Modeling of nuclear and radiological emissions for emergency management

Modellazione di emissioni nucleari e radiologiche per la gestione delle emergenze

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Outline

INTRODUCTION

- Emergency management of CBRN events
- CBRN detection modules in the European Civil Protection pool
- The CBRN rescEU capacity

MODELLING in relation to HARDWARE

- The CBRN DISM vehicle
- Layers of information needed

CASE STUDY

- RN response using a real case
- Software simulations

CONCLUSIONS

Emergencies involving the release of CBRN agents

Accidents leading to the release chemical, nuclear-radiological and biological agents require additional capabilities for first responders.

Specifically, Fire and Rescue Services need to possess **specific skill and capabilities** in **modelling** the potential dispersion of CBRN agents that are being **integrated into the complex response system** in place for these scenarios.

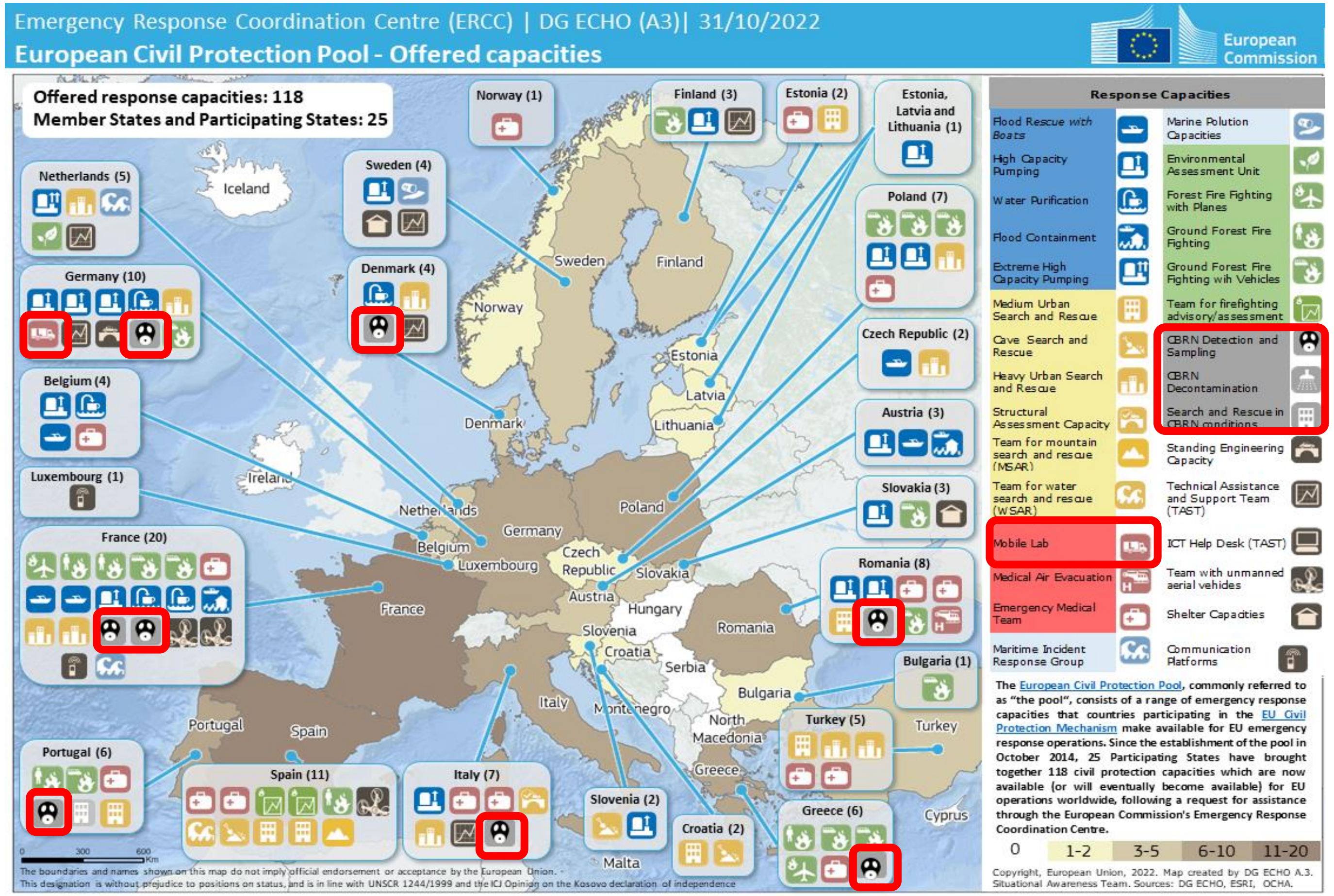
Large scale CRBN accidents, or using the definition used by the European Commission, "**High impact low probability events"** call for a capacity response that require to have the following **sub-capacities:**

- ❑ **Sampling and detection**
- ❑ **Monitoring and surveillance**
- ❑ **Identification**
- ❑ **Decontamination**
- ❑ **Advanced command post**
- ❑ **Modelling of the scenario**
- ❑ **Reach back capability**

The **last three capacities are relevant** for the definition of a **task** that is of primary importance for the resolution of a CBRN scenario, which is the **ability to divide the scenario in risk zones** and the relative **access control** to first responders and rescuers **to the impacted area.**

To respond promptly and efficiently to such events the capacities that Fire and Rescue Services need to deploy on the scenario are **standardized both in Italy** and **by the European Commission**, in case such events call for an international emergency response system.

Requirements of detection and sampling CBRN modules



12. Chemical, biological, radiological and nuclear detection and sampling (CBRN)	
Tasks	• Carry out/confirm the **initial assessment**, including: ○ the description of the **dangers** or the risks, ○ the determination of the **contaminated area**, ○ the assessment or confirmation of the **protective measures** already taken. • Perform qualified **sampling**. • **Mark** the contaminated area. • **Prediction of the situation**, **monitoring**, **dynamic assessment of the risks**, including recommendations for warning and other measures. • Provide support for immediate **risk reduction**.
Capacities	• **Identification** of **chemical** and detection of **radiological** hazards through a combination of hand held, mobile and laboratory based equipment: ○ ability to **detect alpha, beta and gamma radiation** and to **identify common isotopes**, ○ ability to identify, and if possible, perform semi-quantitative analyses on **common toxic industrial chemicals and recognized warfare agents**. • Ability to **gather**, **handle** and **prepare** biological, chemical and radiological **samples** for further analyses elsewhere (1) • Ability to apply an **appropriate scientific model to hazard prediction** and to confirm the model by continuous monitoring. • Provide support for **immediate risk reduction**: ○ **hazard containment**, ○ **hazard neutralization**, ○ provide **technical support to other teams or modules**.
Main components	• **Mobile chemical and radiological field laboratory**. • **Hand held** or mobile detection equipment. • Field **sampling** equipment. • **Dispersion modelling** systems. • Mobile **meteorological station**. • **Marking** material. • **Reference documentation and access to designated sources of scientific expertise**. • **Secure and safe containment** for the samples and waste. • **Decontamination facilities for the personnel**. • Appropriate **personnel and protective equipment** to sustain an operation in a **contaminated and/or oxygen deficient environment, including gas tight suits** where appropriate. • Supply of technical equipment for **hazard containment and neutralization**.
Self-sufficiency	Article 12 applies.
Deployment	Availability for departure maximum 12 hours after the acceptance of the offer.

(1) This process shall, where possible, take account of the evidential requirements of the requesting state.

The **pool is a EU Civil Protection mechanism collecting the capacities offered by the member states and ready to intervene in case of major accidents, occurring in Europe but also elsewhere.**

Requirements of detection and sampling rescEU CBRN capacity


DECONTAMINATION
Implementing Decision (EU) 2021/88


STOCKPILING
Implementing Decision (EU) 2021/1886


DETECTION SAMPLING AND MONITORING
Implementing Decision (EU) 2022/465

MOBILE LABS
Implementing Decision (EU) 2022/465

EU list of high-risk radioactive sources[1]

Radio nuclide	Activity threshold (TBq)
Am-241	6.E-01
Am-241/Be	6.E-01
Au-198	2.E+00
Cd-109	2.E+02
Cf-252	2.E-01
Cm-244	5.E-01
Co-57	7.E+00
Co-60	3.E-01
Cs-137	1.E+00
Gd-153	1.E+01
Ge-68	7.E+00
I-131	2.E-00
Ir-192	8.E-01
Mo-99	3.E-00
P-32	1.E+02
Pd-103	9.E+02
Pm-147	4.E+02
Po-210	6.E-01
Pu-238	6.E-01
Pu-239/Be	6.E-01
Ra-226	4.E-01
Ru/Rh-106	3.E+00
Se-75	2.E+00
Sr-90	1.E+01
Tm-170	2.E+02
Yb-169	3.E+00

'11. **CBRN detection, sampling, identification and monitoring capacity, for the response to emergencies, for search activities, for the response to security events and for the surveillance of major events**

Tasks	— Deployable and reach back CBRN detection, sampling, identification and monitoring capacity, for the response to emergencies, for search activities, for the response to security events and for the surveillance of major events (1).
Capacities	— Ability to provide operational support for the response to emergencies (2), through in-field CBRN detection, sampling, identification and monitoring. — Ability to support search activities, through in-field CBRN detection, sampling, identification and monitoring. — Ability to provide operational support for the response to security events, through in-field CBRN detection, sampling, identification and monitoring. This shall include the ability to support the competent authority of the requesting Member State or third country (3) in its effort to preserve and gather forensic evidence, to secure the chain of custody and to protect classified information. — Ability to support surveillance operations for major events through in-field CBRN detection, sampling, identification and monitoring. — Ability to provide non-deployed reach back technical assessment support for CBRN detection, sampling, identification and monitoring activities, as well as to address safety concerns related to these activities. — Ability to prepare for and address operational challenges to implement CBRN detection, sampling, identification and monitoring activities in the requesting Member State or third country, considering the hazard and threat assessments, plans, procedures and protocols of the requesting Member State or third country. — Ability to operate under the direction of the requesting Member State, as referred to in Article 12(6) and (7) of Decision No 1313/2013/EU, and to provide effective operational liaison and coordination abilities with the relevant authorities of the requesting Member State. (4)
Main components	— Pool of experts capable of assessing and planning CBRN detection, sampling, identification and monitoring activities, based on hazard and threat assessments of the Member State or third country. — Deployable pool of experts capable to perform CBRN detection, sampling, identification and monitoring, for the response to emergencies, for search activities, for the response to security events and for surveillance activities. — Deployable CBRN detection, sampling, identification and monitoring equipment and tools, as well as all required supporting equipment, tools, resources, vehicles, consumables, secured communication, data exchange and information technologies, and small field laboratories (5), as deemed necessary to ensure the capacity's functionality. — Deployable equipment, tools, resources and consumables, as well as an appropriate management system, to handle the contaminated waste caused by the detection, sampling, identification and monitoring activities. — Operational reach back capability for technical and operational assessment, especially in the area of identification, sampling and safety.


Response to emergencies
1


Search
2


Surveillance
3


Response to security events
4


Reach back
5


Coordination, assesment and planning
6

The **rescEU capacity is owned by states and by the commission with higher requirements than the pool and expected to mandatory act in case of emergencies.**

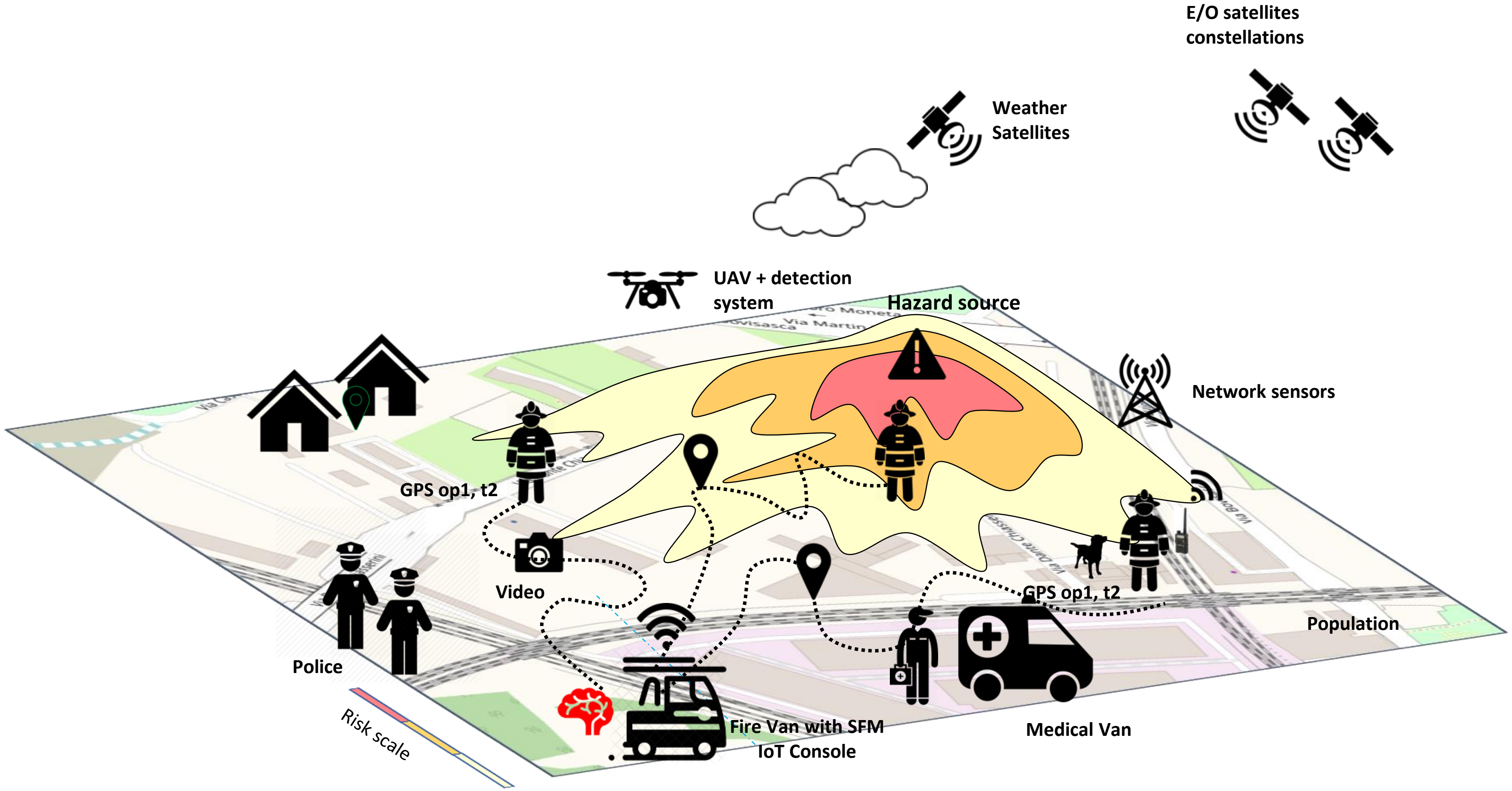
Local decision making unit - Advanced Command Post

Italian Fire and Rescue Services developed a prototype of the CBRN rescEU capacity. A vehicle with advanced command post features has been developed and tested during the pandemic in 2020 and 2021.

