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THE NUCLEAR TERRORIST THREATS: REALITY AND COUNTERMEASURES

After the March 1995 *sarin* attack in the Tokyo subway and the September 11, 2001 attack on the World Trade Center in New York, as well as other recent high-casualty terrorist attacks, Governments have a growing concern for the possible use of the so-called “non-conventional weapons” (chemical, biological and radiological – or nuclear - weapons) in future attacks on civilian targets. How easy would it really be, for an individual terrorist or terrorist groups to manufacture or otherwise obtain such weapons? How easy would it be to deliver such weapons, or disperse radiological materials? What would it do to public health? These are some questions that our Governments are considering. In fact, every western Country is spending a lot of time and money to prevent and to deal with a possible use of non-conventional weapons by terrorist inside its borders.

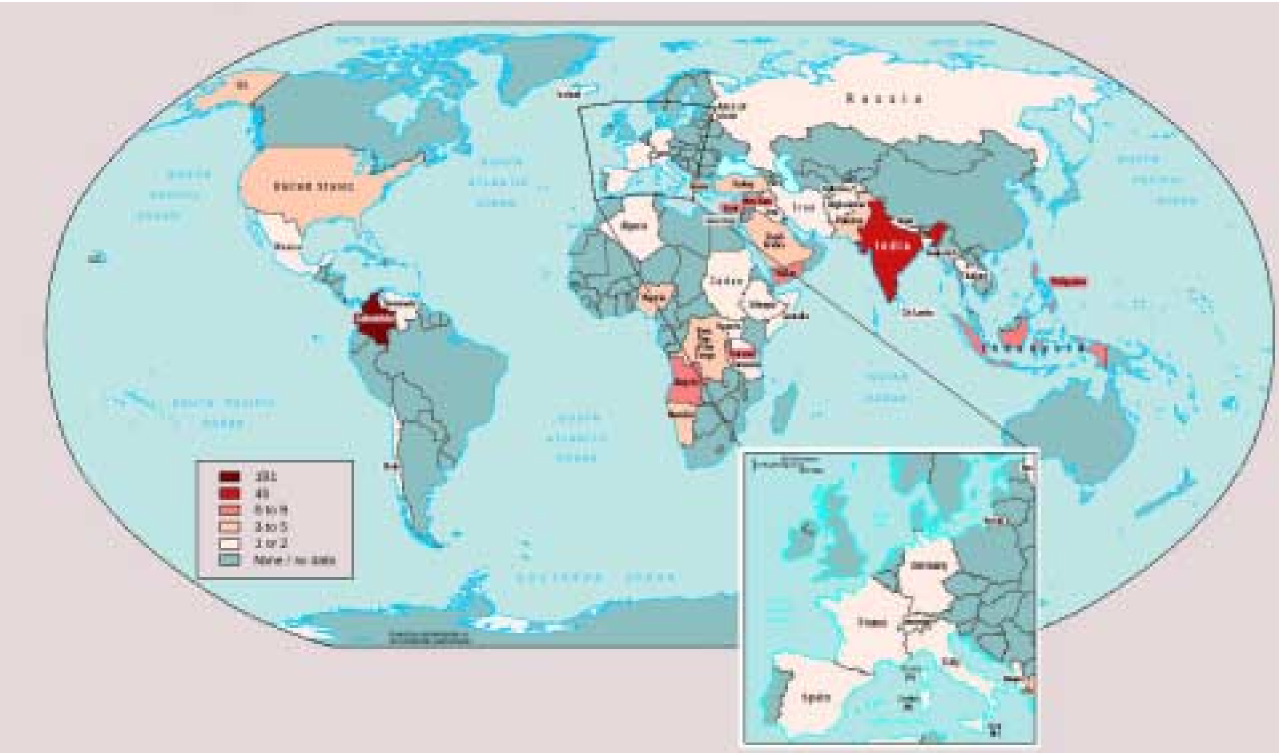


Figure 1 - Number of terrorist attack per Country.

