Come contrastare la dispersione di materiale radioattivo: le competenze ENEA

La dispersione di materiale radioattivo potrebbe derivare da un incidente radiologico o da un atto doloso. In entrambi i casi siamo alla presenza dello stesso scenario ma con importanti differenze che richiedono un approccio completamente differente. L'aspetto più rilevante è la possibilità di prevedere il primo tipo di evento e di preparare una risposta sito-specifica, mentre nel secondo caso è possibile unicamente adottare un approccio di tipo generico.
Nel presente articolo è illustrato l'approccio generico proposto dagli esperti ENEA in caso di dispersione di materiale radioattivo dovuta ad atto doloso. Sono inoltre proposti e discussi l'analisi provvisoria e l'approccio di risposta. Sono esposti gli strumenti, gli impianti e le competenze dell'Agenzia ENEA, che rendono possibile l'impresa.

Facing dispersion of radioactive material: ENEA's skills

The dispersion of radioactive material could derive either from a radiological incident or from a malevolent act. Both situations appear to present the same scenario but there are important differences that require a completely different approach. The most important aspect is the possibility of foreseeing the first kind of event and of preparing a specific-site response, while in the case of a malevolent act only a general approach is possible. This paper shows the general approach proposed by ENEA experts to face a dispersion of radioactive material due to a malevolent act. The provisional analysis and the responding approach are proposed and discussed. The tools and the facilities available in the Agency are considered, together with ENEA skills that make the enterprise possible.

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Introduction

In a terroristic attack radioactive materials could be used in many ways. This kind of event is often called "radiological attack" and means the spreading of radioactive material with the intent to do harm. Radioactive materials are used every day in laboratories, medical centers, food irradiation plants, and for industrial uses; if stolen, or otherwise acquired, many of these materials could be used in a "radiological dispersal device" (RDD). A "dirty bomb" is one type of RDD that uses a conventional explosion to disperse radioactive material over a targeted area. RDDs could also include other means of dispersal such as placing a container of radioactive material in a public place, or using an airplane to disperse

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powdered or aerosolized forms of radioactive material. Another kind of radiological device that could be used by terrorists is the so called RED (Radiation Emission/ Exposure Device), a weapon of terror whereby a high-intensity radiation source is placed in a public area to expose those individuals in close proximity. Prolonged exposure to a high intensity source may lead to acute radiation syndrome (ARS) or to cutaneous radiation syndrome (CRS), or radiation burns.

Many Italian institutions, with national or local relevance, are in the position to be identified as the potential responders to a radiological attack. Nevertheless the majority of these institutions expressed the need for assistance in identifying the most important actions that should take place when responding to an RDD.

The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) develops activities devoted to research, innovation technology and advanced services in the fields of energy, especially nuclear. One of ENEA's tasks is to provide support to the Ministry for Economic Development (MSE), Regions, and local bodies in the specific field of interest, and also in responding to radiological events.

Typical areas of intervention for the Agency are: developing methods to measure and control the radiation and contamination; providing specific information to citizens, public administrations, enterprises and economic operators.

ENEA is already considered the National Focal Point for the assistance to operators in the various phases of radioactive material transport. In this framework, the Agency assists those who need help in transporting radioactive materials within the national territory, even if just transiting. It also acts as an interface between the National Authorities and the IAEA Secretariat during all shipment phases. In addition, for many years ENEA has hosted an Integrated Service for the management of non-electro-nuclear radioactive waste spread all over Italy, which include low- and medium-level medical radioactive sources as well as high-activity sealed radioactive sources. ENEA's Integrated Service is responsible for radioactive waste collection, transport, characterization, storage, treatment and conditioning. Since 2007, pursuant to Legislative Decree No. 52 of 6 February 2007, the Integrated Service is also responsible for orphan sources (radioactive sources for which origin cannot be determined). ENEA acts in these areas with specific Technical Units. Those mainly involved in the research and support related to radiological attacks are the Technical Unit for the Development of Applications of Radiations (UTAPRAD) and the Radiation Protection Institute (IRP). The staff of the above Units owns unique expertise and intervention skills and can meet all kinds of needs associated with the use of ionizing radiation also in a malevolent action.