Local decision making unit - Advanced Command Post

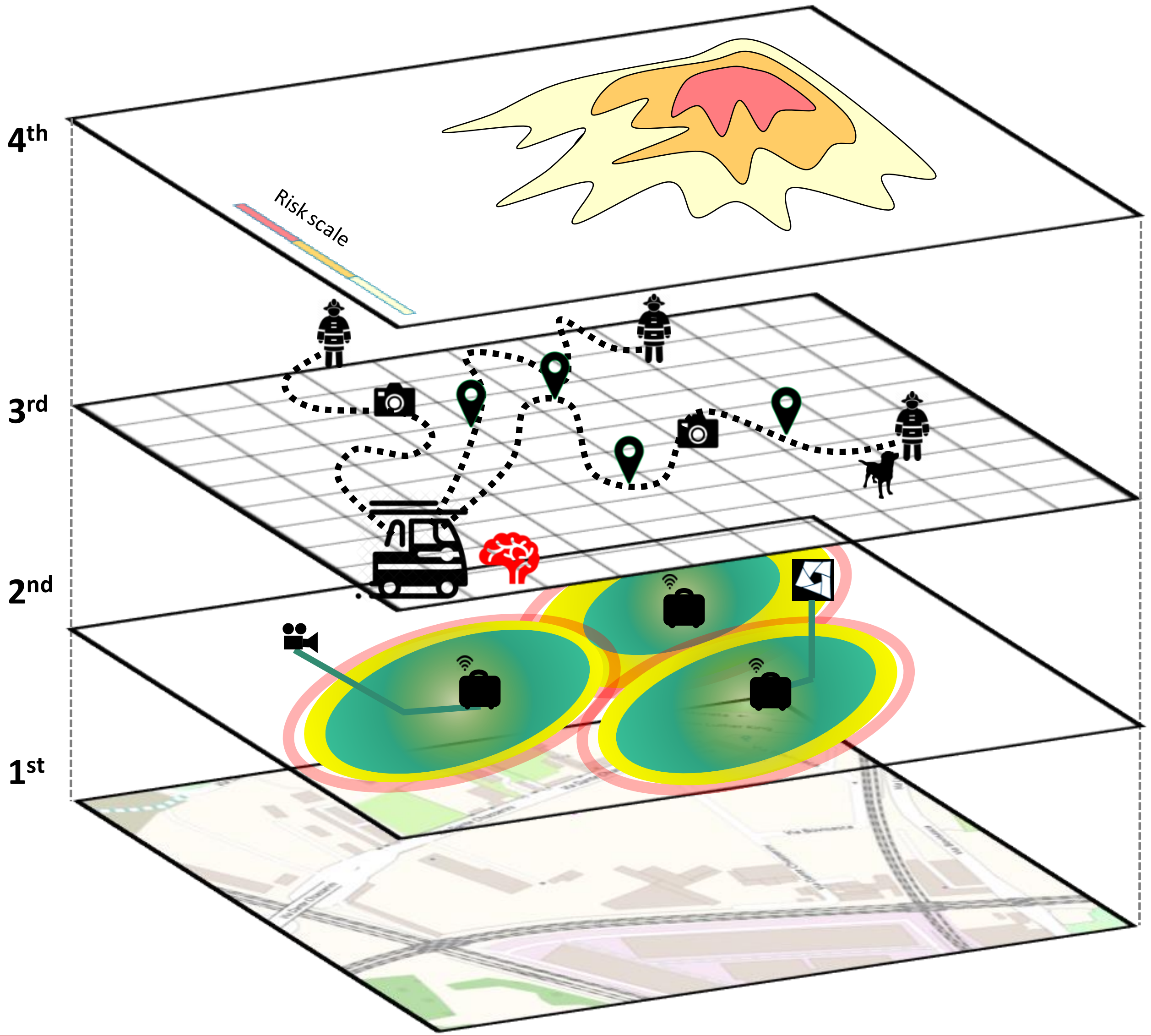
In order to make quick and **appropriate decisions** an **advanced command post** with high level communication requirements is needed.
Amongst the many requirements, reach-back capability is one of them.

Layers of information



Typical expected visualization of an accident.

Local decision making unit - Advanced Command Post



4th layer: Processed info dashboard and risk zoning maps

Dispersion | Dispersion + wind | Leakage and spill | Fire building

Biometric levels | 3d reconstruction | Augmented Reality

3rd layer : localization/tracking grid of first responders, waypoints, pictures and video points, data sources

Responders | Photo | Location | Fire Van | SFM IoT Console

2nd layer: connectivity and coverage (performance of IoT efficiency)

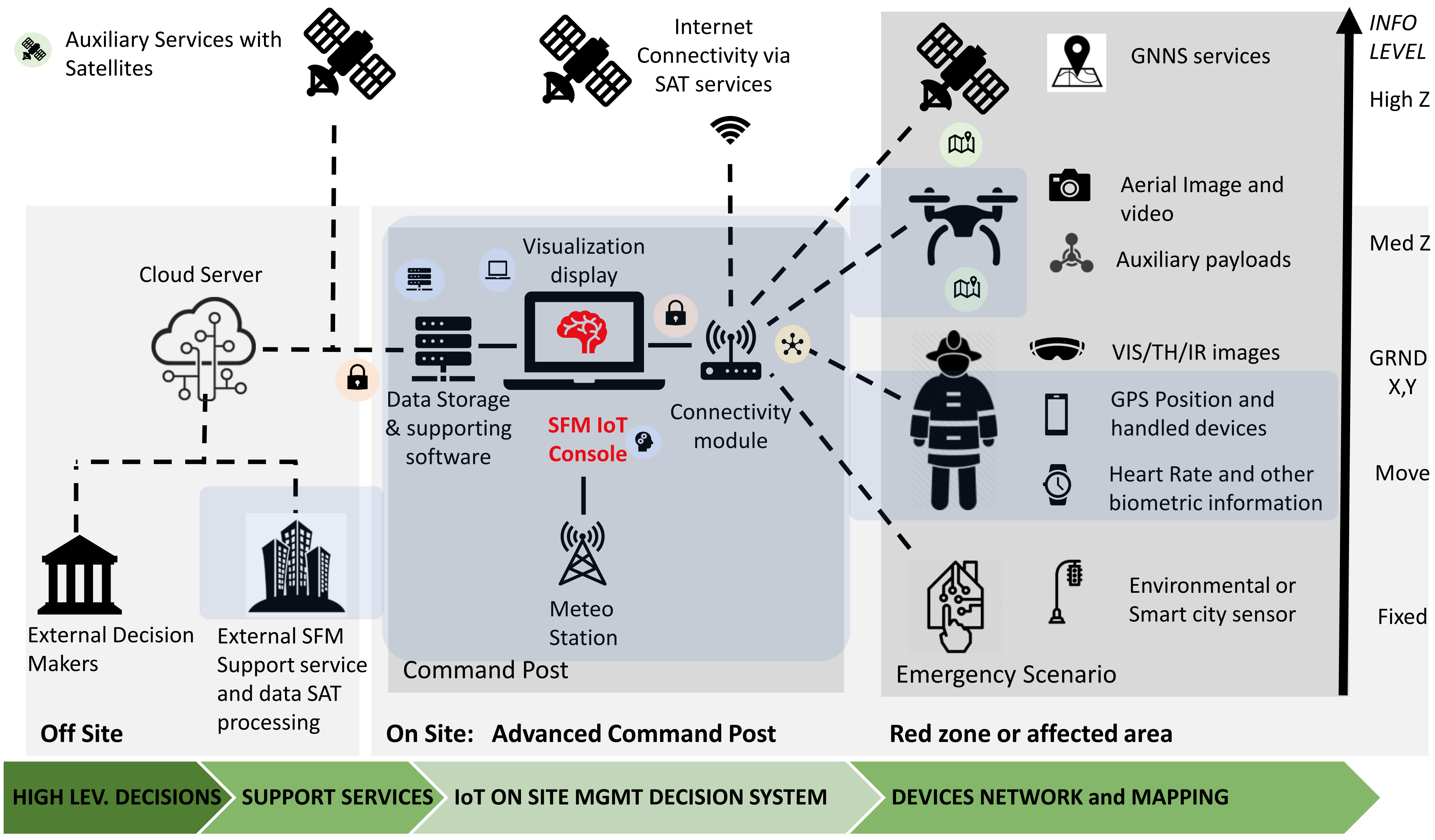
Wi-Fi bags | x-y and z video streaming

Connectivity levels : High | Medium | Low

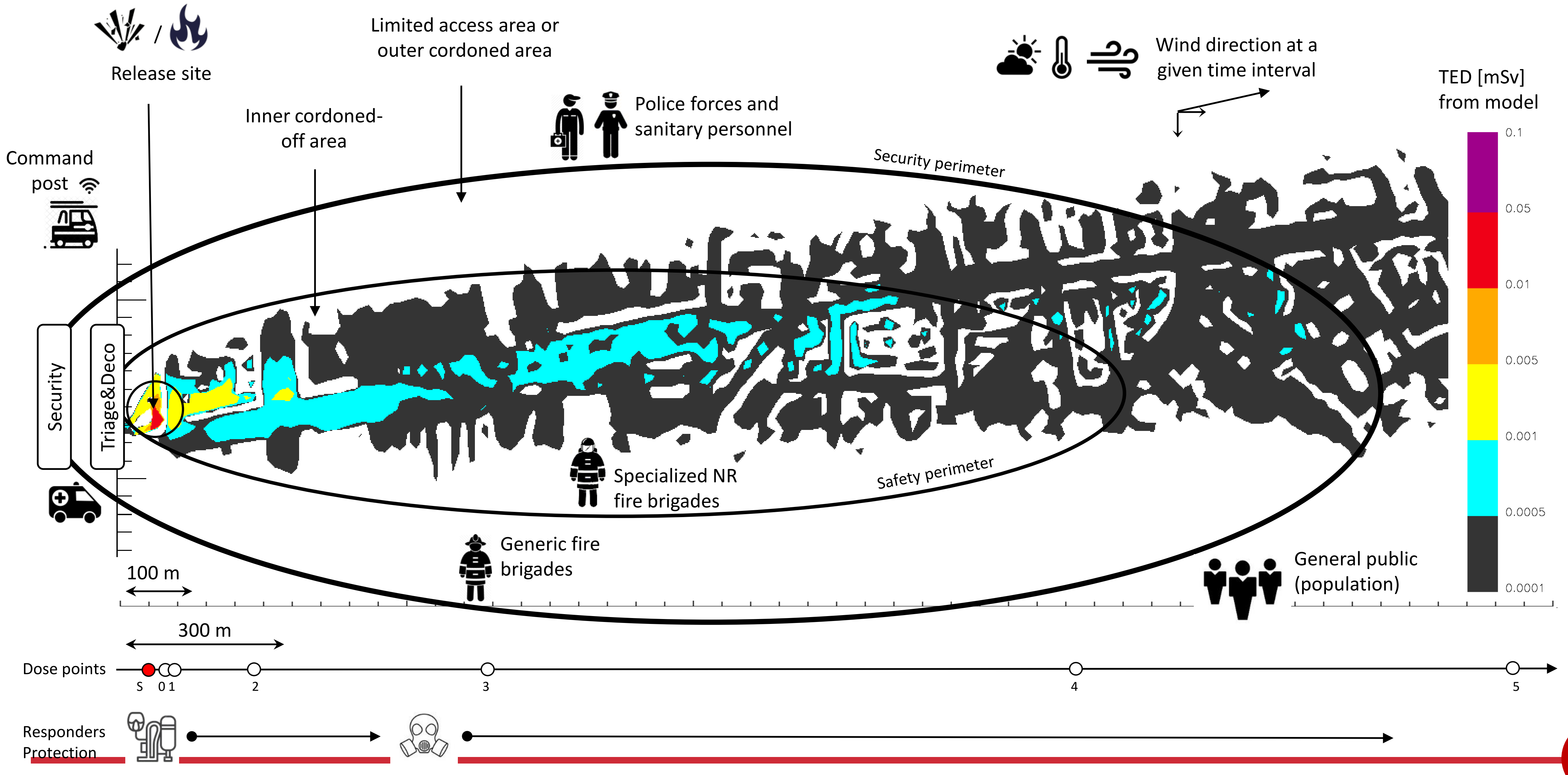
1st layer: mapping system used for scenario's representation

satellite (t-1) | G-map (t0) | UAV (t+1) | ArcGIS retrieved (any t)