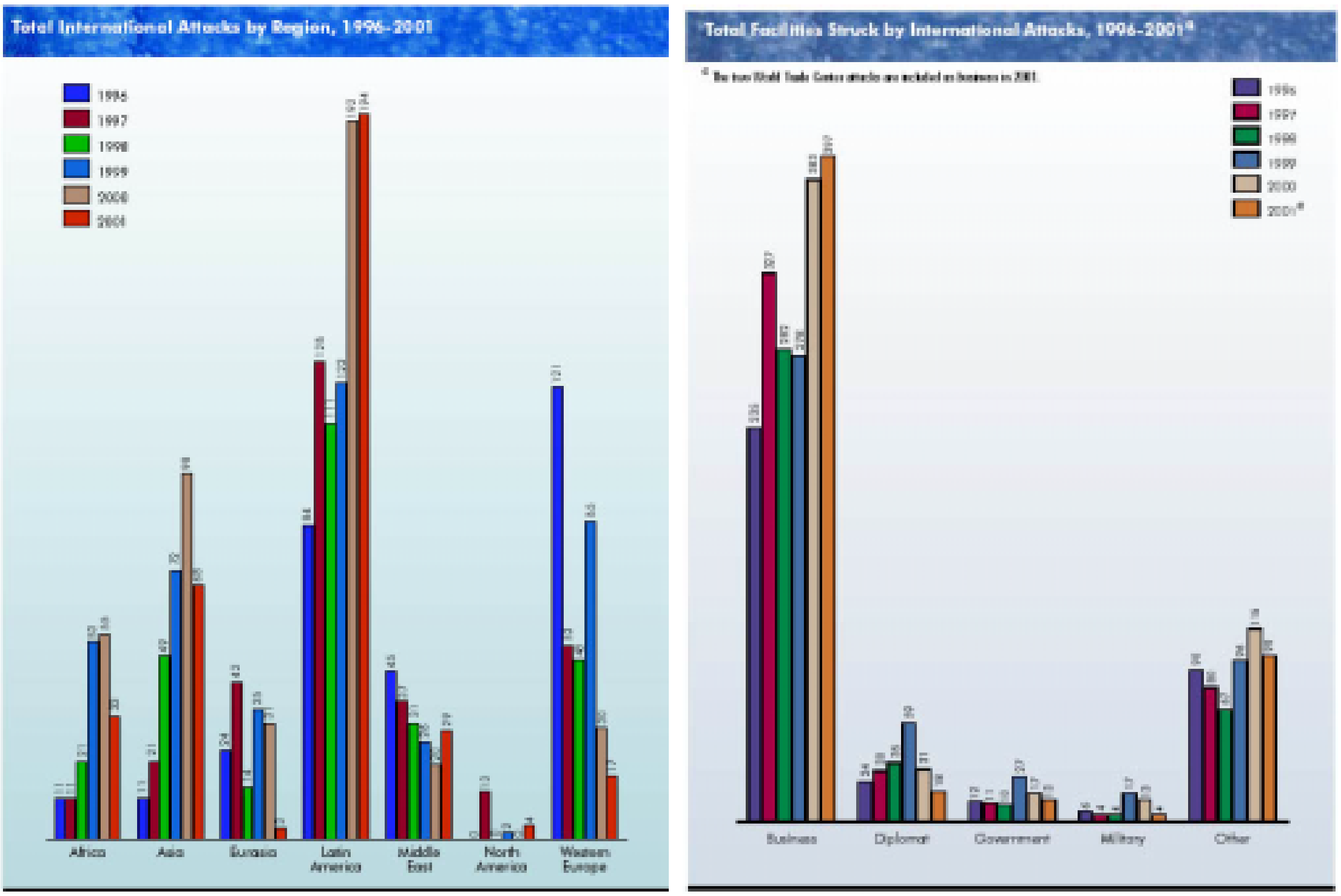


Figure 2 - Number of terrorist attack and Facilities Struck.

As shown in figures 1 and 2 [1], there have been many terrorist attack which have occurred during the last few years. What we could expect for the upcoming months could be worst than what we imagine.

There is a lot of evidences that terrorist groups have had access to materials which could be transformed into weapons.

The IAEA (International Atomic Energy Agency) in a note from June 25, 2002, stated that almost every country in the world have inadequate control and monitoring programs necessary to prevent or even detect the theft of such materials.

"Orphaned" radioactive sources - a term used by nuclear regulators to denote radioactive sources that are outside official regulatory control - are a widespread phenomenon in the Newly Independent States (NIS) of the former USSR. Even the United States Nuclear Regulatory Commission reports that U.S. companies have lost track of nearly 1,500 radioactive sources within the country since 1996, and more than half have never been recovered. A European Union (EU) study estimated that every year up to about 70 sources are lost from regulatory control within the EU. The European Commission, in a recent report, estimated that about 30,000 disused sources in the EU, held in local storage at the users' premises, are at risk of being lost from regulatory control. The majority of these sources would not pose a significant radiological risk if used in a dirty bomb.

The IAEA database includes 284 confirmed incidents since 1 January 1993 that involved radioactive material other than nuclear material. Not all of these incidents reflect deliberate attempts to steal radioactive sources, but an important fraction of cases involved persons who expected to find buyers interested in the radioactive contents of stolen sources and their ability to cause or invoke harm. Customs officials, border guards, and police forces have detected numerous attempts to smuggle and illegally sell stolen sources.

If a perpetrator is willing to disregard his or her own personal safety, radioactive sources could easily be concealed in a truck or packed in a suitcase.

One known case of an attempt to terrorise using radioactive material was the 1995 case where Chechen rebels placed a container with caesium-137 in a Moscow park. Fortunately, the material was not dispersed. [2].

