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Investigation of Damage from Radiological Dispersal Device

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ABSTRACT

Software platforms can be used to assess the radiological impact of potential releases of radionuclides. They are essential tools for use in controlling routine releases to the environment, as well as for planning the measures to be taken in case of accidental releases, for predicting their impact and for the probabilities of using a „dirty bomb". The purpose of this development is: the impact study of Pasquill-Gifford atmospheric stability classes on radiological risks and decision-making. The risk of developing leukaemia was used as the target outcome. The correlation between leukaemia risk and changes in Pasquil–Gifford stability classes was estimated since radioactive contamination from Radiological Dispersal Device in the lower atmospheric layers. The main expected contribution is provision of rapid and essential information on development as a result from radiological event.

Keywords: Radiological dispersal device, accident, assessment, simulation, radionuclides, radiation protection, CBRN protection.

1. INTRODUCTION

NATO member states are exposed to asymmetric threats from national and international terrorism, such as the attacks on the United States in 2001, Turkey in 2003, Spain in 2004, and the United Kingdom in 2005 [1, 2]. These events include to add the at least 19 serious terrorist attacks prevented by the authorities in Europe since September 11, 2001. Suicide terrorist attacks are the deadliest form of terrorism because, although they account for only 3% of all terrorist attacks, they were the cause of death for 48% of the victims of terrorism in the period 1983-2003 [3-5].

There are several suitable radioactive sources which are used in research centres, medical facilities, industrial and military. The possibility of their being used for terrorist purposes varies depending on the source and type of isotope. Every year, there are hundreds of cases of stolen, abandoned or lost medical or industrial radioactive substances around the world. Radiological leakage includes leakages during accidents, indirect damage, or organized sabotage of nuclear, industrial, or medical facilities containing (possessing) radiological material [6, 7].

Radiological dispersal devices (RDDs) do not deliver large doses of radiation to kill people or cause health damage. Furthermore, depending on the situation, an explosion of an RDD can lead to fear and panic, environment pollution, and have significant decontamination costs. Providing quick and accurate information to the public can prevent the panic sought by the people who will use it, e.g., terrorist organizations [8].

A „dirty bomb" differs significantly from a nuclear weapon in terms of damage. A nuclear bomb creates an explosion that is many times more powerful than that of a „dirty bomb". The radiation cloud from a nuclear bomb can spread from tens to hundreds of square kilometres, while the radiation from a „dirty bomb" can be dispersed within a few kilometres of the explosion [6].

The local contamination will depend on size of the explosive, amount and type of radioactive material used, means of dispersal, and weather conditions. Those people closest to the ground zero RDD will be most likely to suffer radiation doses and will be injured from the overpressure. Immediately identification of the radioactive material used will greatly assist authorities in alerting the community to protective measures [8].

According to [8], a radiological dispersal device is „any device, including any weapon or equipment, other than a nuclear explosive device, specially designed to use radioactive material by dispersal to cause health effects or death by radiation."

There are limitations in the manufacture of a radiological dispersal device arising from source's ionizing radiation. To prepare the source for effective dispersal by removing shielding, developers would risk exposing themselves to lethal doses. Difficulties exist in delivering the device and causing successful dispersion of radioactive material. Moderately radioactive sources of gamma and beta radiation (containing up to several hundred curies) or alpha radioactive substances are of interest so that they can be handled safely [9-11]. A suitable substance for this type of device is a radionuclide with a relatively long half-life and high specific activity. According to [10], the radioactive materials relevant for the development of a RDD are listed in Table 1. According to [10] dozens of radionuclides are used in various sealed sources, only a small number are in concentrated amounts or widely available.

Table 1 Radioactive isotopes suitable for RDD

Isotopes	Half-lives (years)	Specific activity Ci/g
^{241}Am	430	3.5
^{252}Cf	2.6	540
^{137}Cs	30	88
^{60}Co	5.3	1.1
^{192}Ir	0.2	9.2
^{238}Pu	88	17
^{210}Po	0.4	4.5
^{226}Ra	1.6	1.0
^{90}Sr	29	140

The spread of radiation by a radiation-dispersing device can affect large areas depending on atmospheric stability. This type of incident can potentially paralyze a city or country, significantly affecting economic, political, and social development. The magnitude of the impact depends on factors including the local population, climatic conditions, and the assessment of radiation doses [10].