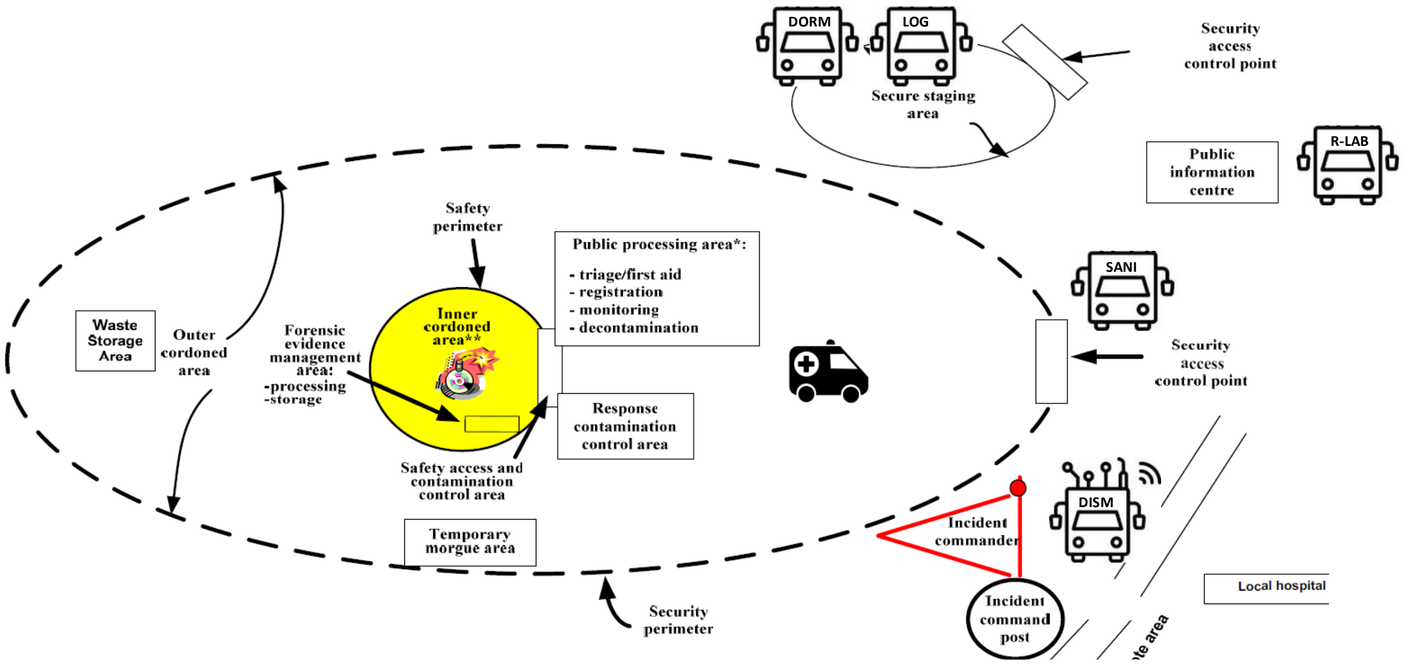
Local decision making unit - Advanced Command Post

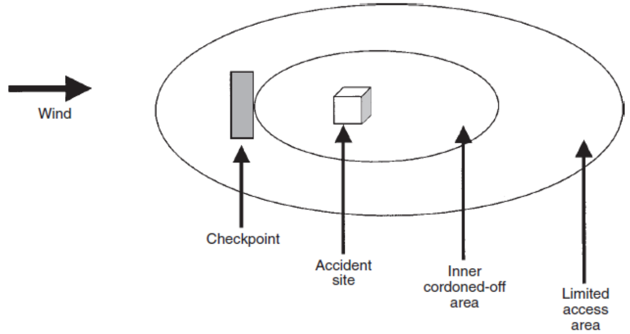


Local decision making unit - Advanced Command Post



Configuration and disposition of vehicles in a generic RN scenario

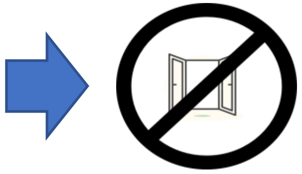




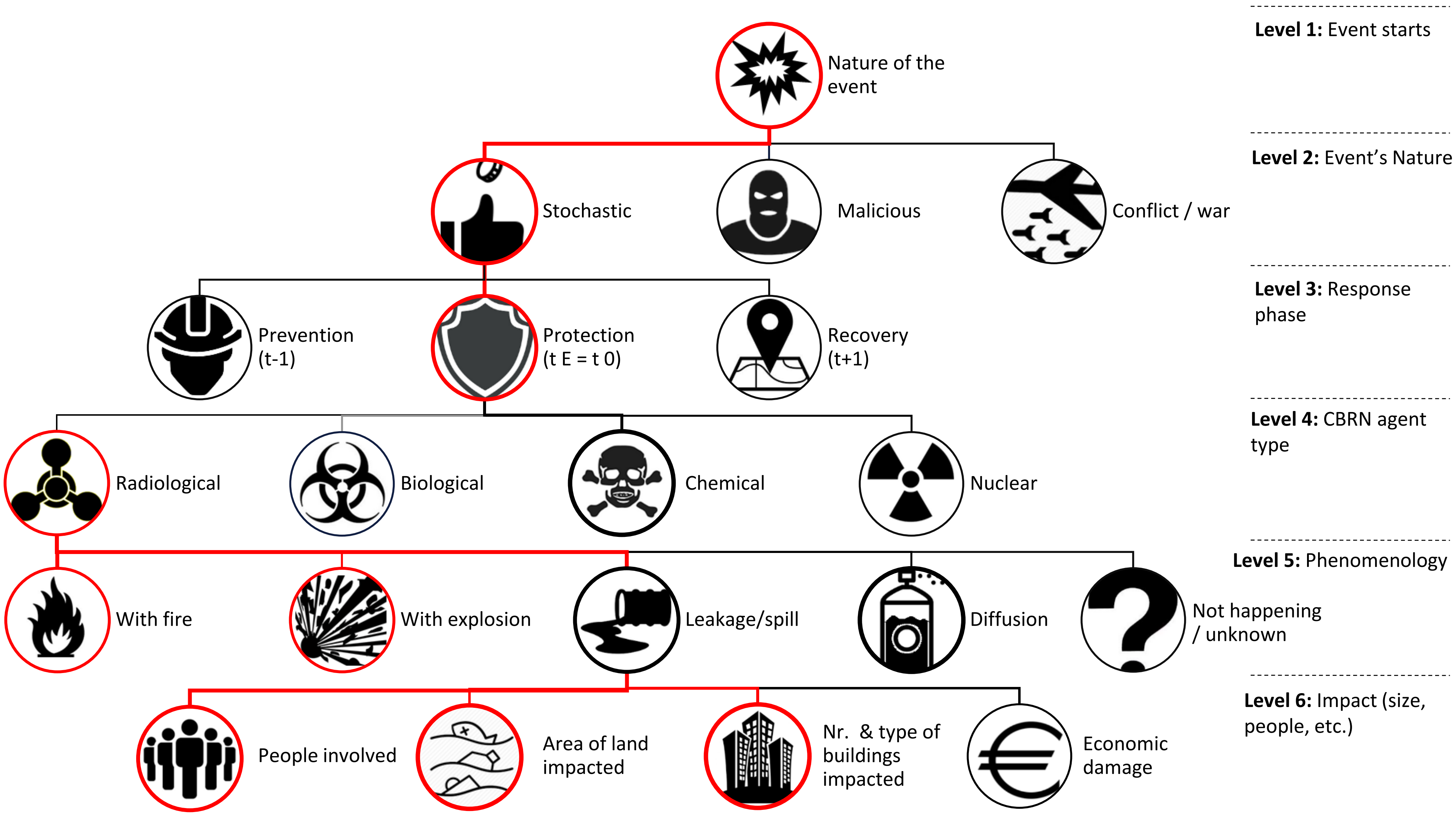
Limited access area	Keep public away (para. 5.10).
(outer cordoned-off area)	Only police, fire fighters, ambulance service and other qualified personnel allowed inside (para. 5.10).
Inner cordoned-off area	Suspected to be contaminated (paras 5.42–5.45) or to have excessive radiation levels (para. 5.39) (external gamma dose rates >100 µSv/h [5] or predetermined evacuation distances as in Annex II). Only lifesaving/first aid/fire fighting actions or actions under personnel protective measures allowed (paras 5.39, 5.42, 5.47). Access or egress allowed only through the checkpoint/decontamination point (para. 5.41).
Checkpoint and decontamination point	Locate upwind (para. 5.41). Provide a radiological control station to check for possible contamination (para. 5.41). If there is any contamination of persons or animals, arrangements should be made for decontamination (para. 5.41). If there is any contamination of equipment, vehicles or other items by radioactive material, it should be decontaminated or packed or suitably wrapped (para. 5.45).

Note: numbers in parentheses indicate paragraph numbers in this publication.

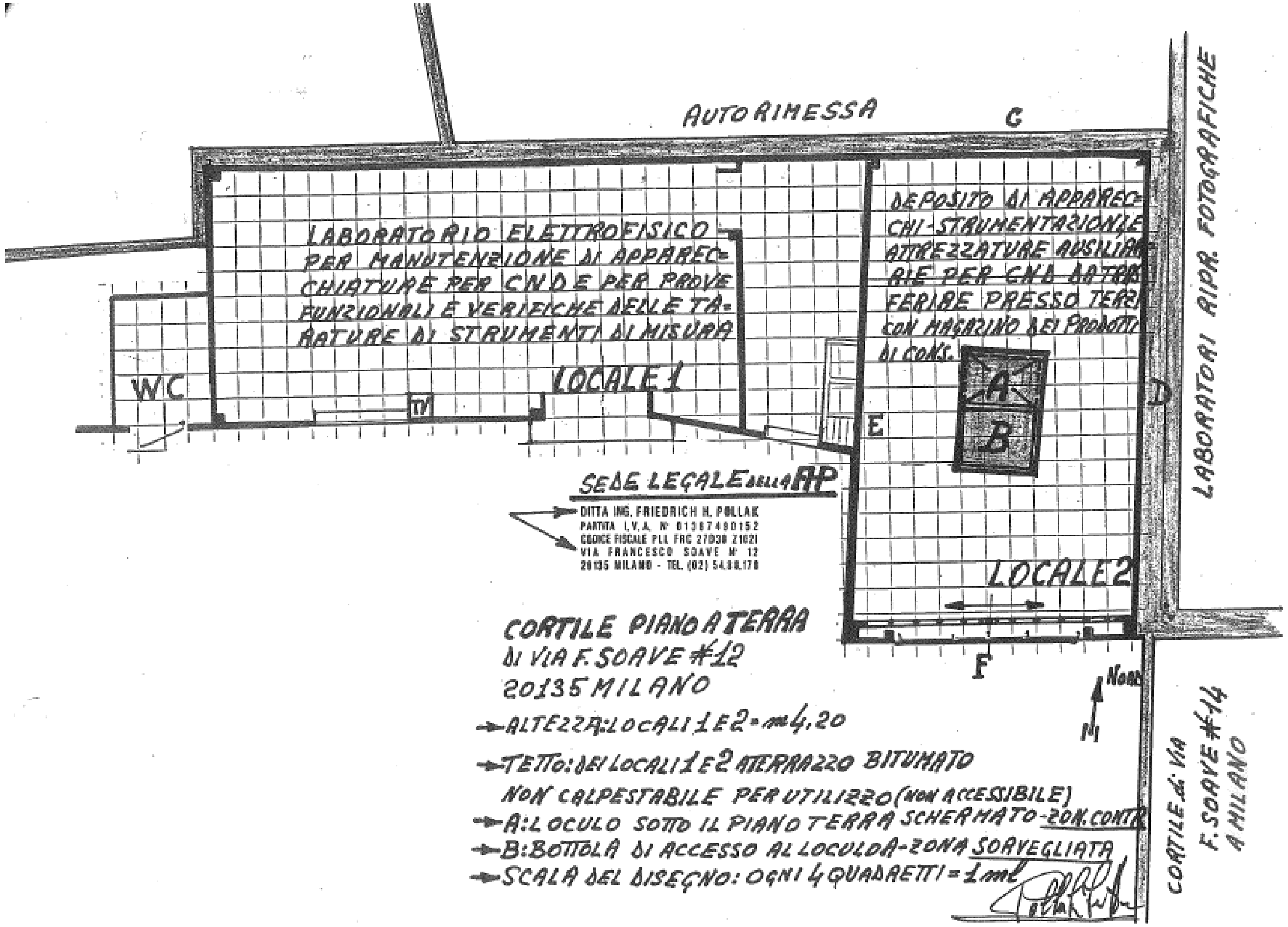
FIG. 1. Action areas and checkpoints for an emergency response scene.