Another possibility to get radioactive material, as several Secret Services noted, is to steal material from a nuclear reactor (operational or shut down) or directly use the reactor as target. The US Departments are now debating about the defence systems of the nuclear plants either to prevent terrorist attack or theft of nuclear material. In fact, as shown below [3], there are many of nuclear plant still operational and several non-operating nuclear plant, stocking highly radioactive materials.

NUCLEAR POWER PLANTS INFORMATION
Operational & Under construction Reactors by Country

Country	**Operational**		**Under Construction**	
	No. of Units	**Total MW(e)**	**No. of Units**	**Total MW(e)**
ARGENTINA	2	935	1	692
ARMENIA	1	376	0	0
BELGIUM	7	5712	0	0
BRAZIL	2	1901	0	0
BULGARIA	4	2722	0	0
CANADA	14	10018	0	0
CHINA	7	5318	4	3275
CZECH REPUBLIC	6	3472	0	0
DEM. P.R. KOREA	0	0	1	1040
FINLAND	4	2656	0	0
FRANCE	59	63073	0	0
GERMANY	19	21283	0	0
HUNGARY	4	1755	0	0
INDIA	14	2503	8	2693
IRAN, ISLAMIC REPUBLIC OF	0	0	2	2111
JAPAN	54	44289	3	3696
KOREA, REPUBLIC OF	18	14890	2	1920
LITHUANIA, REPUBLIC OF	2	2370	0	0
MEXICO	2	1360	0	0
NETHERLANDS	1	450	0	0
PAKISTAN	2	425	0	0
ROMANIA	1	655	1	655
RUSSIAN FEDERATION	30	20793	3	2825
SLOVAK REPUBLIC	6	2408	2	776
SLOVENIA	1	676	0	0
SOUTH AFRICA	2	1800	0	0
SPAIN	9	7524	0	0
SWEDEN	11	9432	0	0
SWITZERLAND	5	3200	0	0
UKRAINE	13	11207	4	3800
UNITED KINGDOM	31	12252	0	0
UNITED STATES OF AMERICA	104	97860	0	0
Total:	441	358199	33	26183

Non-operating Reactors by Country

Country	Shut down	
	No. of Units	Total MW(e)
ARMENIA	1	376
BELGIUM	1	11
BULGARIA	2	816
CANADA	11	5656
FRANCE	11	3951
GERMANY	17	4964
ITALY	4	1423
JAPAN	2	172
KAZAKHSTAN	1	52
NETHERLANDS	1	55
RUSSIAN FEDERATION	4	781
SLOVAK REPUBLIC	1	110
SPAIN	1	480
SWEDEN	2	610
UKRAINE	4	3500
UNITED KINGDOM	14	2054
UNITED STATES OF AMERICA	22	8774
Total:	99	33785

Some of the most important 2002 headlines [4] about nuclear stolen material report that, in the most part of the events, only little sources where involved. It seems that it's really very easy to steal a little source, but it's not quite easy to manage bigger ones.
In fact in several cases, the maximum activity of the sources was about 1 Ci and only in a few cases the activity was over 1 Ci.
The most famous accident involving a lost source is the Goiânia Accident. In this incident, someone dismantled a metal canister from a radiotherapy machine at an abandoned cancer clinic and left it in a junkyard. During the dismantling procedure the metal capsule that contained the caesium-137 source was ruptured (the activity of a source for medical use is 5 - 10 Ci).
Over the next week, several hundred people in Goiânia were exposed to the caesium-137, but they did not know it. Some children and adults, thinking the caesium powder was "pretty", even rubbed it over their bodies. Others inadvertently ate food that had been contaminated with the radioactive powder.
After one week, a public health worker correctly diagnosed radiation syndrome when a sufferer visited a clinic. The Brazilian Nuclear Energy Commission sent in a team and they discovered that over 240 persons were contaminated with caesium-137, four of whom later died.
The accident also contaminated homes and businesses and this required a major clean-up operation.
Several reports (often denied) call for thefts of fissile material from the former Soviet Union nuclear arsenal. No regulatory control has been implemented on these materials during the last 15 years, so it seems very easy to lose track of where and who "handles" them.

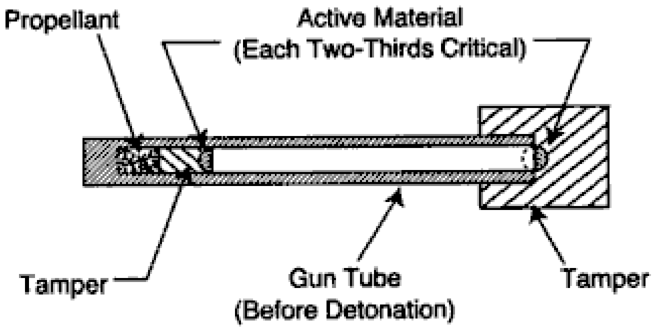
Now we will discuss about the radiological types of non conventional weapons and about the technology and know how required to built them.

