DEVELOPMENT OF A GEOREFERENCING SOFTWARE FOR RADIOLOGICAL DIFFUSION IN ORDER TO IMPROVE THE SAFETY AND SECURITY OF FIRST RESPONDERS

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ABSTRACT

This study deals with the need to develop analytical instruments to optimise rescue operations involving radiological exposure. It reports several aspects of analysis and characterisation of orphan radioactive sources. The protection problems in cases of detection and securing of radioactive sources are analysed, with particular attention to safety and security of operators and population from exposure, identification of attention areas, and detection of specific values of dose. After defining the characteristics of orphan radioactive sources, the authors examine the fundamental radiometric parameters. All these parameters have been integrated in a customised software, known as GREAT (Georeferenced Radiological Evaluation & Analysis Tool), that allows for rapid mapping of radiological risks by georeferencing of the data collected. Particular attention has been dedicated to the theoretical model and support tools aided to the choices of first responders. Radiological event, their consequences and the tools developed will be described by the authors in order to demonstrate the importance of this software for improvement of rescue operations.

Keyword: *Orphan radioactive source; radiological diffusion; first responders; georeferencing software; radiation dose.*

1. INTRODUCTION

Radioactive sources are used throughout the world for many applications, particularly in heavy industries, medicine and research. The risks associated with such uses are strictly connected to their physical characteristics; activity, types of radionuclides, methods of manufacture, etc. (IAEA-TECDOC, 2004). In the case of conventional applications, the risks associated are usually well known and their activities are officially established. In the European Union (EU), the provisions for the protection of population and workers against the risks of ionising radiation are given by European Atomic Energy Community (EURATOM) directives (EURATOM, 1984, 1989, 1990, 2006), while in Italy, the main guidelines are included in MOI (2009, 2011), which is an extension of MOI (1995).

However, problems related to orphan radioactive sources (the ones that are not under control) are different as they can be accidentally found by persons that do not know their effective harm. They may also present particular risks that do not allow for easy identification, due to their small dimensions, often smaller than of a pen. To protect against such events, melting plants have to equip themselves with radiometric instrumentations for control of metal scrap in the input, so as to reduce the risk of accidental introduction of radioactive sources in the processing cycle (Knoll, 2010).

As part of the community plan of action in the field of radioactive waste (EURATOM, 1992), the European Commission published a study on the management and disposal of disused sealed radioactive sources in the EU (Angus *et al.*, 2000). The authors evaluated 500,000 units of sealed radioactive sources that were distributed to operators in the EU states since 1950. Of this amount, 110,000 units are still in use, while the remaining units have been stocked in temporary storage, returned to the manufacturers for the purpose of reuse, or sent to disposal plants and subjected to the system of management of radioactive waste. The national authorities face unsafe situations when sources are not managed properly or are left without any control, with the possibility of dangerous health consequences. Angus *et al.* indicated that around seventy sources get out of the authorities' control every year.

The study deals with the problems mentioned above and the authors present a software that was developed for rapid mapping of radiological diffusion and associated risks in cases of accidental and deliberate releases. The main research objectives are to define a conceptual model for a spatial decision support system (SDSS), oriented to the problem of radiation hazard, for identifying the requirements of both mobile and control rooms; to develop the prototype of the software for first responders, that allows web access in order to georeference source localisation and dose rate measurements at a safe distance from the source and to develop the prototype of the control room components according to the service oriented architecture (SOA) paradigm, which allows usability through Open Geospatial Consortium's (OGC) web services within the Intergraph's incident command tool, known as the Intergraph Incident & Resource Management System (I^2RMS).

2. RADIOLOGICAL CHARACTERISTICS TO MEASURE RADIOLOGICAL RISKS

The main radiological characteristics, particularly those useful for this study, are commonly divided into (Cazzoli *et al.*, 2003):

1. Source:
   - Activities
   - Constant range
2. Field values:
   - Exposure
   - Kerma, is a size of dose, but its measurement in air is also used as the field value
3. Values of the dose:
   - Absorbed
   - Equivalent
   - Effective.