The high-quality consultation provided by ENEA experts includes the identification of the needed tasks, the initial guidance for the first after-event hours, the national, regional, and state/ local agency contacts and the assistance with radiological emergency response capabilities.

The radiological dispersal devices

The terms dirty bomb and RDD are often used interchangeably in the media. Any kind of dirty bomb is in no way similar to a nuclear weapon or nuclear bomb. A nuclear bomb creates an explosion that is millions of times more powerful than that of a dirty bomb. The cloud of radiation from a nuclear bomb could spread tens to hundreds of square miles, whereas an RDD's radiation could be dispersed within a few blocks or miles from the explosion. A dirty bomb cannot be considered a "Weapon of Mass Destruction" but it could be a "Weapon of Mass Disruption," where contamination and anxiety are the terrorists' major objectives.

Most RDDs would not release enough radiation to kill people or cause severe illness. The conventional explosive in the bomb itself would be more harmful to individuals than the dispersed radioactive material. However, depending on the situation, an RDD explosion could create fear and panic, contaminate property, and require potentially costly cleanup. Making prompt, accurate information available to the public may prevent the panic sought by terrorists. Nevertheless, terrorist use of an RDD is considered far more likely than using a nuclear explosive device. It is designed to scatter dangerous and sub-lethal amounts of radioactive material over a general area. Such RDDs appeal to terrorists because they require limited technical

Common radioactive sources

Gamma emitters

Cobalt-60 (Co-60): cancer therapy, industrial radiography, industrial gauges, food irradiation.
Cesium-137 (Cs-137): same uses as Cobalt-60 plus well logging. Iridium-192 (Ir-192): industrial radiography and medical implants for cancer therapy.

Beta emitter

Strontium-90 (Sr-90): radioisotope thermoelectric generators (RTGs), which are used to make electricity in remote areas.

Alpha emitters

Plutonium-238 (Pu-238): research and well logging and in RTGs for space missions.
Americium-241 (Am-241): industrial gauges and well logging.

knowledge to build and deploy compared to a nuclear device. Also, the radioactive materials in RDDs are widely used in medicine, agriculture, industry and research, and are easier to obtain than weapons grade uranium or plutonium. On the other hand, it is very difficult to design an RDD that would deliver radiation doses high enough to cause immediate health effects or fatalities in a large number of people. Therefore, experts generally agree that an RDD would most likely be used to contaminate facilities or places where people live and work, disrupting lives and livelihoods. Experts are convinced as well that the primary purpose of terrorist use of an RDD is to cause psychological fear and economic disruption.

An RDD could cause fatalities from exposure to radioactive materials, depending on many aspects. The speed at which the area of the device detonation is evacuated and how successfully people are recovered at sheltering-in-place are the main parameters on which the event outcome is based. In any case the number of deaths and injuries from an RDD might not be substantially greater than from a conventional bomb explosion.

The size of the affected area and the level of destruction caused by an RDD would depend on the sophistication and size of the conventional bomb, the type of radioactive material used, the quality and quantity of radioactive material, and the local meteorological conditions, primarily wind and precipitation. As a result, the area affected could be placed off-limits to the public for several months during cleanup efforts.