Radioactive particles can be portable or fixed, most of them are small, from millimetres to several centimetres, enclosed in capsules for measuring instruments. Most sources are encapsulated or sealed in stainless steel, titanium, platinum, or other metal housings, and the gamma emitters are enclosed in dense shielding (such as lead) to reduce external gamma radiation. Only some of the materials listed above are considered likely radioactive sources for RDD based on portability combined with relatively high levels of radioactivity. Those with minimal amounts of radioactivity, for example, smoke detectors, brachytherapy needles, are not a concern. Radioactive waste from nuclear power or weapons facilities is also considered a possible source [12, 13].

The radiological risk for the individual who received radiation exposure while working with radioactive sources is calculated using the equation:

radiological risk $= \Sigma_{i=1}^{M} ETF(t)xSF(t)xS(0)xRCxED,$ (1)

where:

- RC– risk factor for external radiation (risk/y) / (pCi/g);
- $SF(t)$ – half-life of the radionuclide;
- ED – exposition;
- ETF – time t, g/y;
- S – radionuclide concentration in the soil, at $t = 0$ [14].

Software platforms can be used to radiological impact assess of actual and potential releases of radionuclides to the environment. They are essential tools for use in controlling routine releases to the environment, as well as planning measures to be taken in case of accidental releases, predicting their impact, and probabilities of using an RDD. Software platforms enable evaluation of radiation events in various aspects. Several platforms must often be used alone or in combination to address the possible effect of using radioactive sources.

The purpose of the report is to examine the impact of the vertical stability of the atmosphere on radiological risks and decision-making. We demonstrate how changes in stability classes can affect the radiation dose from RDD use and ultimately increase the risk of diseases caused by penetrating radiation. In this study, the risk of developing leukaemia was used as the target outcome. The correlation between leukaemia risk and changes in Pasquil-Gifford stability classes was assessed as radioactive contamination in RDD spreads to the lower atmosphere. Changes in atmospheric stability classes should be considered as a factor that may change risk levels. Such changes may impose new criteria for prediction based on the radiological risk posed by the total Total Effective Dose Equivalent (TEDE) equivalent effective radiation dose to the affected population.

The main expected contribution of this development is provision of rapid and essential information on the future development of a radiological event. The limits of radiation contamination are set considering some selected reference levels, namely those for acute radiation syndrome, evacuation and shelter [11]. For the script, the event was in an urban setting.

2. MATERIALS AND METHODS

HotSpot - air pollution modelling software uses all four types of models to assess population risk. The HotSpot software product is designed to provide emergency responders and emergency planning teams with a quick, field-portable suite of software tools for evaluating radioactive material incidents. The modelling software is also used to analyse the safety of facilities working with nuclear material [12]. Ground pollution was simulated using the HotSpot 3.1 codes only and the results were simulated in Ci/m^2. The content of material at risk (MAR) ^{241}Am 3.7 x 1015 Bq. The explosive is a constant of 2.2 lb of Trinitrotoluene (TNT) and was chosen as the amount required for a suitcase bomb [11]. The dispersal parameters of the radioactive substance are as follows: damage ratio (DR) 1.00; leakage factor 1.00; air fraction (ARF) 1.00; respirable fraction (RF) 1.00 and deposition rate 0.15 cm/s [12]. The wind speed is set to 10 km/h (2.80 m/s) at a height of 10 m.

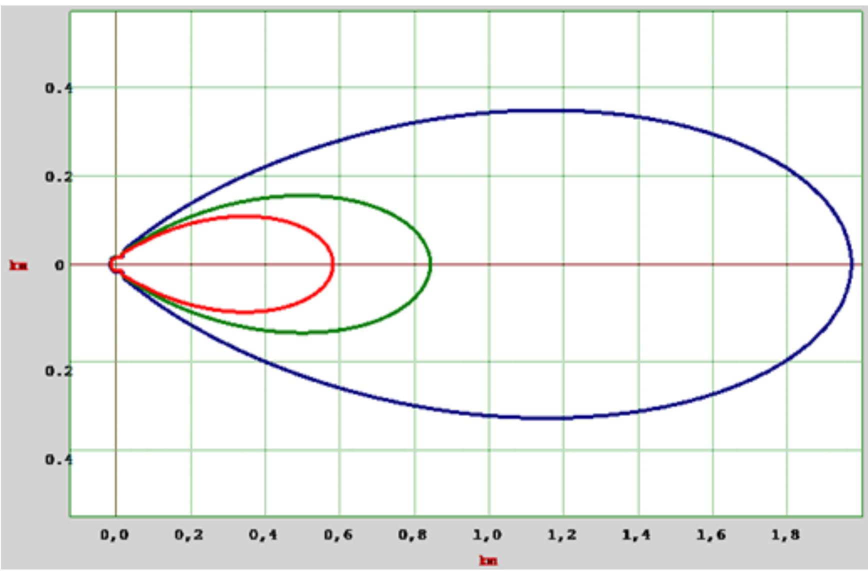
The study was conducted on stability class: A and F, with class A (Scenario 1) considered extremely unstable and class F (Scenario 2) as moderately stable. Distance coordinates for all distances are measured along the GZ plume for distances that are set out in Table 2.