There is a direct relationship between these variables:

Source ➔ *Field* ➔ *Dose*

2.1 In-Field Operations with Unknown Radiological Sources

In cases of operations with the presence of orphan sources, the operators often work with unknown sources. The external exposure of an operator may be limited by observing the following rules:

- Reducing the irradiation time
- Increasing the distance
- Using a screen / shield to reduce the intensity of radiation

2.1.1 Reducing the Irradiation Time

The value of the dose increases linearly with the intensity of radiation I_{dose} and time t (Figure 1). The operation must therefore be planned carefully in order to minimise, as far as possible, the intervention times. In any case, the dose values established by law should not be exceeded. The dose values are defined from three quantities; absorbed dose D, equivalent dose H and effective dose E. Absorbed dose is the amount of energy that is deposited in any material by ionising radiation. Equivalent and effective doses relate the amount of radiation received by a person with resulting biological damage and hence, are called radio-protection quantities. In order to plan for an operation with sealed sources (in absence of contamination risk) the most important value is the effective dose because the effective dose in radiation protection and radiology is a measure of the cancer risk to a whole organism due to ionizing radiation delivered non-uniformly to part(s) of its body. It takes into account both the type of radiation and the nature of each organ being irradiated. (Gallo *et al.*, 2012).

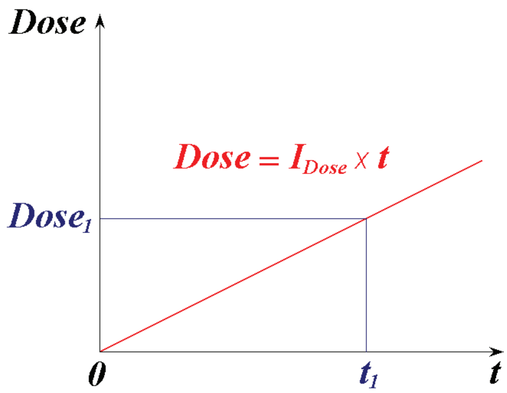


Figure 1: A plot showing the trend of increase of effective dose I_{dose} with time *t*.

2.1.2 Increasing the Distance

Taking into account a generic distance *d* from the source, the value of the field, in terms of intensity of exposure, is inversely proportional to the square of the distance (Figure 2) and directly proportional to the activity, and is expressed using the following equation:

$$I_X = \frac{\Gamma \cdot A}{d^2} \qquad (1)$$

where:

- I_x = Exposure intensity [C/(kg*h)]
- Γ = Gamma specific constant, which is a characteristic of each radionuclide [(C*m^2) / (kg*h*Bq)]
- A = Source activity [Bq]
- d = Distance from source [m].

It is evident how it is important to organise rescue operations keeping the greatest possible distance from the source (IAEA TECDOC-1162, 2000). Starting with the knowledge of the radiation field, in the case of exposure to whole body with the radiation (our case study), it is possible to calculate the values of the doses that should be assumed.

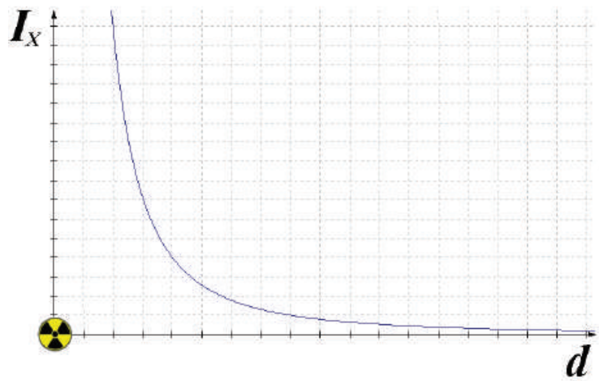


Figure 2: A plot showing the trend of decrease of radiation dose vs time.

2.1.3 Using a Screen / Shield to Reduce the Intensity of Radiation

The radiations, propagating in space, interact with matter in their passage causing ionisation that can be direct (for the alpha and beta radiation) or indirect (for the gamma radiation and neutron) (UNI, 2001). The interaction between radiation and matter and the different penetration capabilities are a function of (IRCP, 1996):

1. Type of radiation
2. Its energy
3. Characteristics of the exposed matter.

Alpha radiations rapidly convert their kinetic energy into material ionisation, with a modest path. The free electrons, in turn, cause a secondary ionisation. Following a possible excitation of atoms, an emission of electromagnetic radiation of low energy (non-ionising) is also possible. Alpha radiation is arrested by less than 10 cm of air or by a simple sheet of paper. In cases of irradiation of people, such radiation stops on the very first layer of the skin, and only in cases of high energy (about 7 MeV) can it reach the germinative layer of the skin, at a depth of 70 µm. This type of radiation is therefore not dangerous in cases of external irradiation. However, the scenario changes in case of internal contamination of the human body (with internal irradiation), where the damage would lead directly to organs and tissues (ICRP, 2007; Knoll, 2010).

