disadvantage is that there are higher operating costs of the entire storage system.

Another belt of defense against the effects of a potential terrorist attack mentioned in [19] is to have rescue procedures in place in case the attack proves effective. As a result, as stated in [5], the U.S. requires the development of evacuation plans for people within a radius of about 16 km (10 miles) from the scene of the incident and the provision of additional protective measures, such as providing iodine pills [5].

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5 Conclusions

- In the 1990s, when considering the likelihood of a terrorist assault involving radioactive materials, it was considered that this scenario is a matter of "When?", not "If?"tags. In the presented work, attention was drawn to the fact that the result of the assessment of the threat of a nuclear or radiological attack depends not only on the availability of radioactive materials, but also on many other factors, m.in. the geographical area and the nature and wealth of terrorist organizations operating in a given area. As a result, the risk of using radioactive materials can never be completely ruled out. In such a situation, the only reasonable solution is to assume that this type of attack is always possible. As a result, the focus was on the consequence of the "When?" question, *i.e.* the question "How?". In particular, two possibilities for the use of an explosive charge to release nuclear or radiological material into the environment were initially analyzed. The first possibility is to disperse the radioactive material in the environment by means of an explosive method. The second option is to attack an object containing radioactive material with explosives and release this material into the environment.
- A key limitation to the ability to draw reliable conclusions from data in publicly available databases on terrorist incidents is the lack of certainty that a given dataset is representative. The paper cites examples of issues related to terrorist incidents involving CBRNE materials, especially nuclear and radiological materials. Significant differences were indicated between the number of data published in publicly available global databases and the

corresponding numbers given in articles concerning selected geographical areas or types of incidents as listed in the databases.

- The threat of a terrorist attack with the use of radioactive material is increasingly treated as real, but it varies depending on the type of material and the possible technique of its use. The use of radioactive material intended for military applications, such as a nuclear warhead, is much less likely than the use of radioactive materials used in civilian industry, such as medicine or energy. In the second case, special care is related to the use of the so-called small bomb.
- The fact that accidents in nuclear power plants do occur, combined with the release of radioactive materials into the environment, indicates that there are always reasons for terrorists to expect that the bombing of a nuclear power plant may end up with the consequences they expect.
- The paper indicates that the degree of terrorist threat strongly depends on the type of object. Civilian facilities, especially nuclear power plants. They are particularly vulnerable due to their symbolic significance and the worldwide fear of a repeat of the Chernobyl disaster. On the other hand, terrorists usually do not aim at such a far-reaching attack. Military warehouses – although to a much lesser extent, due to the security measures present in them – are also not free from terrorist threats, although in this case the most important threat is the theft of nuclear materials and – due to their possible unprofessional security – the threats arising during their transport and smuggling.
- Terrorists may have the means to carry out both a nuclear explosion using a nuclear warhead and a reactor explosion at a nuclear power plant (Apocaliptic or doomsday scenario), but this can only happen in a situation of extreme escalation of the conflict (lose-lose scenario). The basic barrier to carrying out this type of attack is the fear of terrorists that by carrying out this type of attack they will completely lose social support and provoke everyone to fight them.
- Efforts to build and maintain publicly available databases on terrorist attacks should be appreciated. Nevertheless, it seems that it is unrealistic to build a publicly available and reliable database on terrorist incidents, especially with regard to WMD-related incidents. The basic problem is access to data sources and the costs of their verification.
- Preventing the occurrence of a terrorist attack involving the use of CBRN materials and explosives requires that researchers dealing with explosives pay special attention to how to counteract this type of threat.

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