Terrorists are able to attack in three different ways:

1. a nuclear weapon;
2. a "dirty bomb", in which conventional explosive is wrapped in a shroud of radioactive material (as uranium, plutonium, caesium or cobalt) to create a fallout after exploding
3. Water contamination by introducing radioactive material into the municipal water supply.

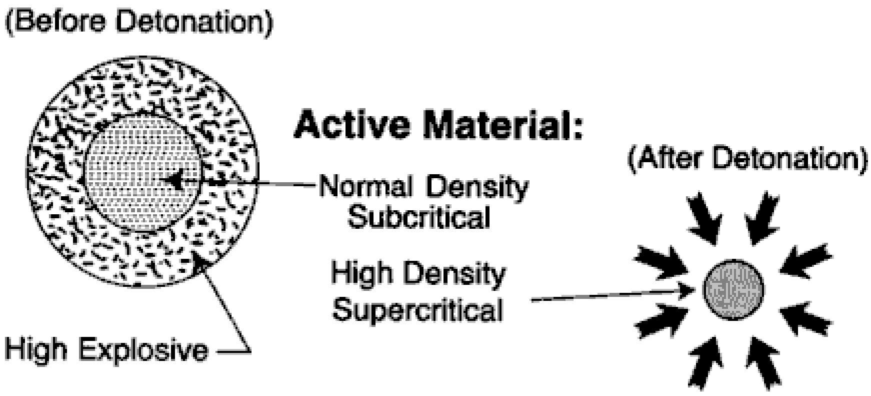
Nuclear Weapon

The basic design of a nuclear weapon can be either the gun type and the implosion type. In the gun type, a sub-critical piece of fissile material (the projectile) is fired rapidly into another sub-critical piece (the target) such that the final assembly is supercritical without a change in the density of the material [5].



"Little Boy", 15 kiloton weapon, was a gun type bomb and was dropped on 06 August 1945 at Hiroshima, Japan. The device contained 64.1 kg of highly enriched uranium, with an average enrichment of 80%.

In the implosion type, a near-critical piece of fissile material is compressed by a converging shock wave resulting from the detonation of a surrounding layer of high explosive and becomes supercritical because of its increase in density.



The "Fat Man" atomic bomb (implosion type) destroyed Nagasaki in 1945 using 6.2 kilograms of plutonium and producing an explosive yield of about 20 kilotons.

The a critical mass depends on the density, shape, and type of fissile material, as well as the effectiveness of any surrounding material (called a reflector or tamper) at reflecting neutrons back into the fissioning mass. Critical masses in spherical geometry for weapon-grade materials are as follows:

	Uranium-235	Plutonium-239
Bare sphere:	56 kg	11 kg
Thick Tamper:	15 kg	5 kg

No particular technology is needed for neither type of nuclear bomb. In fact, the difficulty the terrorist may have is in collecting the necessary fissionable material and making the bomb.
If technical difficulties arise, a terrorist can select the second option: the "dirty bomb".

Dirty Bomb
In this case an explosion is used to disperse radioactive material. Plutonium is preferable, due to its particular radiochemical toxicity by inhalation [6,7] and its high activity (about 2.3 kBq/µg). In addition, the effect of using plutonium in a terrorist attack could lead to widespread panic and it could lead people to feel a sensation of total vulnerability. Radium 226 (half life 1,620 y), Americium 241 (458 y), Caesium 137 (30 y) or Cobalt 60 (5.24 y) could be also used to obtain a long and widespread contamination and dose from inhalation by the population.

When dispersed with explosion, particles of the radioactive material smaller than 3µm will become airborne and can be inhaled. After it enters the human body, the particles deposit in the lungs, and migrate, via the blood stream, to selectively concentrate in the bones (plutonium and caesium) and the liver. The effects of such inhalation could be pulmonary oedema in case of high dose inhalation of Plutonium, or, in case of a little introduction of radioactive material, in cancer which may be induced after a latency time of many years [7].
The tables below show the ICRP (International Commission on Radiological Protection) risk of death per Sv (dose absorbed, 1 sievert = 100 rem), due to a cancer as stochastic effect of ionizing radiation exposure and the same value calculated by different organisations.