Beta radiations and electrons have modest capability of penetration of matter, but higher than those of alpha particles. These radiations can move in the air for about 4 m or 4 mm in water (for energies with order of magnitude of 1 MeV). The germinative layer of the skin can be reached by particles with energies of above 70 keV. Personal protective equipment (PPE) used by firefighters provides good shielding for these types of radiation. In the air, dozens of ionisations per cm are produced. As a result of excitation of the atoms of the exposed material by beta radiation, there is the reemission of energy in the form of electromagnetic waves. The strong deceleration of the beta particles can cause a second order emission of X-ray-called

“Bremsstrahlung”. The emission has intensity that increases proportionally with the atomic number of the irradiated material. The phenomenon constitutes a risk greater than the one of the beta radiation from which it derives, being X-rays more difficult to shield. It is useful not use materials with a high atomic number to shield beta radiation. A good shielding of the beta radiation is also given by the first layer of material with low density, which reduces the production of X-rays (ICRP, 2007; Knoll, 2010).

Gamma radiations can absorbed by huge lengths of matter. In terms of interaction mechanism between matter and radiation, at low energies, the photoelectric effect prevails, at medium energies the Compton effect prevails, while at large energies the pairs creation prevails. For the charged particles, the beam of radiation is slowed down in an almost uniform mode and is stopped almost simultaneously, while for photons, the beam is reduced as it progresses within the material, and the photons that continue on their path maintain the same initial energy. For such radiation, it is important to refer to the so called half-value layer (HVL), or half-value thickness, through which the initial intensity of the incident radiation is halved. These thicknesses are a function of the type of exposed material and the energy of the radiation. X and gamma radiations are effectively attenuated by materials with a high atomic number, such as lead (ICRP, 2007; Knoll, 2010; Gallo *et al.*, 2012).

2.2 Intervention Procedures in Cases of Sealed Radioactive Sources

During an operation with the presence of sealed radioactive sources, there is an immediate need to delimit an area which must be kept away the population. This area should have dimensions of not less than those of the so-called “area of concern”, so as to ensure that the area outside it does not exceed the legal effective dose limit of 1 mSv. The limits of the attention area can be determined analytically using the data of the source (if known) or following in-field measures of intensity and dose. It is necessary to determine the area of danger for the population. This is possible by making measurements of field intensity or dose, depending on the instruments available. With knowledge that the value of the intensity of dose and relative distance uniquely identifies the intensity-distance curve (Figure 2), the intervention can be planned. Multiple measurements are necessary to reduce the errors. Assuming that the operator is working with a tool that provides the intensity value of the effective dose, at a distance d_1 the operator measures an intensity value of effective dose I_{E1}. The value of I_{E1} compared to the values (unknown) A and Γ is:

$$I_{E_1} = \frac{\Gamma \cdot A}{d_1^{\ 2}} \tag{2}$$

Taking into account a generic distance d_2, the value of intensity I_{E2} can be expressed as:

$$I_{E_2} = \frac{\Gamma \cdot A}{d_2^{\ 2}} \tag{3}$$

For Equations 2 and 3, obtaining the values of *A* and *Γ*, the following equation can be derived:

$$I_{E_1} x d_1^2 = I_{E_2} x d_2^2 \tag{4}$$

from which calculate the value of I_{E2} can be computed as follows:

$$I_{E_2} = I_{E_1} x \frac{d_1^2}{d_2^2} \tag{5}$$

Using Equation 5 (setting the intensity values of effective dose for the operation), it is possible to calculate the relative distances and in particular the width of the attention area (Malizia *et al.*, 2012).