3. RESULTS:

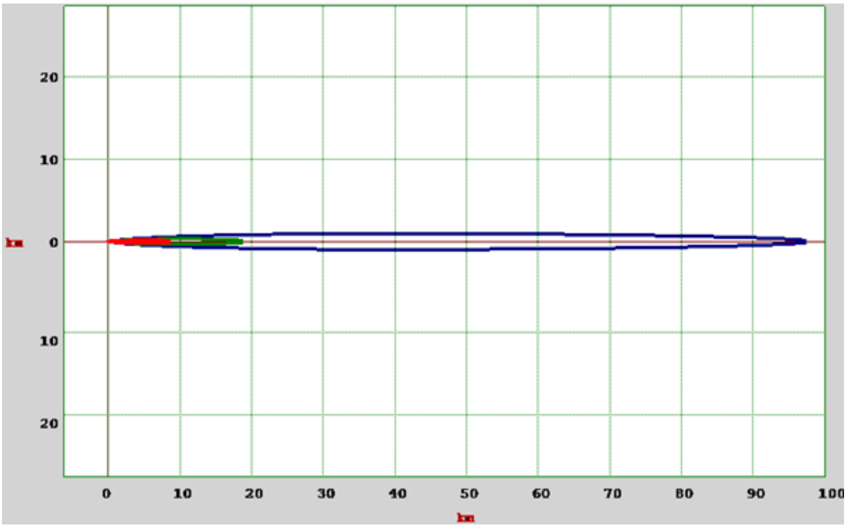
The HotSpot model is recommended by the developers for those simulations that consider distances up to a maximum of 10 km from the release point due to the uncertainties [15] involved Table 2 and Figures 1 until 4.

Table 2 Radiation Equivalent Effective Dose and Ground Radioactive Deposition Data for Pasquill–Gifford Resistance Class A and F

Downwind from GZ, km	**Pasquill–Gifford resistance class A**			**Pasquill–Gifford resistance class *F***		
	TEDE, Sv	**Radioactive deposition on Earth, *kBq/m²***	**Time after the explosion, *h:min***	**TEDE, Sv**	**Radioactive deposition on Earth, *kBq/m²***	**Time after the explosion, *h:min***
0.5	1.3^{-7}	5.0^{-6}	00:02	2.6^{-6}	9.9^{-5}	00:01
1	3.6^{-8}	1.4^{-6}	00:05	1.4^{-6}	5.1^{-5}	00:03
2	9.7^{-9}	3.7^{-7}	00:10	6.2^{-7}	2.3^{-5}	00:06
4	2.7^{-9}	1.0^{-7}	00:21	2.7^{-7}	1.0^{-5}	00:13
6	1.3^{-9}	4.8^{-8}	00:32	1.7^{-7}	6.4^{-6}	00:20
8	7.6^{-10}	2.9^{-8}	00:43	1.3^{-7}	4.7^{-6}	00:27
10	5.1^{-10}	1.9^{-8}	00:54	1.0^{-7}	3.8^{-6}	00:34