ICRP RISK OF DEATH PER Sv RELATED TO CANCER INDUCTION IN 10,000 PEOPLE

WHITE BLOOD CELLS	2.0
MAMMARIAN	2.5
LUNG	2.0
BONE	0.5
THIROID	0.5
OTHERS TISSUES	5.0
TOTAL RISK	12.5

RISK OF DEATH PER Sv RELATED TO CANCER INDUCTION IN 10,000 PEOPLE

BEIR II 1972	115 – 620
UNSCEAR 1977	75 – 175
ICRP 1977	12.5
BEIR III 1980	158 – 501
UNSCEAR	100 - 440

Durante and Manti [8] estimated the radiological risk from an attack using plutonium, using the HotSpot code [9]. This code is widely used to predict the fallout due to fire or explosion of radioactive material or nuclear explosion. The simulation uses the Gaussian plume model for different meteorological conditions. This model, developed by Pasquill, assumes that the dispersion of the radioactive material in atmosphere is ruled by the Fick's law on diffusion and so:

$$\frac{\partial x}{\partial t} = K_x \frac{\partial^2 \chi}{\partial \bar{x}^2} + K_y \frac{\partial^2 \chi}{\partial \bar{y}^2} + K_z \frac{\partial^2 \chi}{\partial \bar{z}^2}$$

where $\chi(\bar{x}, \bar{y}, \bar{z}, t)$ is the concentration of the radionuclide in the point $(\bar{x}, \bar{y}, \bar{z})$ and K_x, K_y, K_z the whirling diffusion coefficients. In the Gaussian plume model, in order to obtain an useful solution to the ground level, the whirling diffusion coefficients are assumed constant and not depending on the time.

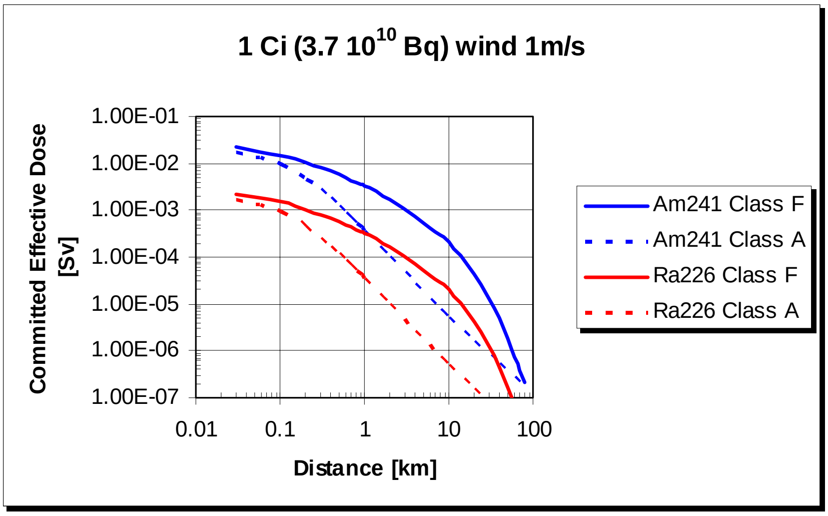
$$\chi(x, y, 0) = \frac{Q}{\pi \cdot \bar{u} \cdot \sigma_y \cdot \sigma_z} \left[e^{-\frac{y^2}{2\sigma_y^2} - \frac{H^2}{2\sigma_z^2}} \right]$$

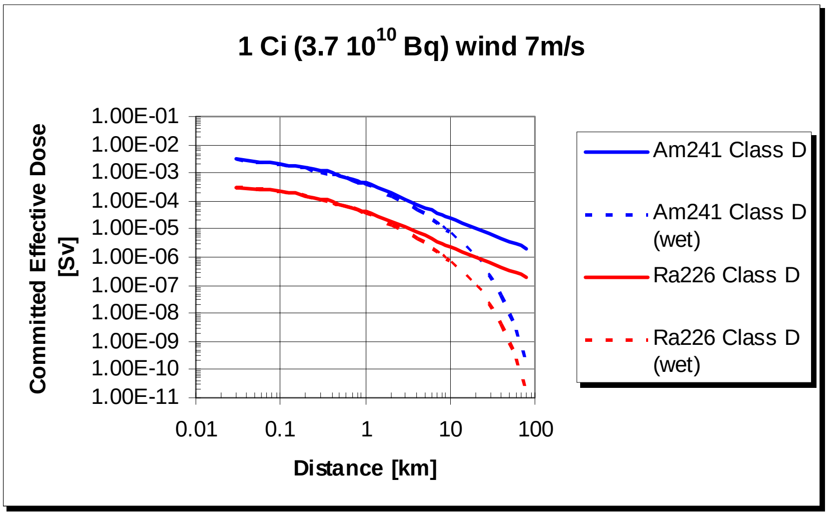
where:

- H is the height of the release;
- Q is the release in Bq;
- $\chi(x, y, 0)$ is the air concentration in Bq/m^3;
- $\bar{u}$ is the wind velocity in m/s;
- σ_y e σ_z are the Pasquill-Gifford coefficients of the atmospheric diffusion.