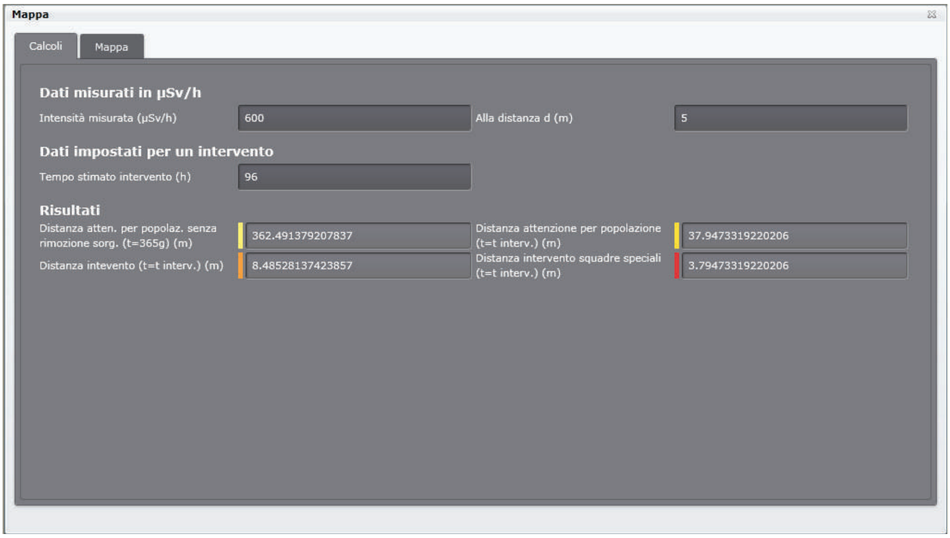
3. ACCELERATING SMARTER DECISIONS: GEOSPATIAL TECNOLOGIES FOR SAFETY IMPROVEMENTS DURING RESCUE OPERATIONS

From this analysis, it is clear that the primary task of first responders is to protect the population from the risks arising from exposure to ionising radiations and then to define promptly the attention area (while working in safe and secure conditions of course) (Malizia *et al.*, 2012; Gallo *et al.*, 2012). It is possible to identify, in an analytical way, the size of the attention area and to carry out calculations of the dose absorbed by those who remain in the irradiated area. One of the problems that need to be dealt with immediately is the possible evacuation of buildings or closure of roads in the attention area. The principal requirements here are essentially:

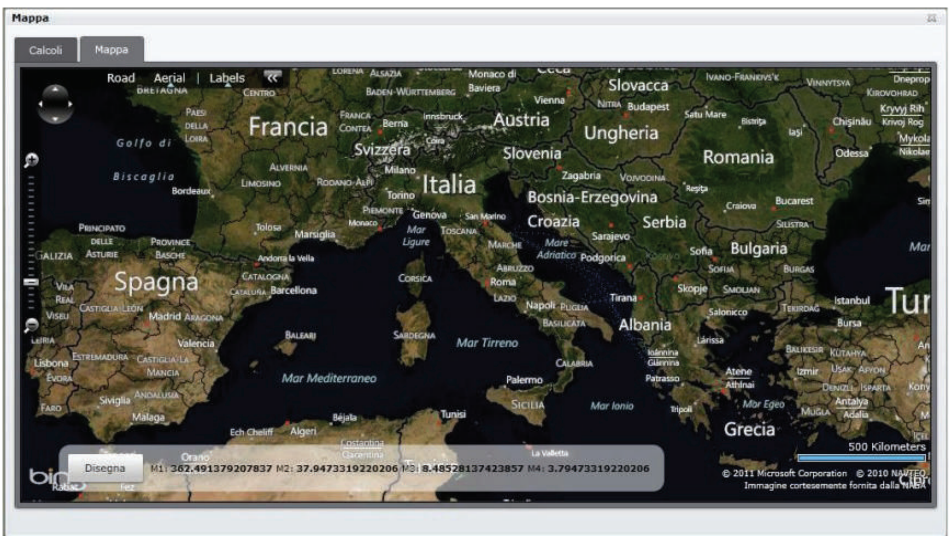
1. To locate the area affected by the radiation
2. To evaluate the possibility moving the source to a safe distance to avoid the evacuation of particular buildings, such as hospitals, or to allow the reopening of important communication routes.