Preparing to the impact

In order to be prepared for facing an RDD impact, it is important to understand the meaning of a specific dose level. The effective dose of 1 mSv is the limit imposed worldwide to guarantee that people not working with radiations will receive an insignificant dose due to the artificial use and production of ionizing radiations. It is not directly correlated with the human safety. In fact normal background radiation varies from place to place but delivers a worldwide average effective dose near 2.4 mSv/year. This implies that an annual dose of 1 mSv is not harmful for humans, who are used to live in a more radioactive environment. The International Commission on Radiological Protection (ICRP), that is the primary international body in protection against ionizing radiation, states that *the most adverse health effects of radiation exposure may be grouped in two general categories: deterministic effects (harmful tissue reactions) due in large part to the killing/malfunction of cells following high doses; and stochastic effects, i.e., cancer and heritable effects involving either cancer development in exposed individuals owing to mutation of somatic cells, or heritable disease in their offspring owing to mutation of reproductive (germ) cells [1].* The induction of deterministic effects is characterized by a threshold dose. Below the threshold the radiation damage of a critical tissue is not sustained enough and the injury could not be expressed in a clinically relevant form. Above the threshold dose the severity of the injury, including impairment of the capacity for tissue recovery, increases with the dose.

In the dose range up to around some hundreds of millisievert no tissues are judged to express clinically relevant functional impairment, and therefore there are not deterministic effects. An average threshold for the

Dose definition

Only the amount of energy from any type of ionizing radiation that is imparted to (or absorbed by) the human body can cause harm to health.
To look at biological effects, we must know (estimate) how much energy is deposited per unit mass of the part (or whole) of our body which the radiation is interacting with.

The international (SI) unit of measure for absorbed dose is the gray (Gy), which is defined as 1 joule of energy deposited in 1 kilogram of mass. The old unit of measure for this is the rad, which stands for "radiation absorbed dose." 1 Gy = 100 rad.

Equivalent dose represents the biological effect to a specific organ or tissue and depends not only on the amount of the absorbed dose but also on the intensity of ionisation in living cells caused by different types of radiation.
Neutron, proton and alpha radiation can cause 5-20 times more harm than the same amount of the absorbed dose of beta or gamma radiation.
The unit of equivalent dose is the sievert (Sv). The old unit of measure is the rem. 1 Sv = 100 rem.

Effective dose is the numerical representation of the biological effect to the whole body and is obtained by adding the equivalent doses to all the organs and tissues weighted by specific coefficients.
The unit of effective dose is the sievert (Sv). The old unit of measure is the rem. 1 Sv = 100 rem.

deterministic effects induction could be fixed around 500 mSv [2], even if some minor tissue reactions (like skin erythema) could be observed in some persons exposed in the dose range from 100 to 500 mSv.
Stochastic effects are health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. In the case of cancer, epidemiological and experimental studies provide evidence of radiation risk albeit with uncertainties at doses about 100 mSv or less. In the case of heritable diseases, there is no direct evidence of radiation risks to humans, yet experimental observations argue convincingly that such risks for future generations could be real. Coming back to the radiological effects that could be expected for the individuals living in the area of an RDD influence, the doses we are generally dealing with should be ranging from less than 1 mSv to some hundreds of millisievert. People staying closer to the strike point could be exposed to higher dose levels, but these persons should be in a small number, not higher than few tenths of individuals.
On the other hand, it has to be noticed that the World Health Organization considers an individual dose of 500 mSv/year acceptable for emergency work [3]. Therefore in general, after an RDD impact, the health effects to the involved individuals are expected to be restricted to the stochastic injuries for most of them, with minor deterministic tissue reactions for those exposed to doses close to 500 mSv or higher.
In general, there is no way of knowing how much warning time there will be before an attack by terrorists using an RDD, nor how high the maximum dose level due to the attack will be, so being prepared in advance and knowing what to do and when is extremely important.
To prepare for an RDD event it is important to build an Emergency Supply Kit, including items like non-perishable food, water, a battery-powered or hand-crank radio, extra flashlights and batteries, a roll of duct tape and scissors.
Taking shelter during an RDD event is absolutely necessary. There are two kinds of shelters, blast and fallout. Blast shelters are specifically constructed to offer some protection against blast pressure, initial radiation, heat, and fire. But even a blast shelter cannot withstand a direct hit from a nuclear explosion.
Fallout shelters can be any protected space, provided that the walls and roof are thick and dense enough to absorb the radiation given off by fallout particles.
The experts of the ENEA Agency use specific computer codes to prepare various scenarios for the calculation of the dispersion of the bearing radionuclides in the atmosphere [4]. The calculations also provide the consequent dose to the most exposed individual and the collective dose. Many scenarios can be investigated

