



Team BLUE

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1. BIOLOGICAL SCENARIO: Diffusion of Ebola virus in Australia (starting from South Australia) considering a number of index cases = 45 and a period from 1 March 2016 to 1 April 2016.

1.1. Summary

The establishment and spread of infectious diseases is a complex phenomenon with many interacting factors, e.g., the environment in which the pathogen and hosts are situated, the population(s) it is exposed to, and the intra- and inter- dynamics of the population it is exposed to. The role of mathematical epidemiology is to model the course and the spread of pathogens. Using the notion of abstracting the population into *compartments* under certain assumptions, the Spatio-Temporal Epidemiological Modeler (STEM) is designed to perform simulations of emerging infectious diseases to prevent their spreading and to plan interventions in case of biological emergency. In this text the STEM software has been used to evaluate a possible biological outbreak scenario in case of an Ebola virus disease (EVD) disseminating in Australia starting from the South of the country. The analysis through the software simulation proved to be extremely useful in helping decision makers to rapidly manage in advance a probable emergency scenario. In addition, an overview describing the main characteristics of the EVD, completes the final part of this text.

1.2. Introduction

Ebola virus disease (EVD) described as “one of the world’s most virulent diseases” by WHO (World Health Organization), was sadly reported to rapidly spread in Central and West Africa from 2013 till nowadays, triggering thousands of deaths [3]. This new Ebola outbreak caused most international concern since the epidemic reached urban areas. So, considering that, currently, a lot of infectious diseases are often dramatically spreading worldwide, the development of new strategies to face with that kind of emergencies is even-growing urgent. On that purpose mathematical modeling is a useful tool designed to help scientists and public health officials to understand and potentially prevent the spread of such diseases. The Spatio-Temporal Epidemiological Modeler (STEM) is a Java-based software which uses models of diseases (based on

differential equations) to simulate the development or space-time evolution of a disease. In an increasingly connected world with extremely efficient global transportation links, the vectors of infection can be quite complex. STEM facilitate the creation of flexible models considering population, geographical information about the involved country, the disease characteristics (i.e. transmission rate, incubation rate and so on) within a modular and hierarchical modeling structure which contains all specific features useful to develop a complete scenario provided with graphs and maps showing the final analysis. These models are known as *compartmental models in epidemiology*, which usually investigate through ordinary differential equations (deterministic), but can also be viewed in more realistic stochastic framework. These compartments, in the simplest case (**SI** model), can stratify the population into two health states: **Susceptible** to the infection of the pathogen (often denoted by **S**) and **Infected** by the pathogen (given the symbol **I**) and capable of transmitting the disease (Fig. 1). This model can perfectly suit for some infections which do not confer any long lasting immunity upon recovery and individuals become susceptible again [1].

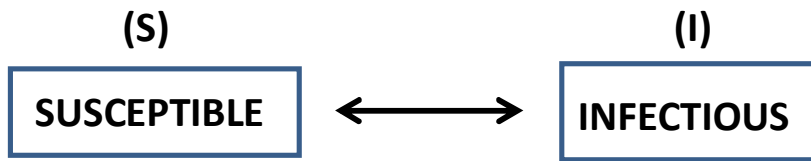


Fig. 1. SI model.

Differently, for many important infections there is a significant incubation period during which the individuals has been infected but are not yet infectious themselves (Fig. 2). During this period the individuals are considered as **Exposed** (E). This model (**SEIR** model) assumes that individuals are in the following epidemiological states: **Susceptible** (S, healthy population and at risk); **Exposed** (E, infected, but not yet infecting others); **Infectious** (I, infected and infecting others → capable of transmitting the disease); **Removed or Recovered** (R, population who dies or recovers from the disease and become susceptible again). Instead, diseases with a short latent period that confer immunity after infection can be analyzed using the **SIR** model, which uses the same SEIR model compartments except for the Exposed individuals [1].