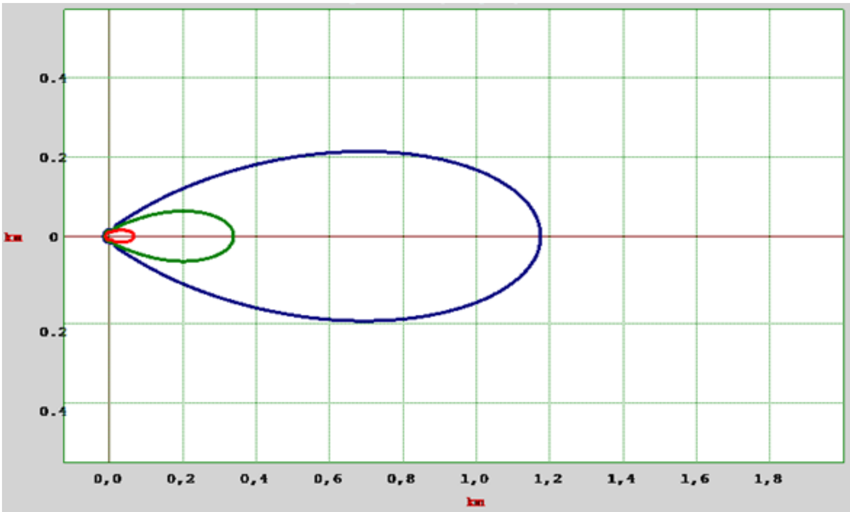


a)

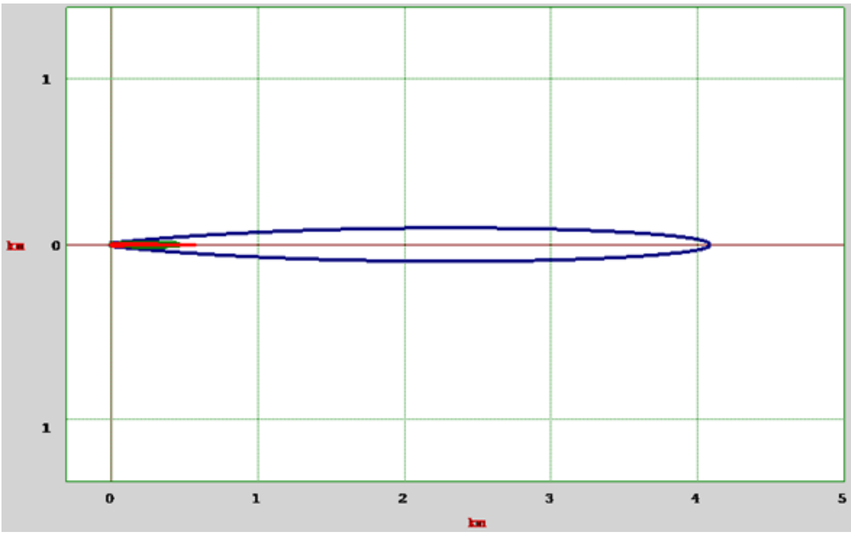


b)

Figure 1. Dependence of TEDE and the distance from the centre of the explosion for Pasquil–Gifford resistance class a) A and b) F.



a)



b)

Figure 2. Dependence of radioactive deposition and the distance from the centre of the explosion in the direction of the wind for resistance class: (a) A and (b) F.

Atmospheric processes can reduce or enhance dispersion and deposition after the initial release of a radiological source. Three of the most important parameters that drive the phenomena are wind speed, atmospheric stability, and precipitation. Thinning occurs most rapidly at high wind speeds, with unstable atmospheric conditions, with sharp temperature gradients where the surface layer is hotter than the air above it, and during precipitation. For these reasons, land surface deposition as a function of wind distance was estimated in this case.

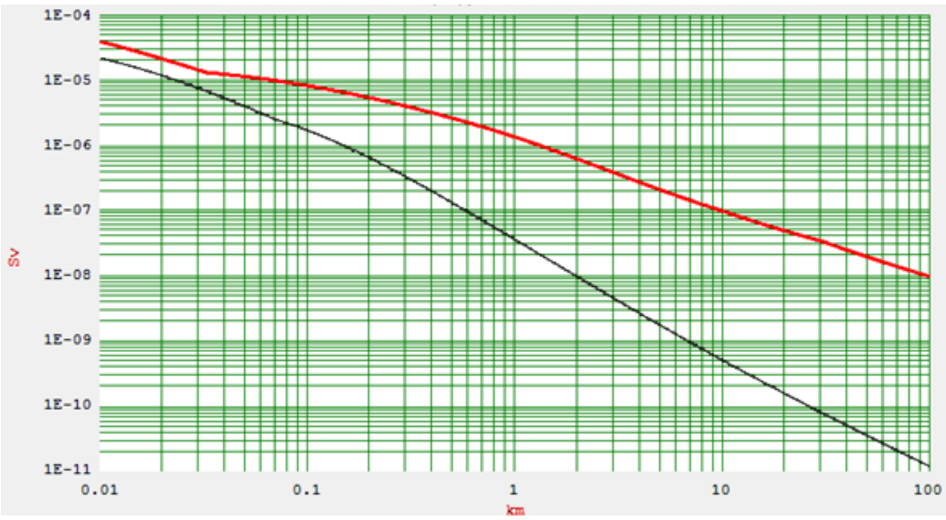


Figure 3. Dependence of TEDE equivalent effective dose and the distance downwind from GZ: black colour is for Scenario 1 and red for Scenario 2.