and the results are available to be used by the competent authorities. Typical commercial computer codes used in this kind of simulations are Hotspot [5] and Rascal [6]. The special features of these two codes are complementary, giving the results useful for preventing the major damages and for applying the best recovering measures. Participation to International exercises like those of the INEX series (international nuclear emergency exercises), organized under the OECD Nuclear Energy Agency's (NEA) Working Party on Nuclear Emergency Matters (WPNEM) [7], is extremely important for testing, investigating and improving national and international response arrangements for nuclear accidents and radiological emergencies. ENEA experts participate to the organization of this kind of international workshops improving their experience and comparing their knowledge with that of other high level professionals.

Facing the impact

Protection from radiation is afforded by:

- minimizing the time exposed to radioactive materials;
- maximizing the distance from the source of radiation;
- shielding from external exposure
- protecting from ingesting or inhaling radioactive material.

While the explosive blast is immediately obvious, the presence of radiation is recognized only by trained personnel with specialized equipment on the scene. Whether the event occurs indoors or outdoors, it would be safer to assume radiological contamination has occurred, particularly in an urban setting or near other likely terrorist targets. Avoiding or limiting internal exposure is important to protect from inhaling the radioactive dust resulting from the explosion. The best solution is to seek shelter from any location (indoors or outdoors), but if dust or other contaminants are manifest in the air, also other precautions could be used. Some of them are very simple, like breathing through the cloth of a shirt or of a coat to limit the exposure. Anyway also avoiding breathing radioactive dust, the proximity to the radioactive particles may still result in some radiation exposure (external).

If the explosion or radiological release occurs inside, individuals must get out immediately and seek safe shelter. Those who are outdoors have to seek shelter indoors immediately in the nearest undamaged building. If appropriate shelter is not available, people must cover their nose and mouth and move as rapidly as they can upwind, away from the location of the explosive blast. If the event occurs outside, individuals who are indoors must manage to turn off ventilation and heating systems, to close windows, vents, fireplace dampers, exhaust fans, and clothes dryer vents. It is therefore important to seek shelter immediately, preferably underground or in an interior room of a building, placing as much distance and dense shielding as possible between the refuge and the crucial point in which the radioactive material originates. After finding safe shelter, those who may have been exposed to radioactive material should decontaminate themselves following these steps: remove and bag potentially contaminated clothing; isolate the bag away from people; shower contaminated individuals thoroughly with soap and water; then, after officials indicate it is safe to leave shelter, seek medical attention. Table 1 shows a possible action program for the first 12 hours after the impact.

The ENEA Institute of Radiation Protection (IRP), with the skills and equipment of its laboratories distributed in five ENEA research centers, is able to supply advanced technical measurements, dose assessment and radiological safety advice to the people involved in the event. Among these services provided by ENEA IRP the monitoring of the contamination is one of the most advanced. It is mainly aimed at the individual monitoring of internal contamination by radionuclides and takes advantage of the application of the most up-to-date methods of analysis and measurement for the determination of radioactivity in the human body (in vivo), in the biological samples (in vitro measurements), and in many other kinds of material mixtures. Actually, at the moment, ENEA IRP laboratories are the only one in Italy able to address every need in the field of individual monitoring for internal dosimetry.

Potential safety implications

People closest to the point of the RDD impact would be the most likely to sustain injuries due to the explosion.