In order to address these problems and improve rescue operations systems, a software that allows the geo-referencing of results of radiological calculations is needed. Hence, the authors have developed the software GREAT (Georeferenced Radiological Evaluation & Analysis Tool), interfaced with Intergraph's geospatial solutions, for an unknown radioactive source case, by applying the equations outlined above. In the first screen of the software (Figure 3(a)), called *Calcoli* (calculations), values of radiation intensity, measured in mSv/h, distance to which the measurement is taken and estimated time of operation is entered. By setting these boundary conditions, the software calculates the values of attention area, operating distance and in-field distance for special rescues teams, as well as the distance of attention for the population in case of non-removal of the source, conventionally identified for a residence time of 365 days.

The second screen of the software (Figure 3(b)) enables the user to display the attention areas on Microsoft Bing Maps (MBM). On the left of the screen, there is a zoom slider and darts to move the sight of the map, an operation which can also be performed using a mouse, in order to frame the area concerned. The display of the various areas of attention is possible by clicking on *Draw* (after assigning the source point on the map). The identification of the source point can be done manually by clicking with the mouse on the point identified or by entering the coordinates of latitude and longitude values.



(a)



(b)

Figure 3: The screens of the software: (a) The first screen, which is used to include boundary condition of operation parameters. (b) The second screen, which is used for mapping operations.

The developed software is a web application built with Silverlight, which is a Microsoft technology that allows for deploying rich internet applications (RIAs). The programming language used is C# (C sharp). Regarding the map, Silverlight Bing Map is used for the control of the components, providing input coordinates and drawing the map.

In Figure 4, the presence of a source is simulated at Policlinico Tor Vergata University as the focus area. The software immediately provides a map of the area to organise the evacuation. The critical areas are identified by the circles, of which the largest is the attention area for the population.

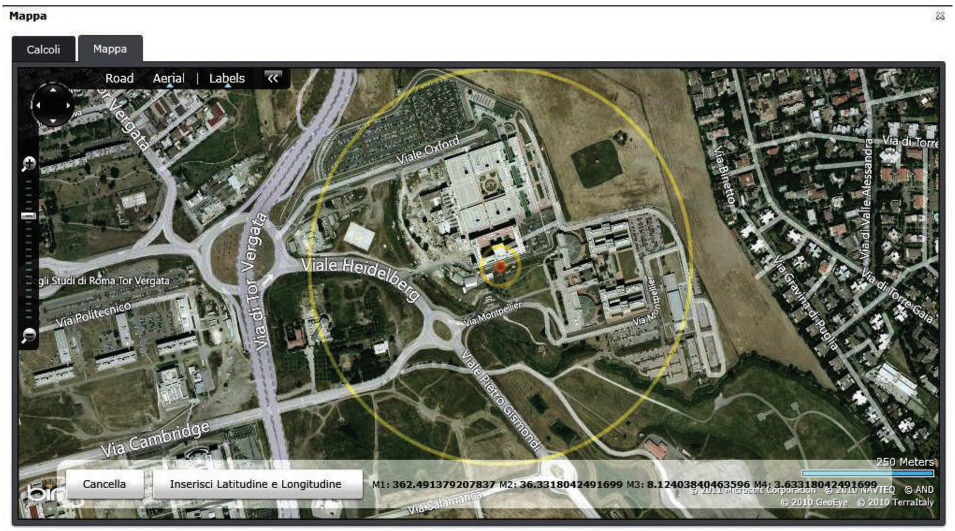


Figure 4: Simulation of a radiological risk at Policlinico Tor Vergata University.

The software has been interfaced with geospatial solutions from of Intergraph's Emergency Operation Centers. An emergency operations centre (EOC) enhances an area's ability to coordinate multi-agency responses to disasters and emergencies. It is equipped to perform a number of crisis management functions but is also able to function as a day-to-day operations resource, and supports efforts to test and exercise contingency and response plans (Cassani *et al.*, 2010). It is activated during emergencies that overwhelm the normal day-to-day functions of first responders. It typically performs the functions of information collection, processing, display and dissemination, management and coordination of interagency activities, implementation of relevant plans, and command and control of assigned resources.

The key to Intergraph's approach is standards and interoperability. Intergraph has enjoyed a long, successful partnership with OGC, since it was found in 1994, to create open and extensible software application programming interfaces for geographic information systems (GIS) and other mainstream technologies. Intergraph's I^{2}RMS (Figure 5) serves as the core of an EOC, and provides a full-SOA system to view and manage resources and activities associated with an event, as well as providing integrated situational awareness during planning, response, recovery and mitigation. Its open architecture and standards-based design provides the interoperability and information sharing vital for success during each phase of consequence management.