Defining a RN scenario



The scenario – abandoned orphan radiological sources Milan downtown



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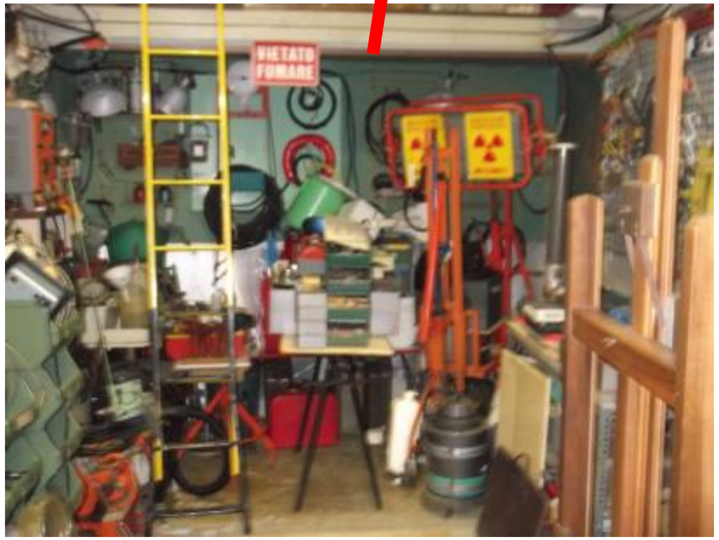
The scenario – abandoned orphan radiological sources Milan downtown



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The reference scenario – Co and Cs sources found on site

Table 1. Main properties of the two radionuclides considered in the scenarios.

Radionuclides	T 1/2 [Years]	Energy * [MeV]	Melting Point (+) [°C]	Activities [Bq]	
Co-60	5.27 years	1.1732	1495	1.00×10^{10}	1.50×10^{14}
Cs-137	30.17 years	0.6617	490	1.00×10^{10}	1.90×10^{13}

* Gamma energy of the most probable decay. + Pure cesium melts at 28.5 degrees, but the table reports cesium oxide.

Table 2. Direct radiation from the plume and from the ground, [8].

Radionuclide	Effective Dose Coefficient		Effective Dose Rate per Unit of Deposition on the Ground	
	Plume [Sv/h]	Ground [Bq/m²]	Plume [Sv/h]	Ground [Bq/m²]
Co-60	1.2×10^{-13}	2.3×10^{-15}	4.3×10^{-10}	8.3×10^{-12}
Cs-137 *	2.6×10^{-14}	5.5×10^{-16}	9.4×10^{-11}	2.0×10^{-12}

* The dose coefficients for the radionuclide include the contribution of the decay products.

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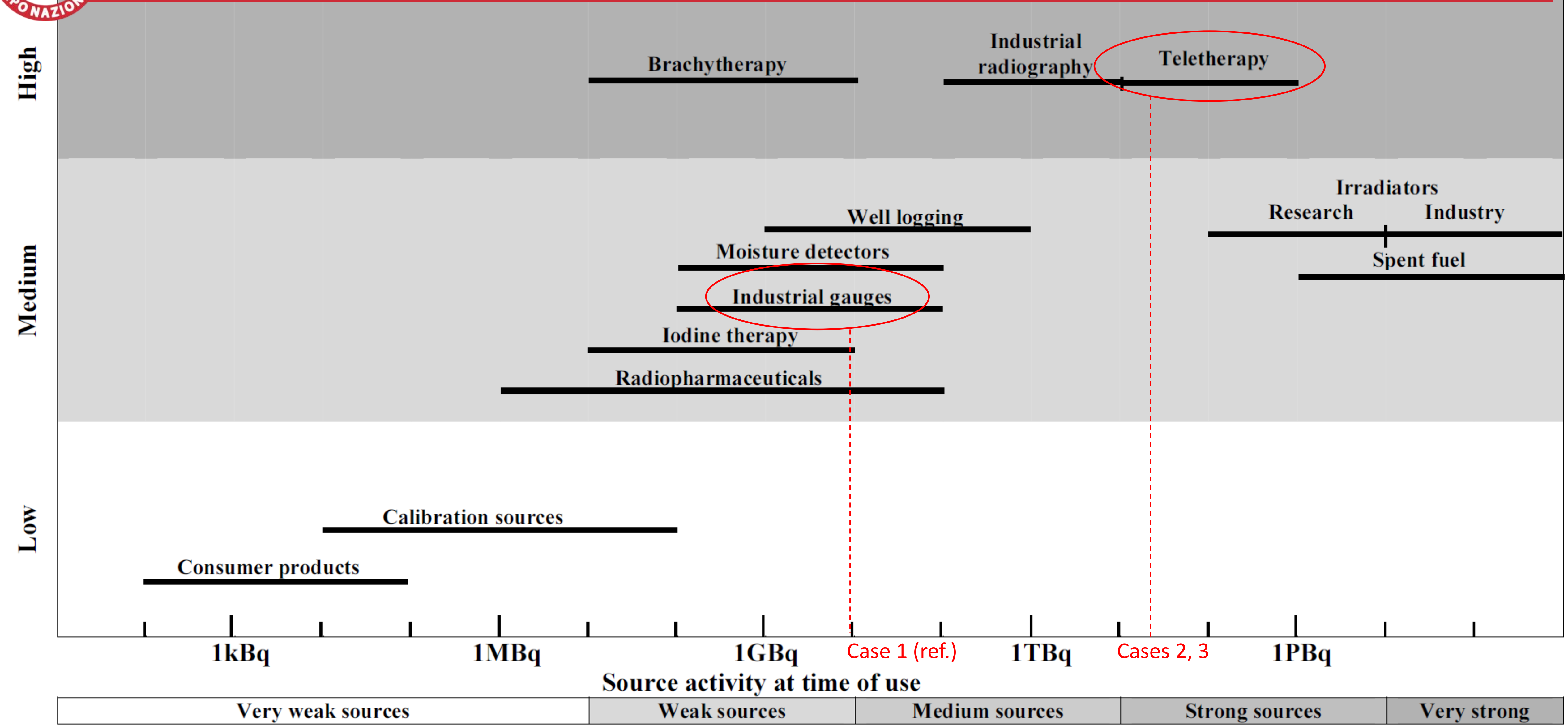
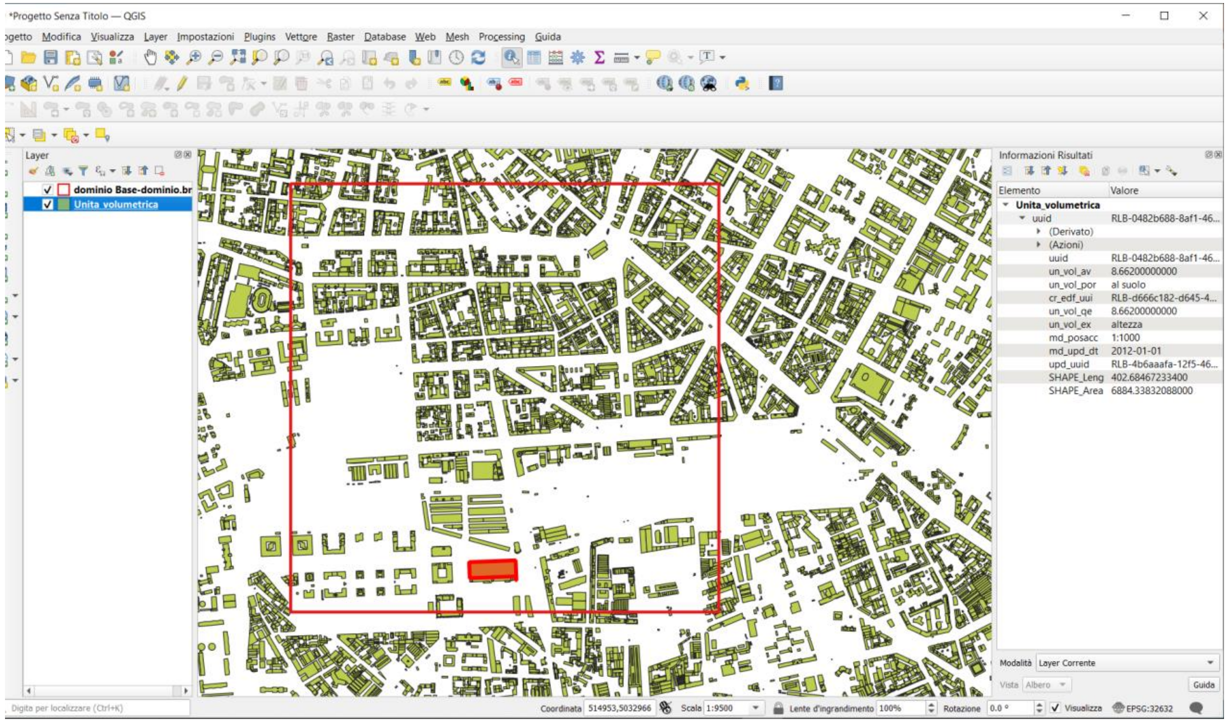
Defining the complexity of the response as a function of the activity



A classification that compares the severity and complexity of the different incidents as a function of the activity. This figure is readapted from IAEA 1162.

The reference scenario – area selected for simulations



1.3 x 1.3 km2 centered around the building where orphan sources where found

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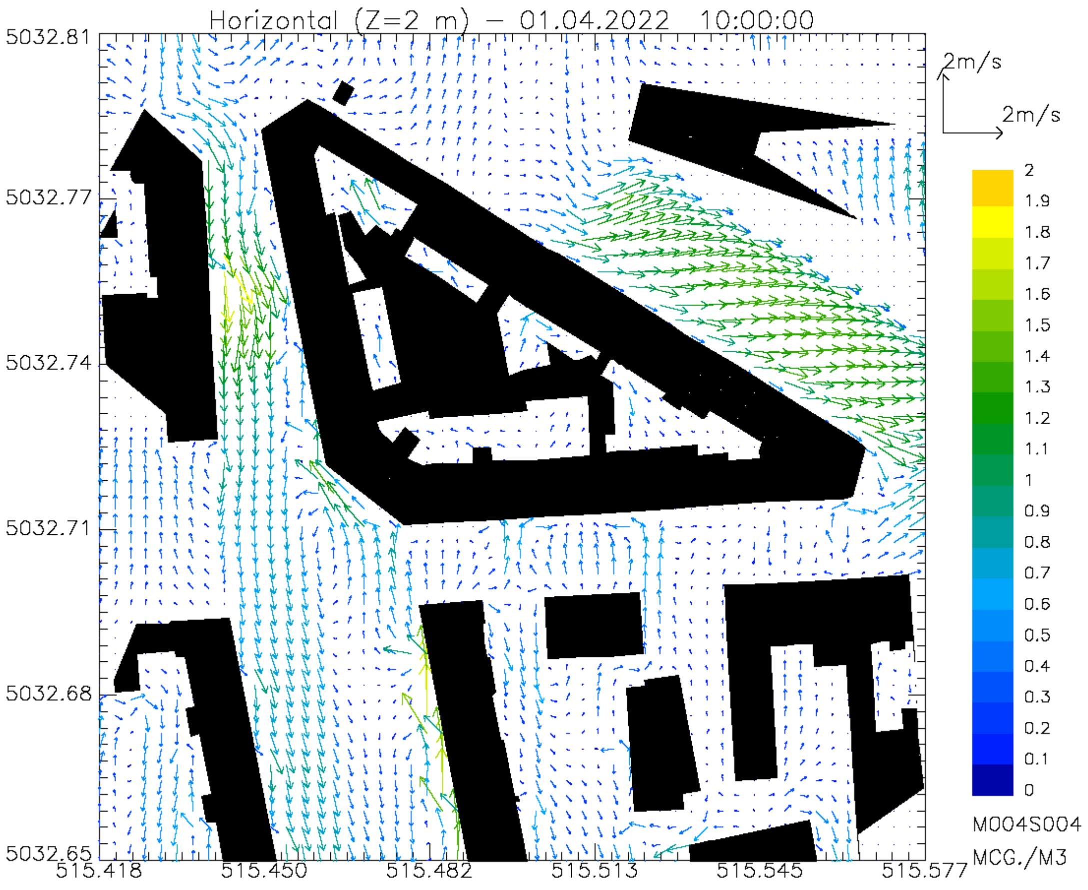
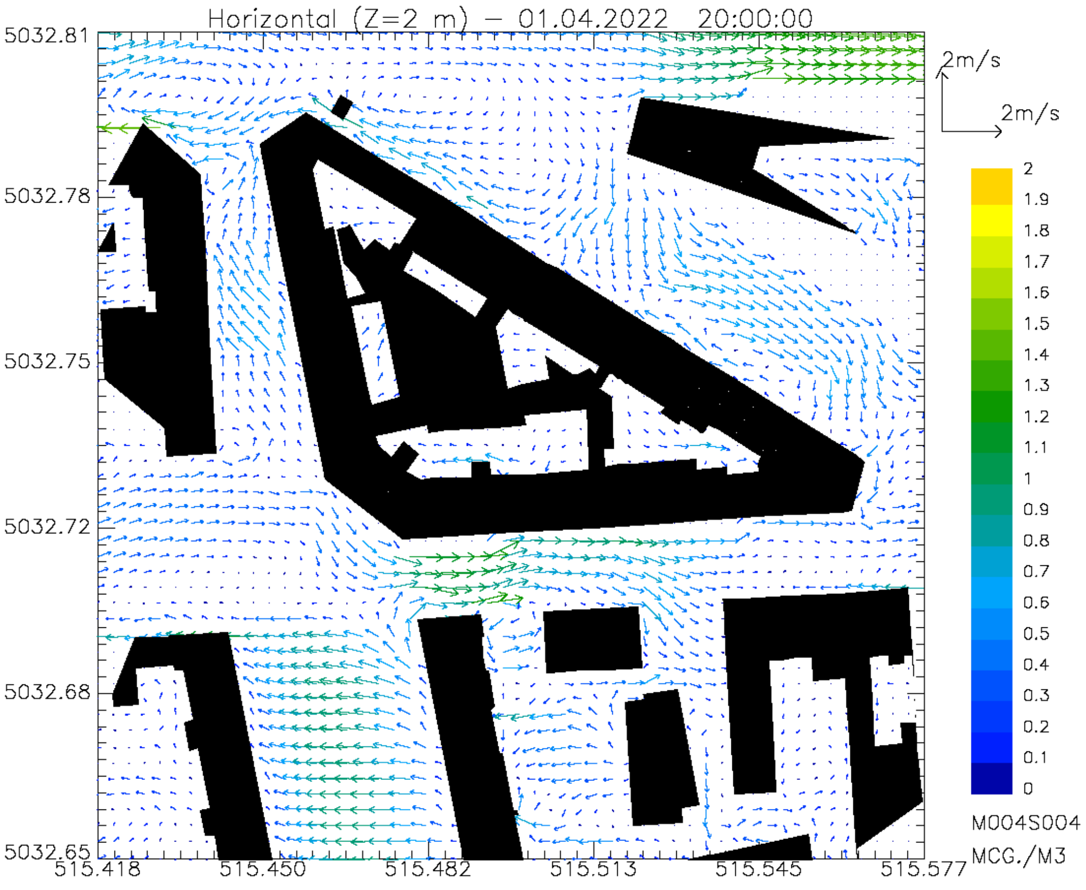
The reference scenario – Wind