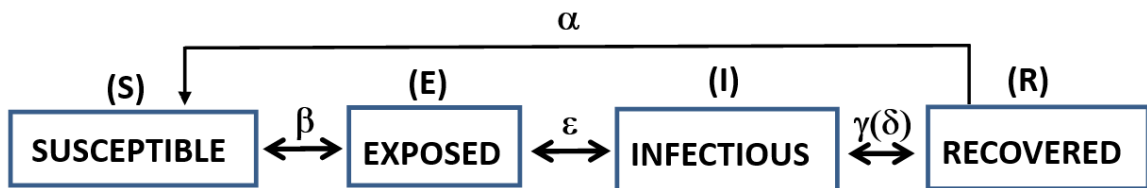


Fig. 2. SEIR model. Transition rates are reported between each compartment. Their specific epidemiological features are indicated in Table 1.

Compartmental models may have *closed* or *open populations*. In a *closed population* the set of individuals represented by model is static so that the effect of demographic changes (birth and natural death) is minimal during the course of epidemic (this condition is usually adopted in SEIR models). In a *open population* there is a continuous immigration and emigration from the population, usually via birth and death [2].

Table 1. Epidemiological features present in the SEIR compartment model.

Epidemiological features	
N	Size of the population
ε	Incubation rate (per unit time)
γ	Recovery rate (per unit time)
δ	Infectious mortality rate
β	Transmission rate
α	Immunity loss rate

The WHO observed that infectious diseases are constantly responsible for millions of deaths worldwide; moreover, aetiological agents are able to rapidly change and evolve bringing back re-emerging diseases which were considered eradicated. Thus, together with bioterrorism threats, that condition arises great concern promoting international scientists to understand how pathogens spread in the population and how to minimize their hazardous effects [3].

Following the common main aims of epidemic modeling, STEM software allows:

- to understand the spreading mechanism of the considered disease,
- to predict the future course of an epidemic and
- to understand how to control the spread of the epidemic [1].

In the next part of this text there is a description of the main steps used to create a new model disease using the STEM software exploiting the SEIR (susceptible-exposed-infectious-removed) epidemic model (*section 1.3*). In the *section 1.4* are reported the simulation results obtained by a scenario conditions based on the Ebola Virus hypothesis of in Australia considering a 45 number of index cases during a period ranged from 1 March 2016 to 1 April 2016.

1.3. Methods: the STEM software

First of all the software permits to create a new STEM Project (Fig. 3a), listed in the Project Explorer window, and a new Scenario (Fig. 3b), both starting from the Designer View:

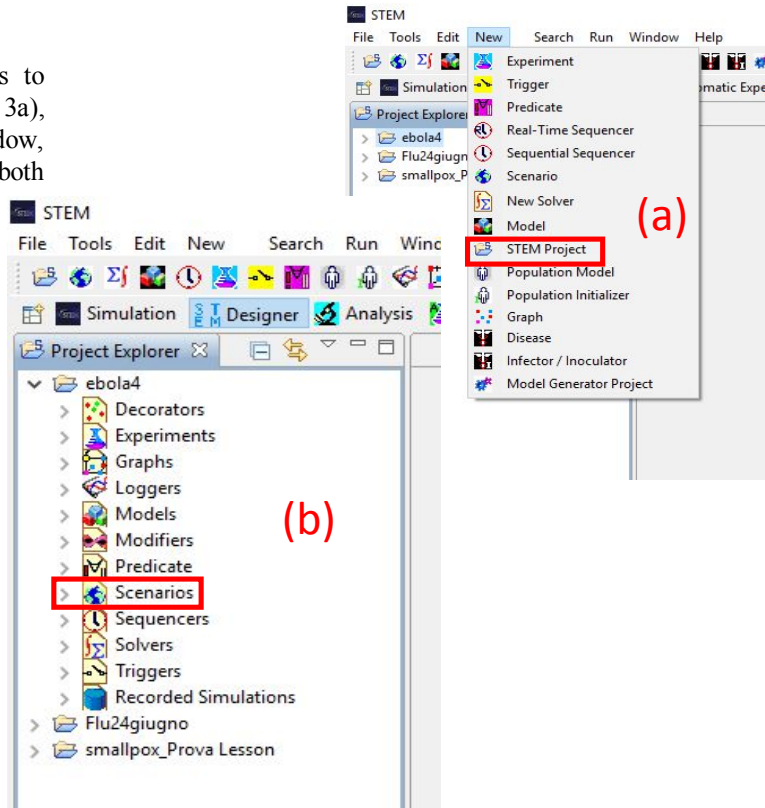


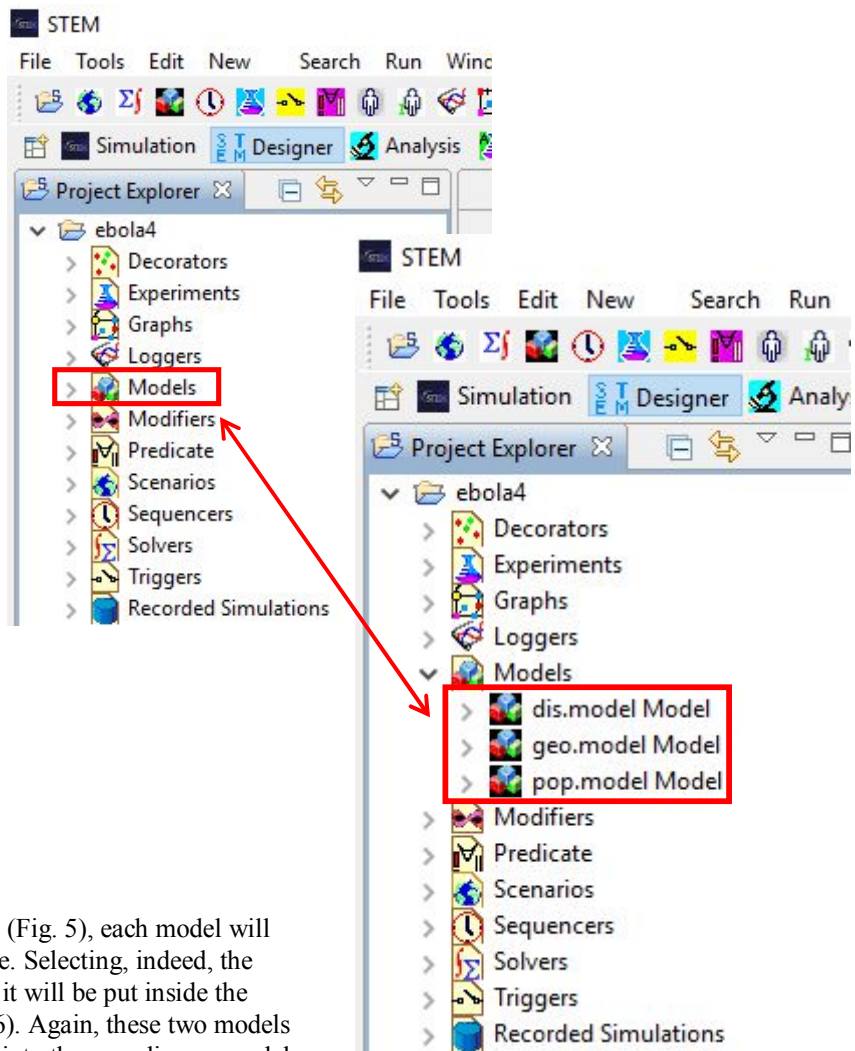
Fig. 3. (a) Creating a New Project;
(b) creating a New Scenario.

As previously mentioned STEM works on a hierarchical basis. So, the *New Project* contains a substructure inside the *Scenario* which includes (in order of creation),

3 models (Fig. 4):

- the *Geography* model (geo);
- the *Population* model (pop);
- the *Disease* model (dis);

plus an *Infector*, a *Sequencer*, a *Solver* and a *Logger* (Fig. 8, 9).



Starting from the “geo” model (Fig. 5), each model will be included in the previous one. Selecting, indeed, the geographical area to consider, it will be put inside the population model (pop) (Fig. 6). Again, these two models (geo and pop) will be inserted into the new disease model (dis) finally created (Fig. 7).

Fig. 5. Creating the “geo” model.