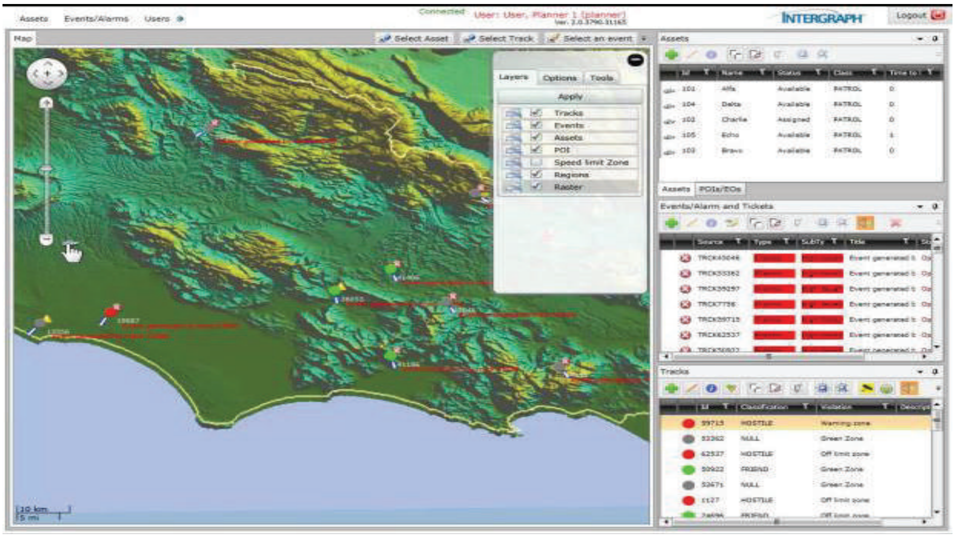


Figure 5: Intergraph I2RMS's 2D Common Operational Picture (COP) interface.

I[2]RMS goes beyond simple resource monitoring to what is called presence management. The Common Operational Picture (COP) console of I[2]RMS integrates several key components, including wireless communications, geospatial software, location tracking tools and the Internet, to help operators to plan, manage and track mobile assets and personnel. I[2]RMS can track and manage multiple resources using the latest in radio frequency identification (RFID) technology, Global Positioning System (GPS), automatic vehicle location (AVL) systems, cell and sensor technologies (using radar and electro-optic sensors) and geospatial mapping applications (2D and 3D COP interfaces). This solution is service oriented architecture (SOA) based and offers a thin-client system to view and manage these resources. Intergraph's SmartClient is used to give EOC's personnel a rich data entry GIS client into a simple web browser using a Java-based technology. The solution is designed to be a client of OGC's web services, and to publish maps and reports on the Internet using Intergraph's geospatial Web servers, GeoMedia WebMap and ERDAS Apollo.

4. CONCLUSION

Orphan radioactive sources are a potential dangerous for the population. In cases of their occurrence, it is important to take the necessary radiation protection measures, such as evacuation and closure of adjacent areas to quickly identify the areas affected by the radiation hazard. The use of the developed georeferencing software makes it simpler to achieve good safety and security standards. It is clear how such a tool, providing an overview of the scenario and areas involved, can optimise the operations of first responders who are equipped with handheld computers with web access. The detection of a safe area in which to temporarily place the source is relatively simple and can be readily verified using the software.

The software can also be a useful aid for companies and institution that deal with transport of radioactive sources, with the possibility to check, for the intended path, the areas potentially affected as a result of an accident with the source of exposure. In addition, it can also be potentiated with a mask for cases of known sources, as well as with the inclusion of other fields for the evaluation of additional elements such as values of doses taken by those who are in the radiological hot spot.

REFERENCES

Angus, M.J., Crumpton, C., McHugh, G., Moreton, A.D. & Roberts, P.T. (2000), *Management and Disposal of Disused Sealed Radioactive Sources in the European Union*. Safeguard International Ltd., Abingdon, Oxfordshire.

Cassani, I., Fiduccia, A., Malizia, A., Mugavero, R. & Quarta, A.M. (2010). Emergency operation center e protezione da eventi CBRN: Un Web-SDSS per le analisi di supporto alla gestione di incidente ad un reattore nucleare. *Atti 14a Conferenza Nazionale ASITA*, 9-12 November 2012, Fiera di Brescia.