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The reference scenario – dose calculations

Per trasformare le concentrazioni/deposizioni di attività simulate dal modello in dosi assorbite in Sv, vengono utilizzate le tabelle di trasformazione per differenti sostanze (Co-60 e Cs-137, qui vengono presentati i risultati solo per Co-60) contenute nel documento CEVaD «Emergenze Nucleari e Radiologiche, Manuale per le valutazioni dosimetriche e le misure ambientali» di ISPRA.

Tabella 6.3 – *Irradiazione diretta dalla nube* (+)

Radionuclide	Coefficiente di dose efficace ($Sv / Bq\ s\ m^{-3}$)	Intensità di dose efficace per unità di concentrazione in aria ($Sv\ h^{-1} / Bq\ m^{-3}$)
F-18	$4,6\ 10^{-14}$	$1,7\ 10^{-10}$
Co-57	$5,0\ 10^{-15}$	$1,8\ 10^{-11}$
Co-60	$1,2\ 10^{-13}$	$4,3\ 10^{-10}$
Ga-67	$6,5\ 10^{-15}$	$2,3\ 10^{-11}$

Tabella 6.4 – *Irradiazione diretta dal suolo* (+)

Radionuclide	Coefficiente di dose efficace ($Sv\ s^{-1} / Bq\ m^{-2}$)	Intensità di dose efficace per unità di deposizione al suolo ($Sv\ h^{-1} / Bq\ m^{-2}$)
F-18	$9,8\ 10^{-16}$	$3,5\ 10^{-12}$
Co-57	$1,1\ 10^{-16}$	$4,0\ 10^{-13}$
Co-60	$2,3\ 10^{-15}$	$8,3\ 10^{-12}$
Ga-67	$1,4\ 10^{-16}$	$5,0\ 10^{-13}$

Coefficienti simili esistono anche per Cs-137 (qui vengono presentati solo i risultati per Co-60

Per il calcolo delle dosi dai risultati del modello, che prevedono concentrazioni medie di attività ogni 10 min, i coefficienti sono stati moltiplicati per il fattore 10/60 * 1000 per passare in dosi di mSv su 10 minuti

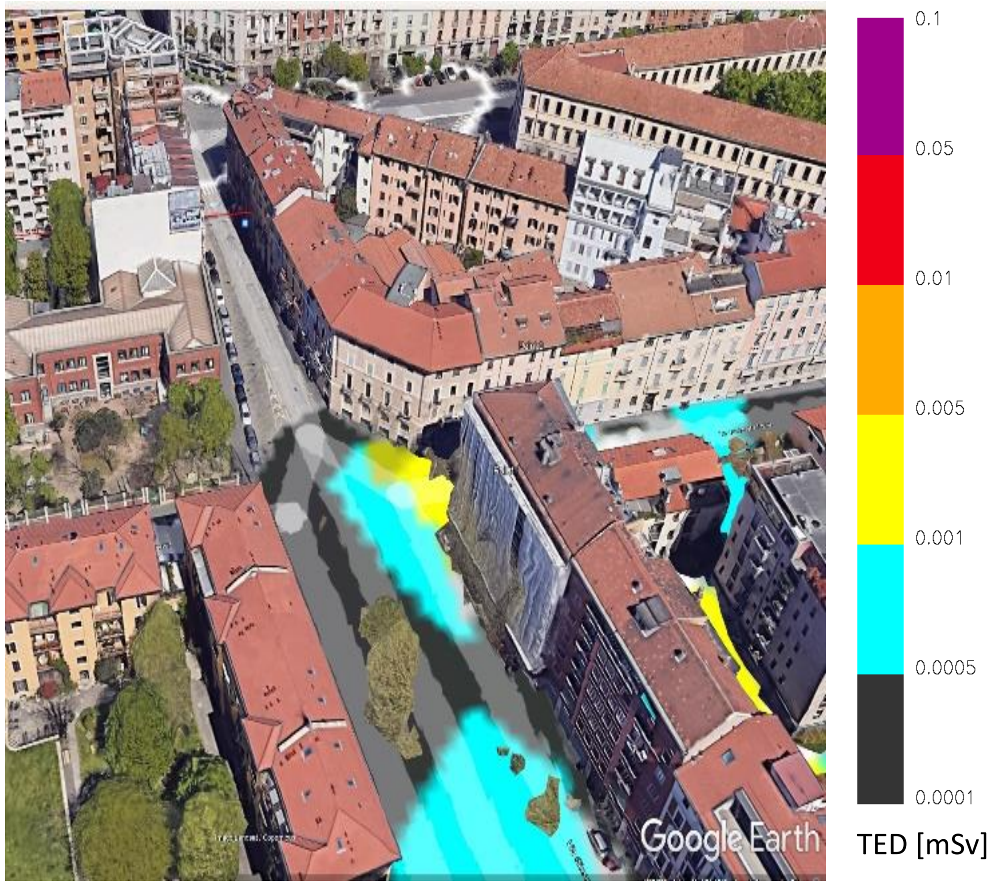
Le dosi su 10' vengono poi integrate sulle 2 ore (calcolo media su 2 ore e moltiplicazione per 12)

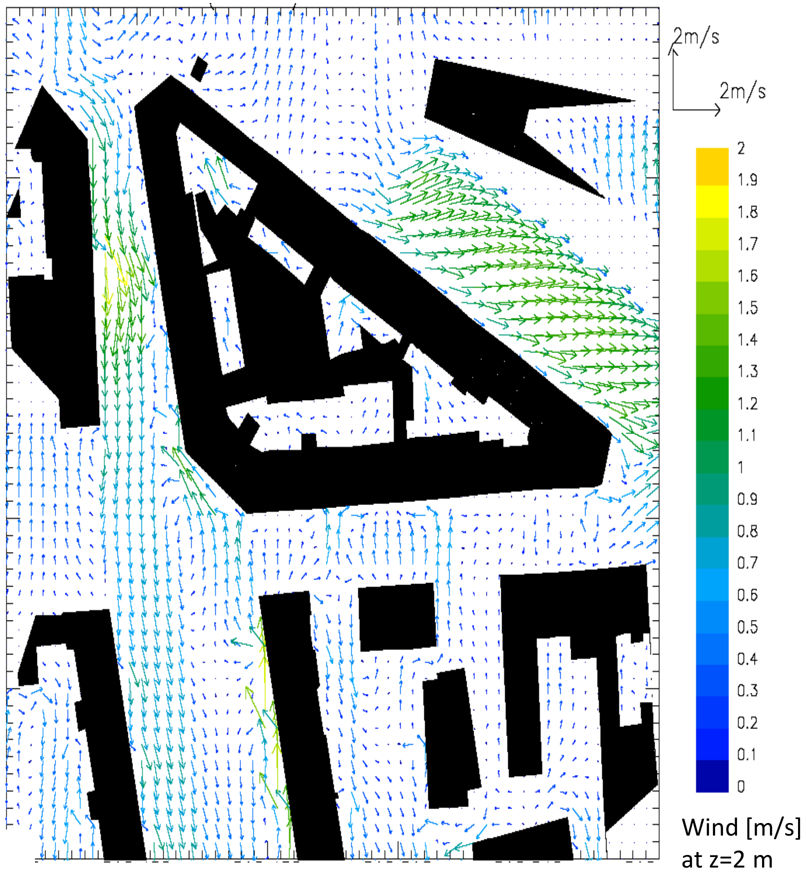
Tabella 6.5 – *Inalazione di aria contaminata: coefficienti di dose efficace impegnata* (+)

Emergenze radiologiche

Nuclide	Tipi di assorb (*)	Coefficiente di dose efficace impegnata (Sv / Bq)			Dose efficace impegnata per unità di concentrazione integrata in aria ($Sv / Bq\ s\ m^{-3}$)			Intensità di dose efficace impegnata per unità di concentrazione in aria ($Sv\ h^{-1} / Bq\ m^{-3}$)		
		Lattanti	Bambini	Adulti	Lattanti	Bambini	Adulti	Lattanti	Bambini	Adulti
H-3	S	$1,2\ 10^{-9}$	$3,8\ 10^{-10}$	$2,6\ 10^{-10}$	$4,0\ 10^{-14}$	$6,7\ 10^{-14}$	$6,7\ 10^{-14}$	$1,4\ 10^{-10}$	$2,4\ 10^{-10}$	$2,4\ 10^{-10}$
C-14	S	$1,9\ 10^{-8}$	$7,4\ 10^{-9}$	$5,8\ 10^{-9}$	$6,3\ 10^{-13}$	$1,3\ 10^{-12}$	$1,5\ 10^{-12}$	$2,3\ 10^{-9}$	$4,7\ 10^{-9}$	$5,4\ 10^{-9}$
F-18	S	$4,2\ 10^{-10}$	$1,0\ 10^{-10}$	$5,9\ 10^{-11}$	$1,4\ 10^{-14}$	$1,8\ 10^{-14}$	$1,5\ 10^{-14}$	$5,0\ 10^{-11}$	$6,4\ 10^{-11}$	$5,5\ 10^{-11}$
Fe-55	F	$4,2\ 10^{-9}$	$1,4\ 10^{-9}$	$7,7\ 10^{-10}$	$1,4\ 10^{-13}$	$2,5\ 10^{-13}$	$2,0\ 10^{-13}$	$5,0\ 10^{-10}$	$8,9\ 10^{-10}$	$7,1\ 10^{-10}$
Co-57	S	$4,4\ 10^{-9}$	$1,5\ 10^{-9}$	$1,0\ 10^{-9}$	$1,5\ 10^{-13}$	$2,7\ 10^{-13}$	$2,6\ 10^{-13}$	$5,2\ 10^{-10}$	$9,6\ 10^{-10}$	$9,3\ 10^{-10}$
Co-60	S	$9,2\ 10^{-8}$	$4,0\ 10^{-8}$	$3,1\ 10^{-8}$	$3,0\ 10^{-12}$	$7,1\ 10^{-12}$	$8,0\ 10^{-12}$	$1,1\ 10^{-8}$	$2,5\ 10^{-8}$	$2,9\ 10^{-8}$