Decision exposure rate (microSv/h)	Radiation Zones (microSv/h)	Activities	Total accumulated stay time for first 12 Hrs
Background	Uncontrolled	No restrictions. The best location for Incident Command and decontamination activities.	Unlimited
10	Low Radiation Zone 10 - 100	If feasible, restrict access to essential individuals. Initial decontamination of first responders should occur near the outer boundary of this area. Uninjured personnel within this zone at the time of the RDD explosion can be directed to proceed directly home to shower if resources do not permit contamination surveying at the scene.	Full 12 Hours
100	Medium Radiation Zone 100 – 1000	Restrict access to only authorized personnel. Personal dosimetry should be worn. It serves as a buffer zone/transition area between the high and low radiation zones. People within this zone at the time of the explosion should be surveyed for contamination before being released	5 - 12 Hrs
1000	High Radiation Zone 1000 - 10000	Restrict access to authorized personnel with specific critical tasks such as firefighting, medical assistance, rescue, extrication, and other time- sensitive activities. Personal dosimetry should be worn. People within this zone at the time of the explosion should be surveyed for contamination before being released.	30 minutes - 5 Hours
10000	Extreme Caution Zone > 10000	This area, located within the high radiation zone, is restricted to the most critical activities, such as lifesaving. Personal dosimetry required. Limit time spent in this area to avoid Acute Radiation Sickness. People within this zone at the time of the explosion must be surveyed for contamination before being released.	Minutes to a few hours

TABLE 1 Possible radiation zones and suggested activities during the first 12 hours
Source: [8] with modifications

As radioactive material spreads, it becomes less concentrated and less harmful. Prompt detection of the type of radioactive material used will greatly assist local authorities in advising the community on protective measures. Radiation and contamination can be readily detected with the suitable equipment. Nevertheless the subsequent decontamination of the affected area may involve considerable time and expense, and requires expert staff. Immediate health effects from exposure to the low radiation levels expected from an RDD would likely be minimal. The deterministic health effects of ionizing radiation are directly proportional to the dose.

In other words, the higher the radiation dose, the higher the risk of injury. This kind of effect is evident only after a specific dose threshold. Early effects occur only to the individuals that receive an effective dose higher than 500 mSv. Late effects, like cancer, could occur also at low dose levels. Yet, just because a person is near a radioactive source for a short time or gets a small amount of radioactive dust on himself or herself this does not mean he or she will get cancer. Exposure at the low radiation doses expected from an RDD would increase the risk of cancer only slightly over naturally occurring rates. Long-term health studies on the survivors of the 1945 nuclear bombings of Hiroshima and Nagasaki indicate that for those who received radiation doses from 0 up to 100 mSv, less than 0.1% of cancers in that population were attributable to radiation [9].

The psychological impact, due to the fear of being exposed, is estimated to be by far the highest source of safety issue in the population after an RDD event. Unless information about potential exposure is made available from a credible source, people unsure about their exposure might seek advice from medical centers, complicating the centers' ability to deal with acute injuries.

Doses and tissue reactions

Symptoms/ Effects	Effective dose threshold [Sv]
No symptoms of illness	< 0.20
No symptoms of illness; minor, temporary decreases in white cells and platelets	< 0.50
No general symptoms of illness; local skin reaction; decreases in white cells and platelets	> 0.50
Possible acute radiation syndrome; 10% will have nausea and vomiting within 48 hours and mildly depressed blood counts	> 1.00
Half of those exposed will die within 30 days without medical care	> 3.00

Conclusions

The safety impact of a radiological device, also in a crowded place, would probably be relatively low, but the uncertainty in the prediction process is really large and it is not easy to be prepared to respond to this kind of event.

The ENEA agency has the required competencies in the radiological field, particularly in radiation protection, and owns the essential hardware and software instruments to face an RDD impact. National and international studies, and experiences developed by ENEA professionals are the basis on which the Agency would construct a complete program for preparing and responding to an event of diffusion of radioactive materials. The main points to be considered are decision-making on protection strategies, public health, monitoring and assessment capability, safety and security of populations and infrastructure, and planning for recovery.

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