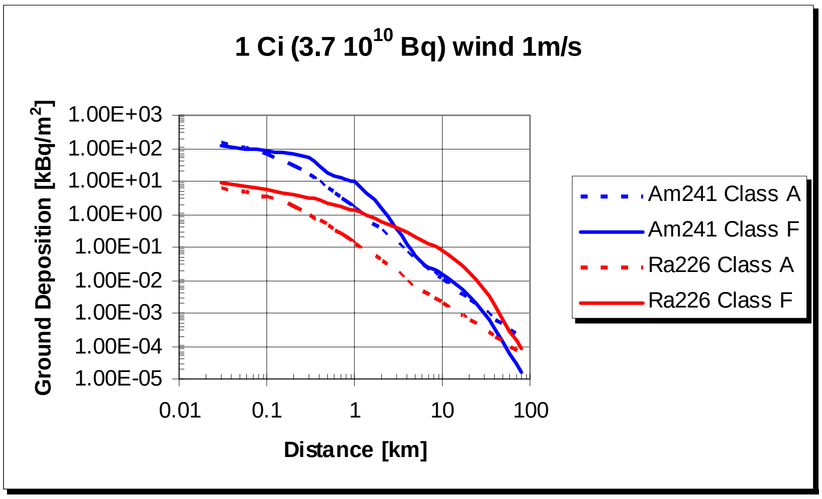
The code, moreover, provides ground contamination, re-suspension and the committed effective dose (CED), which is the dose in 50 years due to an ingestion/inhalation of a radioactive material, as a function of downwind

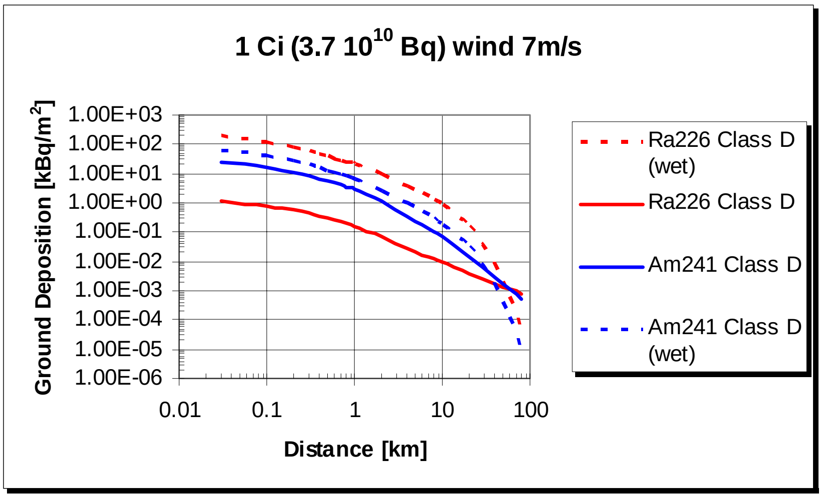
distance from the point of release. In the in the worst examined case of plutonium explosion, the number of exceeding cancers was about 80, which should be compared to the 15.000 naturally occurring cancer deaths in the exposed population of about 76.000 civilians, assuming a 20% cancer death rate.
In case of explosion, several nuclides could be available to terrorists. In fact they could use Caesium 137, Radium 226, Cobalt 60 or Americium 241. All of them are quite available due to their use in normal life, especially in medical and industrial field (cancer treatments, food irradiation, oil inspection, etc.).
We use Hotspot to predict the committed effective dose and the ground deposition using 1 pound of TNT and 1 Ci ($3.7 \cdot 10^{10}$ Bq) of radionuclide with different meteorological stability classes (related to the condition of the temperature profile during the dispersion, given by the wind velocity and the solar radiation during the day), wind and wet deposition.
In this work, professional software was not used for security reason.
In the figures below the CED and the ground deposition due to a Am^{241} and Ra^{226} sources are shown.





As we found, the worst case of use of a radionuclide with explosive is the use of americium 241, which is available from the fire detection systems and lightning rods, widely used in Italy. In fact, due to a new national law, all of the devices using radioactive sources, when broken down, have to be substituted by other devices without radioactive sources, but the most part of these devices has not been declared to the Regulatory Authority and so every owner can put them everywhere. In the case of Am^{241}, at 1 km from the explosion, the CED in about 4 mSv, which is a very low value of dose. The values obtained with Ra^{226} are one order of magnitude lower than Am^{241}. In Italy the limit of annual dose for the population is 1 mSv and 20 mSv for the professional exposed personnel. These limits assure that it is impossible that a deterministic damage occurs.





The values of the ground depositions are more interesting because they might be the most important result of the terrorist attack. In fact a ground deposition of about 10 kBq/m^2 would impose the necessity to clean the entire area (if it's an urban area) and to make a decision about what has to be done (evacuation, decontamination, prohibition of drinking or eating particular food coming from the contaminated area, etc.).