The reference scenario – Simulation results





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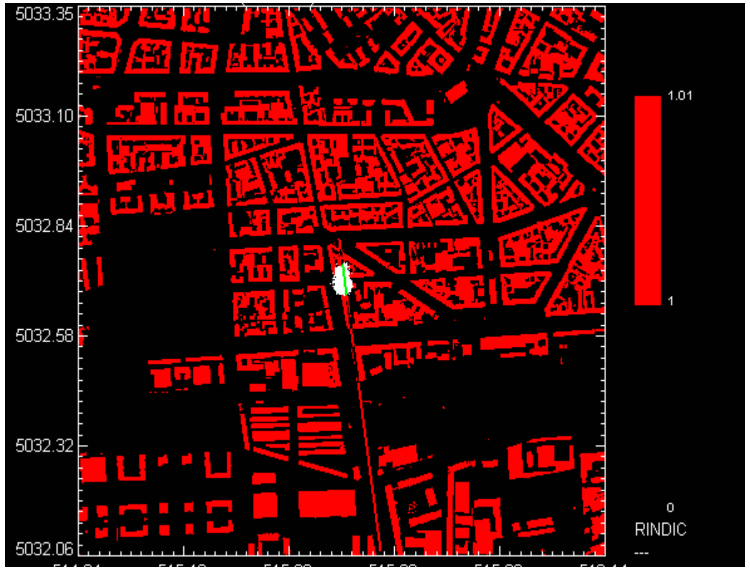
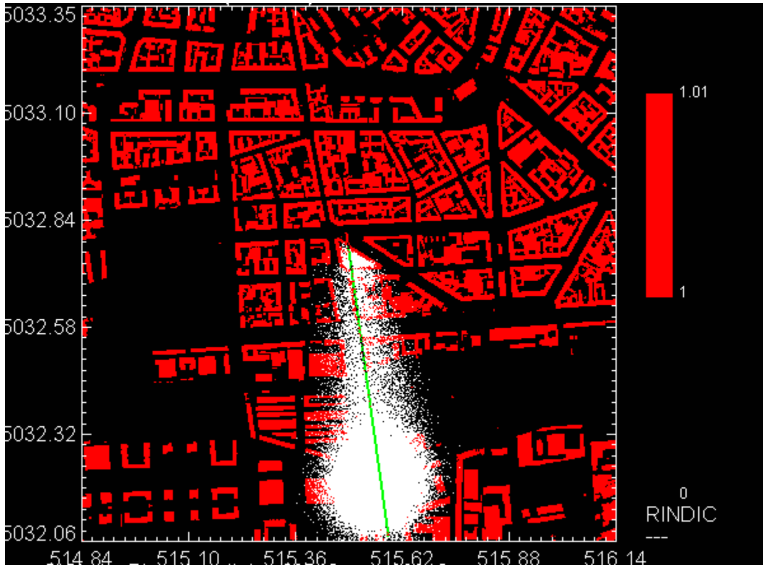
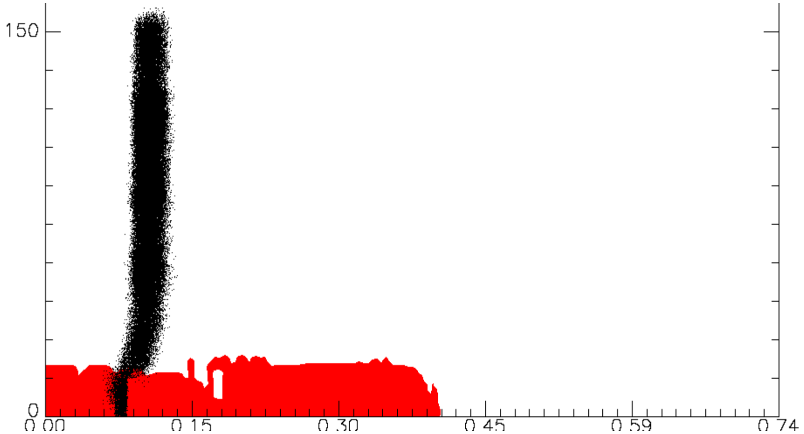
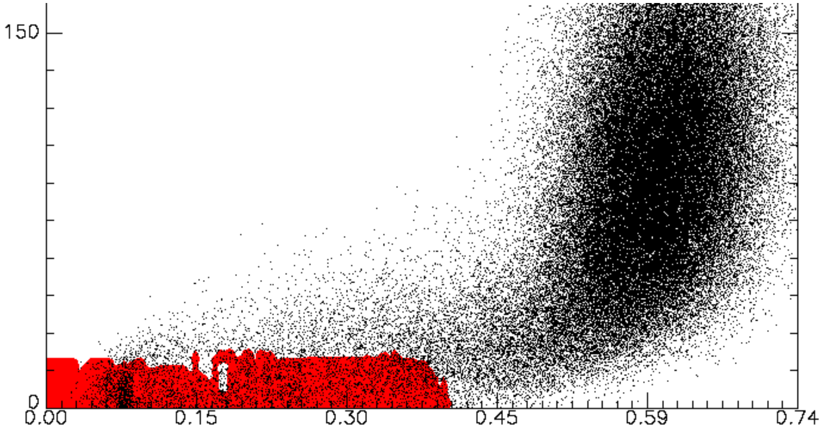
The reference scenario – Dirty bomb









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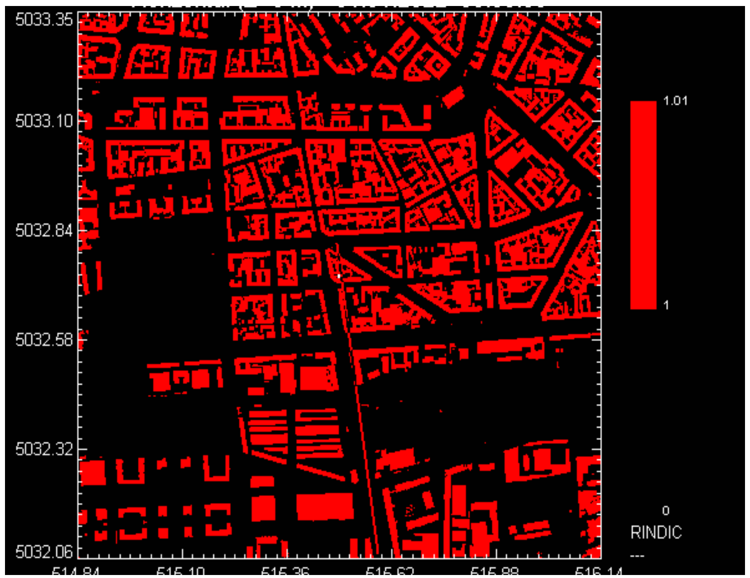
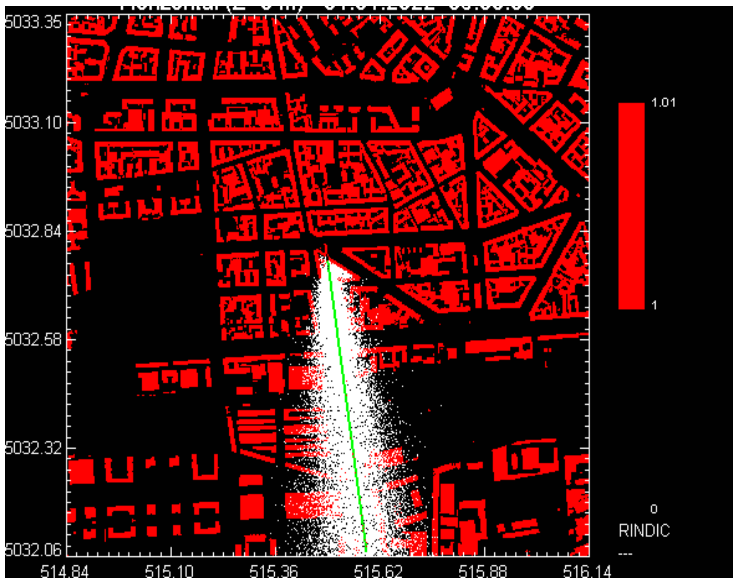
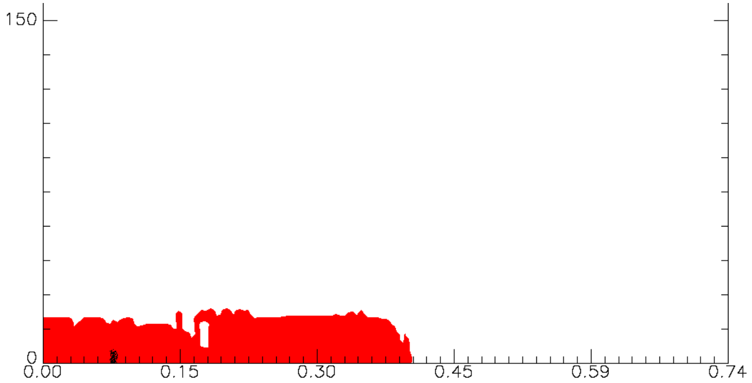
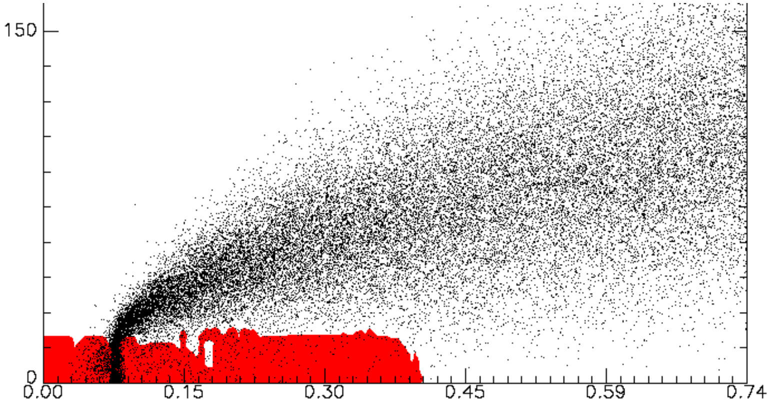
The reference scenario - Fire









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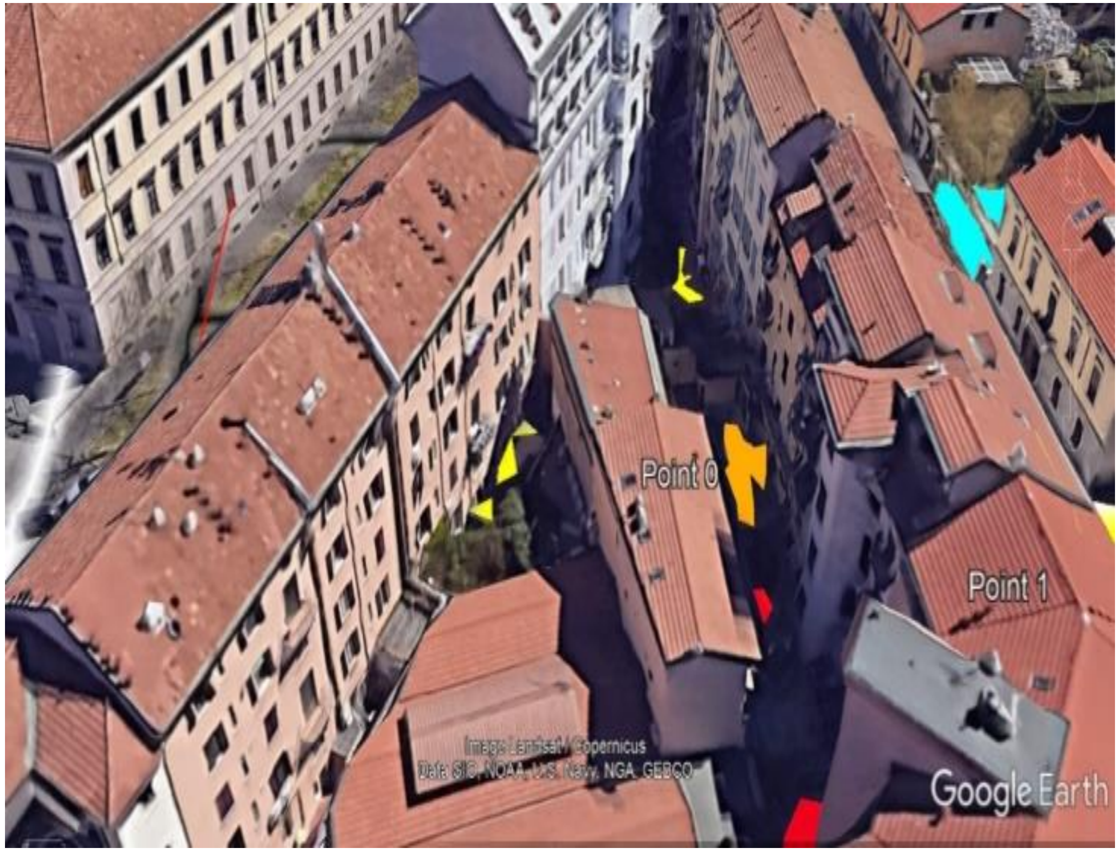
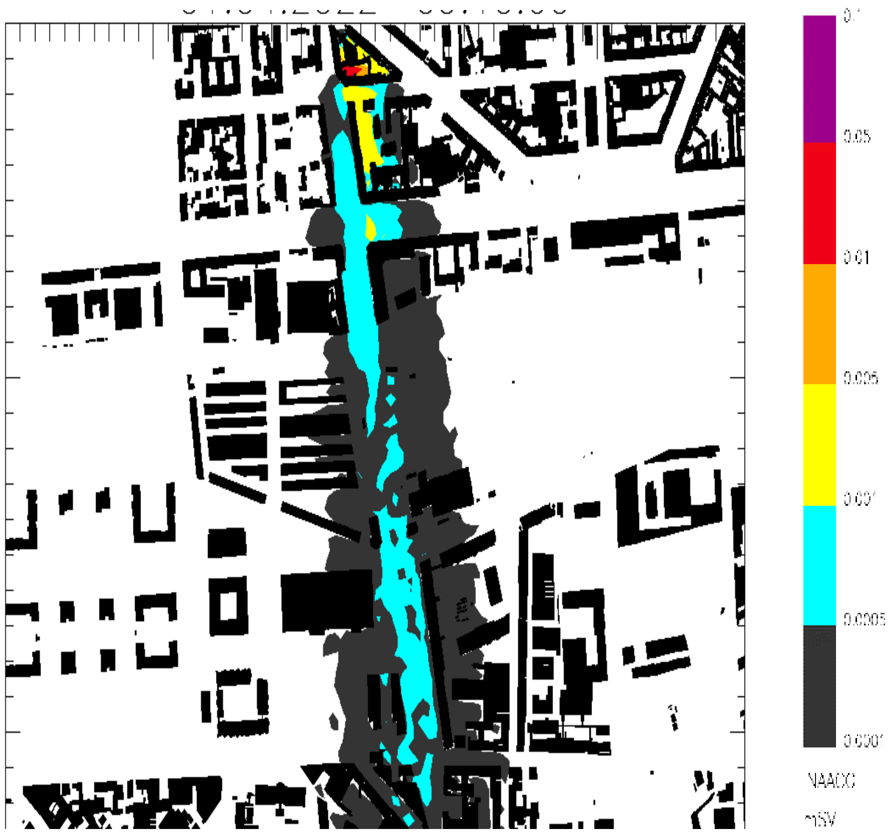
The reference scenario – Simulation results