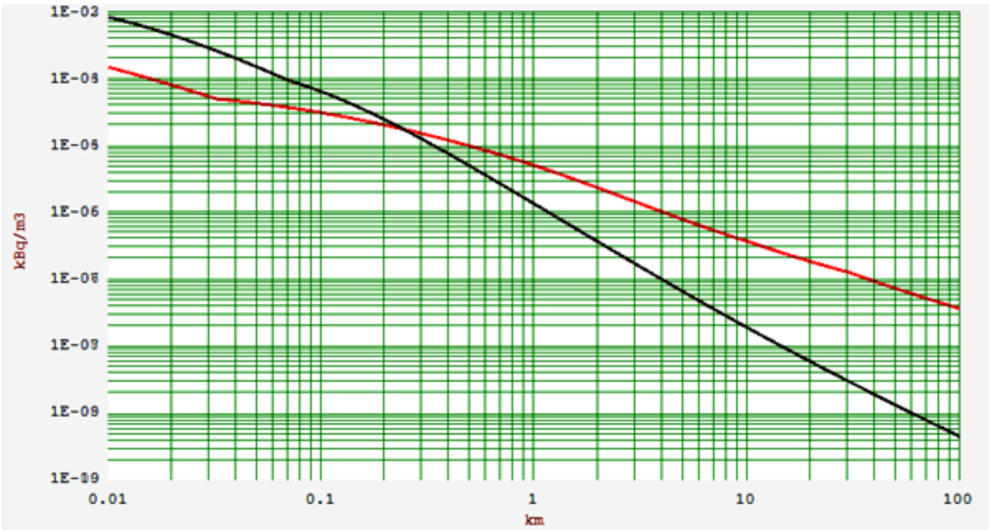


Figure 4. Dependence of radioactive deposition on the ground and the distance downwind from GZ: black colour is for Scenario 1 and red for Scenario 2.

Estimate the conversion factors for the HotSpot dose, we referred to HotSpot incorporates Federal Guidance Reports (FGR) publication [11]. The residence time is assumed to be 0 minutes to simulate that the material is released immediately to atmosphere. In Figure 3 and 4 the graphical results obtained for each considered scenario are depicted. For each stability class and wind speed value, TEDE diagrams and ground deposition diagrams are plotted as a function of leeward distance. The calculated doses can be received by a person at a height of 1.5 m above ground level, who remained entire time during passage of the cloud. Since the release occurs at a release height of 10 m, the doses first increase with distance, reach a maximum value, and then decrease. The heat and smoke will lift the tiny particles of ^{241}Am into the air and depending on the nature of the radioactive material released, these particles will settle to the ground as they are carried by the wind contaminating the earth's surface. Large particles will pollute in the immediate vicinity of the outflow, while smaller ones (fine and mostly respirable) will travel long distances or rise to high altitudes until they are deposited on the ground. The performed simulations proved the significant influence of resistance classes on the areas of radiation contamination.

In scenario 1, the equivalent dose for the first zone is 0.58 km, for the second zone it is 0.84 km and for the outer zone it is 2.0 km. For scenario 2, the length of the first contour is 17 times greater than scenario 1, for the second it is 24 times greater. The outer the difference is even greater, nearly 49 times more. For the radiative deposition under the two scenarios of Figure 4 is evident that at about 250 m from the place of the explosion they have the same values. From the Figure 2 has been seen the outer contour of scenario 2 is 4 times larger than that of scenario 1.

4. CONCLUSION

There are several interrelationships between ground concentrations and release height concentrations depending on meteorological conditions. A high-concentration plume of dispersed radioactive material, contaminants are deposited on the Earth's surface over short distances in the case of weather conditions without cloudy skies and light winds, and when the vertical stability changes from unstable to stable near the explosion. Under stable conditions, maximum concentrations near the Earth's surface amount of material are smaller than those occurring under unstable conditions and occur at a greater distance from the source of dispersion. Large concentrations of radioactive material logically spread over larger distances, minimal concentrations in cases where there are several leakage sources can spread over large areas.

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CONFLICT OF INTERESTS

I confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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