Water Contamination

Dispersion of radioactive material into the water supply of a large city probably it's easier than other radiological attacks, but it possibly only be a demonstration of vulnerability and not a real danger to the population. In fact, in the majority of cases, the material does not cause damage. As a matter of fact, Plutonium is much less hazardous in water than in air, since in water it would dissolve in small amount and remain suspended [10], with the remainder being immobilised in sediments. Moreover, the materials (especially metals) used in such an attack have to be prepared chemically to dissolved in water and so the terrorists would have to manipulate large amount of activity in a lab, which could be an hotel room or something similar.
Sutcliffe et al. [11] excluded any serious health consequences of plutonium contamination in water supplies.

COUNTERMEASURES

All the western countries are responding to the new nuclear threat using every possible measure, whether national or coming from international co-operation. In Italy the public administration is working to rewrite the emergency nuclear national plan, considering, besides the nuclear power plant incidents, the new hypothesis of nuclear terrorism. This new threat needs preparation, readiness and resources never mind before 11 September. In particular, Police, Fire Department and Armed Forces need to know the use of particular instruments to give

the first warning on the possibility of illicit transit of radioactive material through the borders or from a suspect explosion or from discovering nuclear material. There is the need to train particular sampling units, able to work in a contaminated area and to pick up suspect samples, which have been detected before. The suspect materials would be transferred to a specifically equipped lab, in which every information about the material would be detected and send to the operative central agency that allows to the decision makers to estimate the scenario and manage the emergency.
The difference between the hypothesis estimated in the national emergency plans and the terrorist threat is in the impossibility to foresee the place and the size of the event.
In fact, when we speak about the terrorist will, we speak about something which want to bypass the normal mechanism and the normal security procedures that a Country is running and that should be the most evident as possible.
Due to this type of threat which could involve suicide terrorist, the emergency organisation would not be able to foresee the size and the possible countermeasures of the event if it did not plan an efficient organisation that can detect the event, evaluate and manage it without any previous information.
In the NATO organisation, Italy participates to the so-called "Prague Initiative", which was born during the last Summit in Prague.
NATO leaders agreed to a new military concept of defence against terrorism as part of a package of measures to strengthen the Alliance's capabilities in this area, including improved intelligence sharing and crisis response arrangements. NATO is also working with Partners to implement a Civil Emergency Planning Action Plan to improve civil preparedness against possible chemical, biological or radiological attacks against civilian populations and help national authorities deal with the consequences of such attacks.
Alliance leaders also endorsed implementation of five nuclear, biological and chemical (NBC) weapons defence initiatives, which will enhance the Alliance's capabilities against weapons of mass destruction: a Prototype Deployable NBC Analytical Laboratory; a Prototype NBC Event Response team; a virtual Centre of Excellence for NBC Weapons Defence; a NATO Biological and Chemical Defence Stockpile; and a Disease Surveillance System [12].

The Disease Surveillance System collects information about the unusual disease outbreaks, due, possibly, to an NBC agent. Then the information is merged with data from the intelligence service and the field surveillance. The information collected will be sent to the NBC Event Response Team. This team, once the NBC event has been detected, assesses the effects of this event, advises NATO commanders about mitigating the effects and, if necessary, sends the sampling team to collect field samples of various materials. The samples are then sent to the deployable Labs, that, at the same time, have been deployed near the action. These labs conduct very reliable scientific analyses on the samples and return information about the type of attack, the agent used and the possible countermeasures against the agent. The NATO Biological and Chemical Stockpile provides, then, the necessary medical products, moving them rapidly into theatre.

Disease Surveillance System

Système de surveillance épidémiologique

Collect information on unusual disease outbreaks

Recueillir des informations sur les cas de maladies atypiques

Alert NATO Commander of biological outbreak

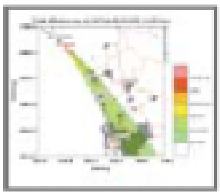
Alerter le commandement de l'OTAN en cas d'incident biologique

Fuse data with other information sources

Fusionner les données avec d'autres sources d'information

Nuclear, Biological and Chemical (NBC) Event Response Team

Equipe de réaction aux incidents nucléaires, biologiques et chimiques (NBC)



Assess the effects of an NBC event

Evaluer les effets d'un incident NBC

Advise NATO Commanders on mitigating effects of an NBC event

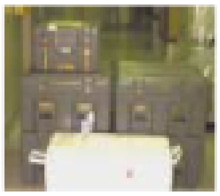
Conseiller le commandement de l'OTAN sur les parades à mettre en œuvre

Enable NATO Commanders to "reach back" to national experts for technical advice

Permettre au commandement de l'OTAN de communiquer avec les experts techniques des pays

Deployable Nuclear, Biological and Chemical (NBC) Analytical Laboratory

Laboratoire déployable d'analyses nucléaires, biologiques et chimiques (NBC)