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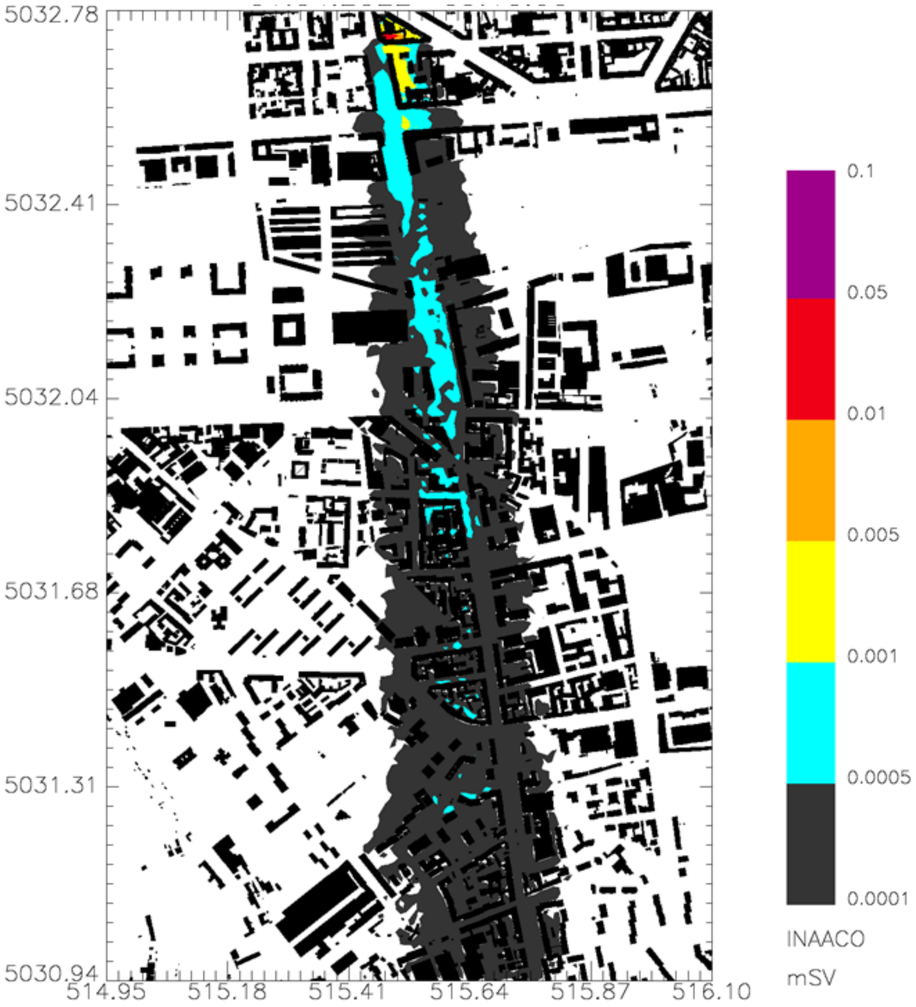
The reference scenario – Simulation results

Source: Co-60	Point 0 (in)	Point 1 (out)	Point 2	Point 3	Point 4	Point 5
Distance from S (m)	*26*	*24*	*164*	*645*	*950*	*1769*
TED [microSv]	6,18	1,41	1,07	0,55	0,50	0,23
Inahled Dose [microSv]	6,06	1,38	1,05	0,53	0,49	0,22
Direct Dose [microSv]	0,09	0,02	0,02	0,01	0,01	0,00
Indirect Dose [microSv]	3,64E-02	7,81E-03	5,15E-03	3,09E-03	3,63E-03	5,01E-04



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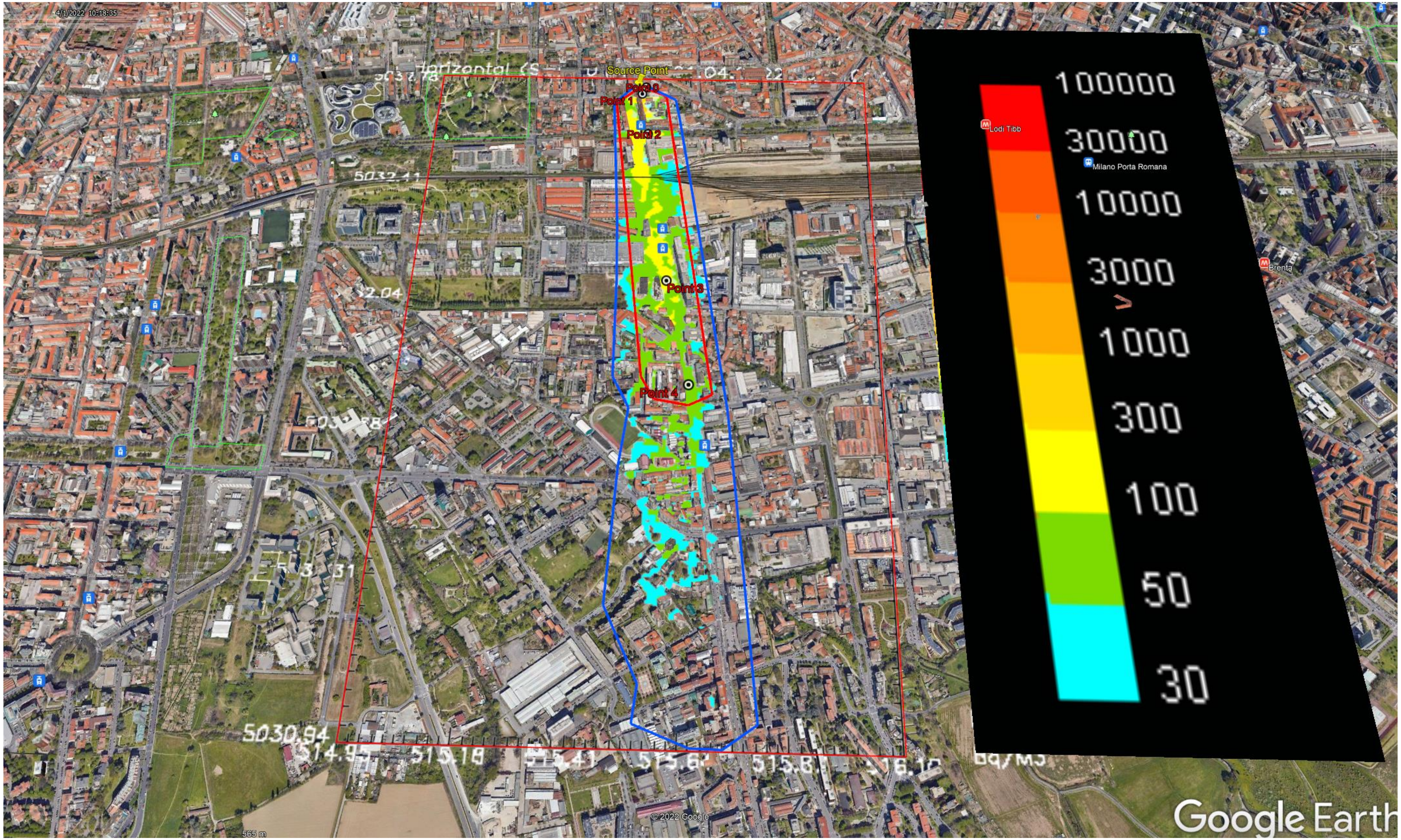
The reference scenario – Simulation results



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The reference scenario – Dirty bomb (inhalation dose in 2 hours)

AVISU 1.13.0 07/October/2022 11:41
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Model MSPRAY Simulation time: 01.04.2022 09:10:00 Variable: INAACO
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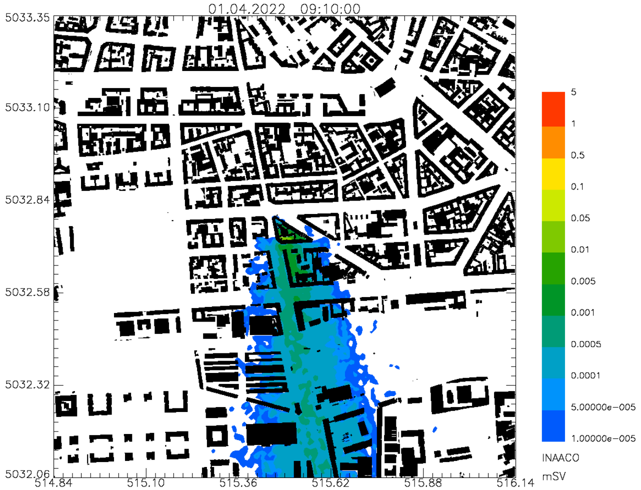
Global data range: [0,0.0352246]



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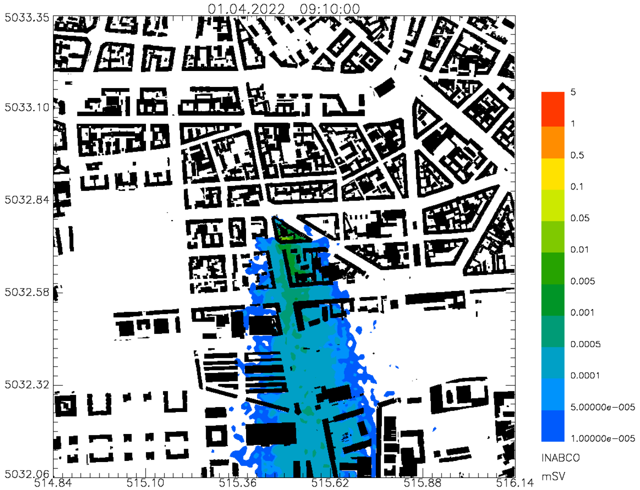

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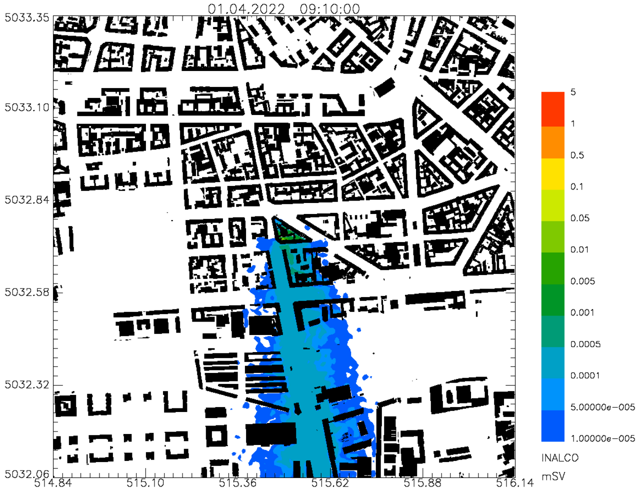

AVISU 1.13.0 07/October/2022 11:49
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Model MSPRAY Simulation time: 01.04.2022 19:10:00 Variable: INAACO
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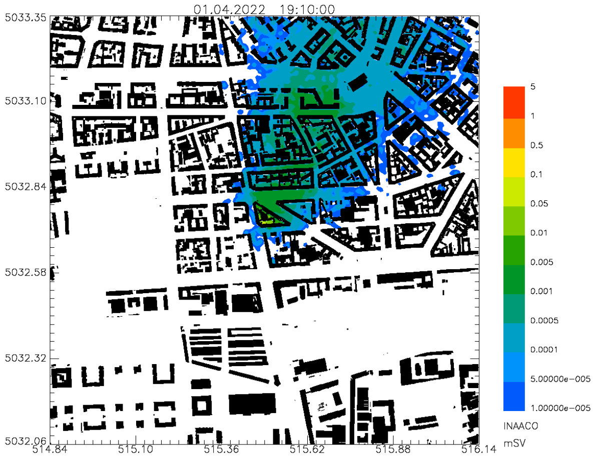

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Model MSPRAY Simulation time: 01.04.2022 19:10:00 Variable: INABCO
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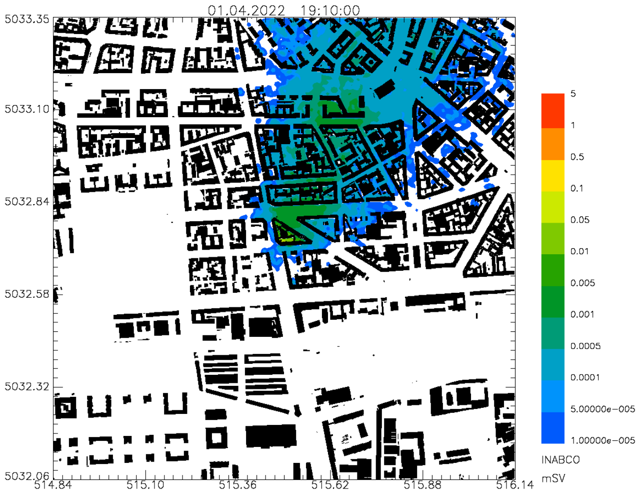