Cazzoli,S., Biazzi, L., Campagni, A., Cianchi, A., Malgieri, F., Marinaro, M., Sinigallia, R. & Sumini M. (2003). *Individuazione e confinamento in sicurezza di sorgenti radioattive orfane*. Notiziario dell'Esperto Qualificato, N. 64 -65 / Gennaio – agosto 2003. Anno XXIII N. 1-2

European Atomic Energy Community (EURATOM) (1984). *Council Directive 84 / 466: Basic Safety Standards for the Health Protection of the General Public and Workers Against the Dangers of Ionozing Radiation*. European Atomic Energy Community (EURATOM), Brussels.

European Atomic Energy Community (EURATOM) (1989). *Council Directive 89 / 618: Health Protection Measures to be Applied and Steps to be Taken in the Event of a Radiological Emergency*. European Atomic Energy Community (EURATOM), Brussels.

European Atomic Energy Community (EURATOM) (1990). *Council Directive 90 / 641: Operational Protection of Outside Workers Exposed to the Risk of Ionizing Radiation During Their Activities in Controlled Areas*. European Atomic Energy Community (EURATOM), Brussels.

European Atomic Energy Community (EURATOM) (1992). *Council Resolution OJ C 158: Renewal of the Community Plan of Action in the Field of Radioactive Waste*. European Atomic Energy Community (EURATOM), Brussels.

European Atomic Energy Community (EURATOM) (2006). Council Directive 2006 / 117: *Supervision and Control of Shipments of Radioactive Waste and Spent Fuel*. European Atomic Energy Community (EURATOM), Brussels.

Gallo, R., De Angelis, P., Gallo, N., Malizia, A., Fiduccia, A., D'Amico, F., Fiorito, R., Gucciardino, A., Richetta, M., Bellecci, C., & Gaudio, P. (2012). Development of software for the identification mapping of radiological diffusion in order to improve the rescue operations. *MIMOS Conference*, 10 October 2012, , Rome.

International Atomic Energy Agency (IAEA) (2000). *IAEA-TECDOC-1162: Generic*

Procedures for Assessment and Response During Radiological Emergency. International Atomic Energy Agency (IAEA), Vienna.

International Atomic Energy Agency (IAEA) (2004). *IAEA-TECDOC-1388: Strengthening Control Over Radioactive Sources in Authorized Use and Regaining Control Over Orphan Sources*. International Atomic Energy Agency (IAEA), Vienna.

International Commission on Radiological Protection (ICRP) (1996). *IRCP Publication 72 (1996): Age – Dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients*. International Commission on Radiological Protection (IRCP), Ottawa, Ontario.

International Commission on Radiological (ICRP) (2007). *ICRP Publication 103 (2007): The 2007 Recommendations of the International Commission on Radiological Protection*. International Commission on Radiological Protection (IRCP), Ottawa, Ontario.

Knoll, G.F. (2010). *Radiation Detection and Measurements, 4th Ed.* John Wiley & Sons, New York.

Malizia, A., Lupelli, I., D'Amico, F., Sassolini, A., Fiduccia, A., Quarta, A.M., Fiorito, R., Gucciardino, A., Richetta, M., Bellecci, C. & Gaudio, P. (2012). Comparison of software for rescue operation planning during an accident in a nuclear power plant. *Defence S&T Tech. Bull.*, **5**: 36-45.

Ministry of Interior (MOI) (1995). *Legislative Decree No. 230 / 1995: Regulatory Control of Radioactive Waste Management*. Ministry of Interior (MOI), Italy.

Ministry of Interior (MOI) (2009). *Legislative Decree No. 23/ 2009: Actuation of Council Directive 2006/117 / EURATOM of 20 November 2006 on the Supervision and Control of Shipments of Radioactive Waste and Spent Fuel*. Ministry of Interior (MOI), Italy.

Ministry of Interior (MOI) (2011). *Legislative Decree No.100/11 : Modification of Legislative Decree No. 230 / 1995*. Ministry of Interior (MOI), Italy.

UNI (Ente Nazionale Italiano di Unificazione) (2001). *UNI 10897: Carichi Di Rottami Metallici - Rilevazione Di Radionuclidi Con Misure X E Gamma*. Ente Nazionale Italiano di Unificazione (UNI), Milan.