Quickly and easily transportable into theater

Rapidité et facilité de mise en œuvre sur le théâtre

Investigate and collect samples of possible NBC contamination

Recherche et prélèvement d'échantillons de contaminants NBC

Conduct highly reliable scientific analysis of samples

Analyses scientifiques très fiables

NATO Biological and Chemical Defence Stockpile

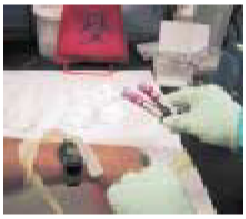
Stock OTAN de moyens de défense chimique et biologique

Identify and share national stockpiles

Recenser et mettre en commun les stocks nationaux

Rapidly move needed defence materiel into theater

Acheminer rapidement les produits et matériels nécessaires sur le théâtre



Improve medical treatment protocols

Améliorer les protocoles thérapeutiques

Nuclear, Biological and Chemical (NBC) Training

Entraînement nucléaire, biologique et chimique

Enhance senior-level NBC education

Intensifier la formation des responsables de haut niveau dans le domaine NBC

Improve operational understanding of NBC defence

Améliorer la compréhension des systèmes de défense NBC au niveau opérationnel

Expand and strengthen NBC defence training

Etendre et renforcer l'entraînement à la défense NBC

Prototype Team Exercise Plan

Date	Place Exercise Name	Purpose
8–13 Nov 02	Liberec, Czech Republic	Team Building & Interoperability
7–14 or 18–25 Mar 03	Rota, Spain	Response Team Collective Training
24 Apr– 8 May 03	Suffield, Canada	Field Training Exercise
Jun 03	Possibly France, Italy or Belgium	Deployment Readiness Exercise
28 Aug– 6 Sep 03	Dugway, Utah, USA	Validation of Tactics, Techniques & Operational Procedures
21–27 Sep 03	France	Sampling & Identification of Radiological Agents
10–18 Nov 03	Exercise ALLIED ACTION Turkey	Final Validation

After the first step made in Liberec (Czech Republic) last November, as shown in this figure, there will be several training stages to improve the capabilities of the initiatives.

The next exercise will be in Canada the next April 24. During this exercise, for the first time, real chemical, biological and radiological agents will be used, in order to check the real capability of the sampling teams and the deployable labs to manage real agents and to move and work in a contaminated area.
Italy participates to the Initiative with experts of managing nuclear emergencies, meteorologists, deployable labs, sampling teams and medical surveillance specialists.
The CISAM (Joint Center of Studies for Military Applications) provides the deployable lab, which is a NATO standard shelter, and two technicians that will be able to detect every radioactive isotope, using alpha and gamma spectrometry, smear counters, and low energy gamma spectrometer (to detect U and Pu). In the Lab there is also a particular plastic scintillator, able to detect and separate natural and artificial radioactivity, mounted on a vehicle to find hidden sources, even of very low activity, patrolling a particular zone.
The Group of the Prague Initiative will be validated at the end of this year in Turkey and will be full operating at the beginning of the 2004. It will be able to work with a minimum notice all over Europe and in that Countries in which NATO Forces has been deployed.

CONCLUDING REMARKS

There is a lot of evidences that terrorist groups could accumulate nuclear material to carry out a nuclear bomb or a dirty bomb to be used on large urban areas. It is very important to understand the risks associate with these types of attack in order to assure adequate countermeasures.
This paper has provided an estimate of the possible use of radioactive material (fissile or not) by a terrorist and the expected effect of the attack. In addition, an estimate was given of the expected doses from explosion of a dirty bomb, using a Gaussian-plume model. The results of our calculation should be simply considered as an example to provide estimates and the order of magnitude of the risk.
The event may not be a real danger to the health of the population, but it is a very great environmental damage and reason of social break downs. All the possibility of creating fear and panic in the population is sufficient for the terrorist purposes.
We have not discussed about the other possible threats: chemical and biological. Mainly because it is not our specific field. Anyway is important to note that a chemical attack would be very dangerous in terms of number of lives lost, but it would not be persistent and after a few hours after the attack the entire area would be clean. It is the same for a biological attack. In fact, as the last anthrax attack in the USA, there would be several deaths or injuries and a subsequent epidemic course that have to be managed. As it happens in all the epidemic courses, the number of illnesses, after a time of stability of number of cases per time, that depends on the type of biological agent used, would rapidly decrease.
In case of radiological attack, as we said, there would be no immediate deaths due to the attack, but the entire area contaminated by the radiological agent will have to be cleaned and secured. In fact most of the radioactive agents discussed before have an half life of minimum 5 years and so they will persist in the area for centuries of years.
It would be better if all western countries organise themselves to copy the package of measures of the NATO, born with the “Prague Initiative”, in order to face the new threats.
To achieve the possibility of responding with adequate countermeasures to the new threats, all Countries also need, besides just the will to do it, also the work of many people and the investment of a large amount of financial resources to be spent now and in the near future.

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