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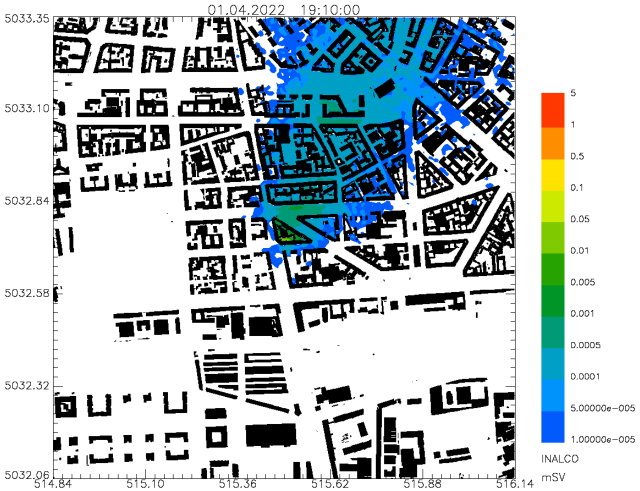

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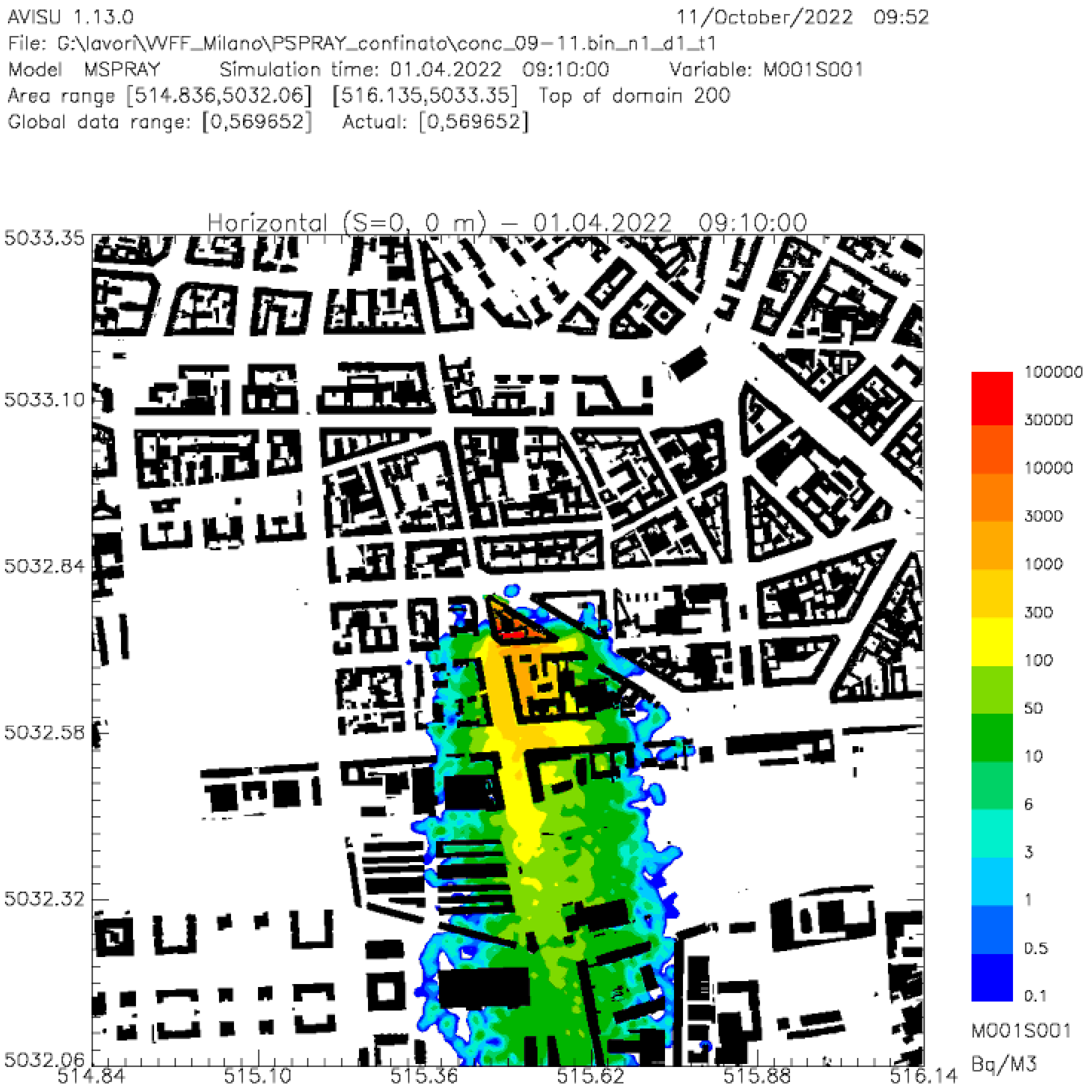
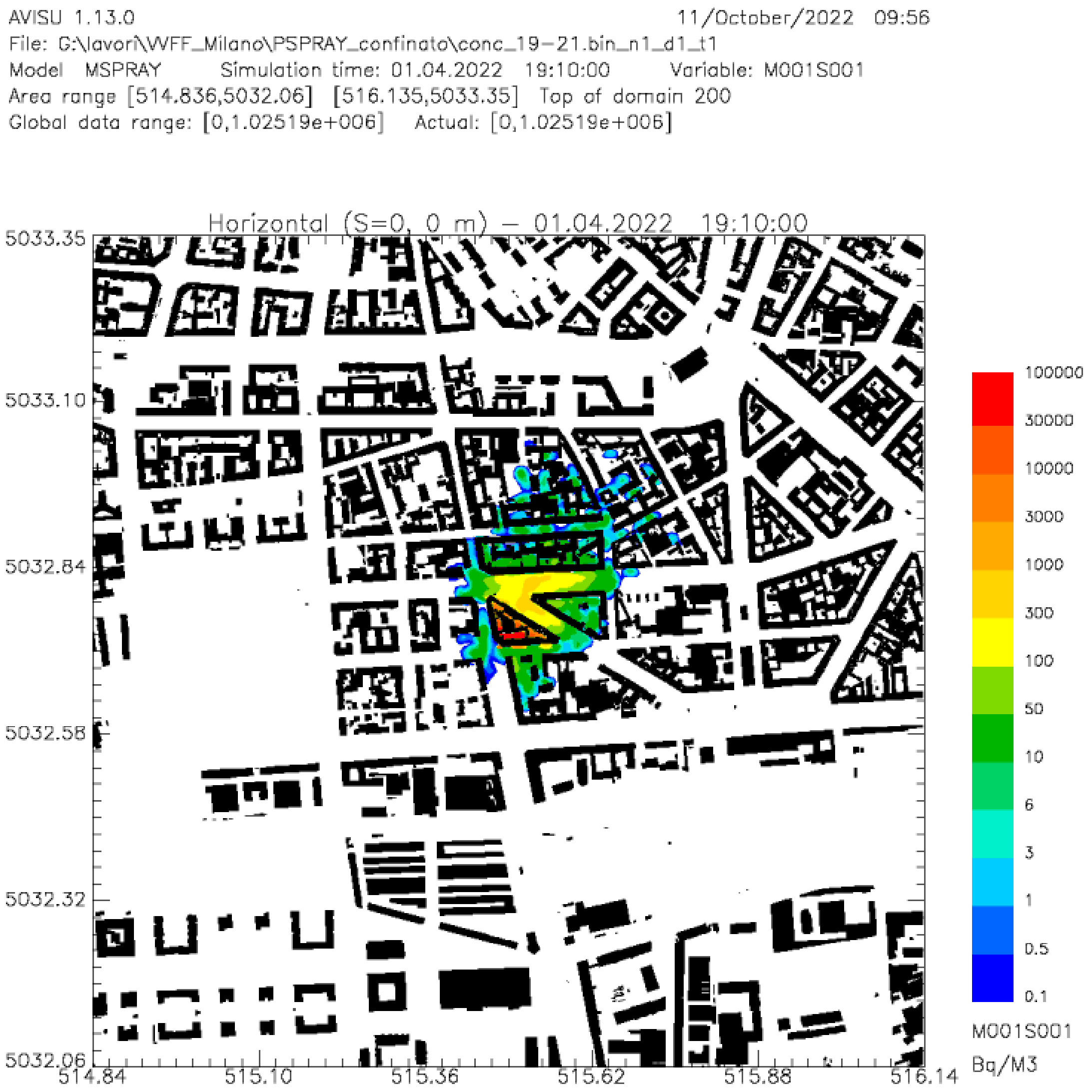
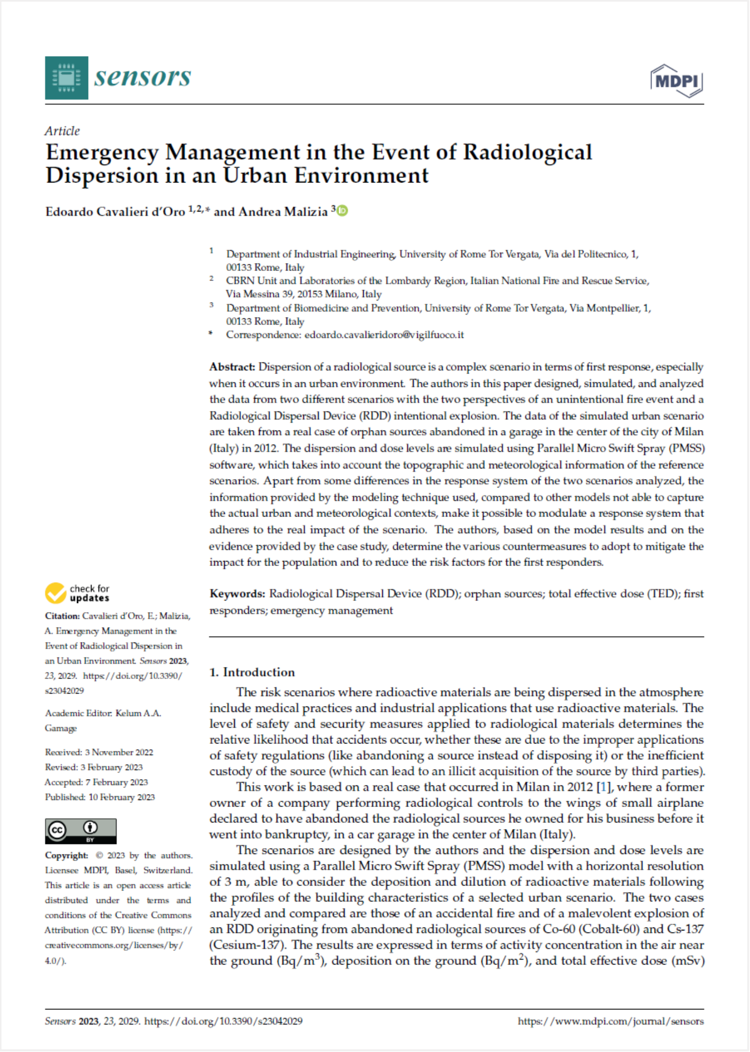
The reference scenario – Dirty bomb (inhalation dose in 2 hours)





Conclusions

- ✓ Arianet model has been tested to portray the actual situation of a NR emergency.
- ✓ Several simulations have been run in order to simulate different dispersion models: fire and eplosion.
- ✓ A publication has been published in order to continue the exploration of modelling for NR scenarios with more sophisticated models
- ✓ Results, compared to previous results, reveal to be very useful for creating a zonization of the scenario more coherent with the actual dispersion of radionuclides.
- ✓ Further research should include the automatization of inputs such as buildings and weather from the various database and also the creation of a set of source cases to add to the model.



sensors MDPI

Article

Emergency Management in the Event of Radiological Dispersion in an Urban Environment

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Abstract: Dispersion of a radiological source is a complex scenario in terms of first response, especially when it occurs in an urban environment. The authors in this paper designed, simulated, and analyzed the data from two different scenarios with the two perspectives of an unintentional fire event and a Radiological Dispersal Device (RDD) intentional explosion. The data of the simulated urban scenario are taken from a real case of orphan sources abandoned in a garage in the center of the city of Milan (Italy) in 2012. The dispersion and dose levels are simulated using Parallel Micro Swift Spray (PMSS) software, which takes into account the topographic and meteorological information of the reference scenarios. Apart from some differences in the response system of the two scenarios analyzed, the information provided by the modeling technique used, compared to other models not able to capture the actual urban and meteorological contexts, make it possible to modulate a response system that adheres to the real impact of the scenario. The authors, based on the model results and on the evidence provided by the case study, determine the various countermeasures to adopt to mitigate the impact for the population and to reduce the risk factors for the first responders.

Keywords: Radiological Dispersal Device (RDD); orphan sources; total effective dose (TED); first responders; emergency management

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1. Introduction

The risk scenarios where radioactive materials are being dispersed in the atmosphere include medical practices and industrial applications that use radioactive materials. The level of safety and security measures applied to radiological materials determines the relative likelihood that accidents occur, whether these are due to the improper applications of safety regulations (like abandoning a source instead of disposing it) or the inefficient custody of the source (which can lead to an illicit acquisition of the source by third parties).

This work is based on a real case that occurred in Milan in 2012 [1], where a former owner of a company performing radiological controls to the wings of small airplane declared to have abandoned the radiological sources he owned for his business before it went into bankruptcy, in a car garage in the center of Milan (Italy).

The scenarios are designed by the authors and the dispersion and dose levels are simulated using a Parallel Micro Swift Spray (PMSS) model with a horizontal resolution of 3 m, able to consider the deposition and dilution of radioactive materials following the profiles of the building characteristics of a selected urban scenario. The two cases analyzed and compared are those of an accidental fire and of a malevolent explosion of an RDD originating from abandoned radiological sources of Co-60 (Cobalt-60) and Cs-137 (Cesium-137). The results are expressed in terms of activity concentration in the air near the ground (Bq/m^3), deposition on the ground (Bq/m^2), and total effective dose (mSv)

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Thank you for your attention !

QUESTIONS ?

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