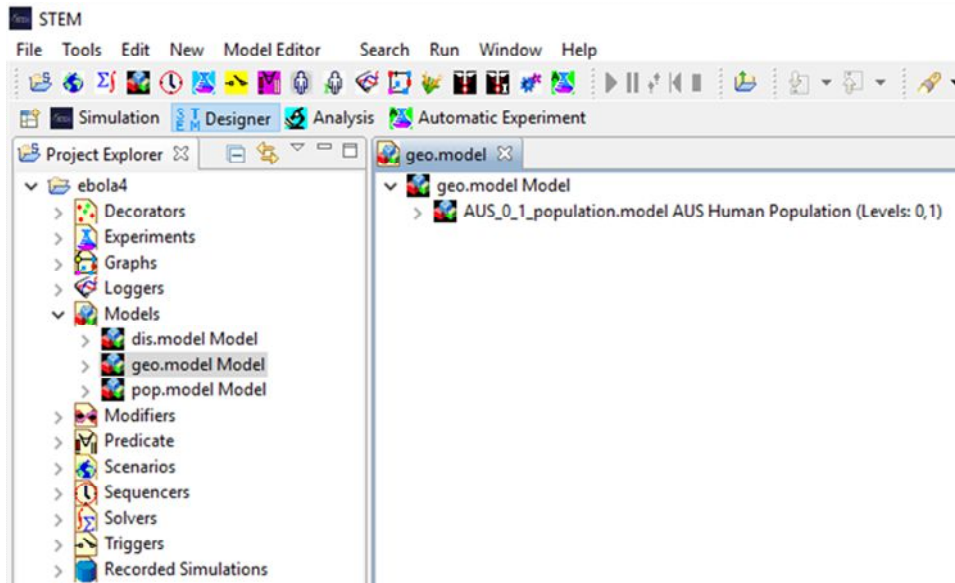
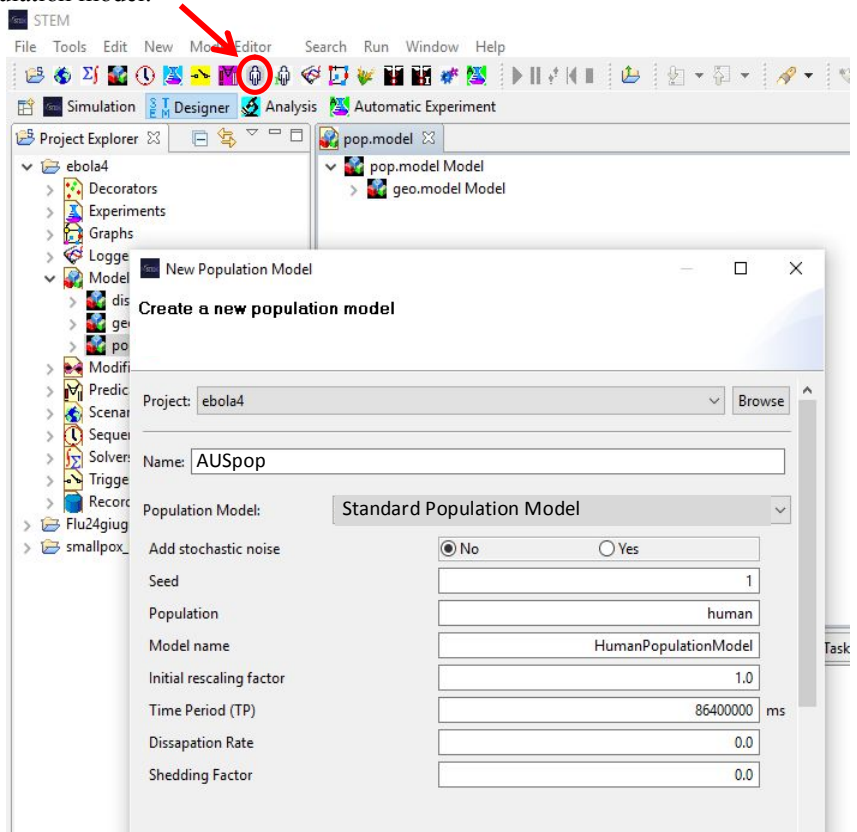


Fig. 6. Creating the “pop” model.

The “pop” model will store the geography model plus a decorator of Standard population model.



Finally, the “dis” model created shall consider all the specific Epidemiological features (Table 1) characterizing the disease of the study (in particular, the figure 7 shows transition rates referred to EBOV strain [36]).

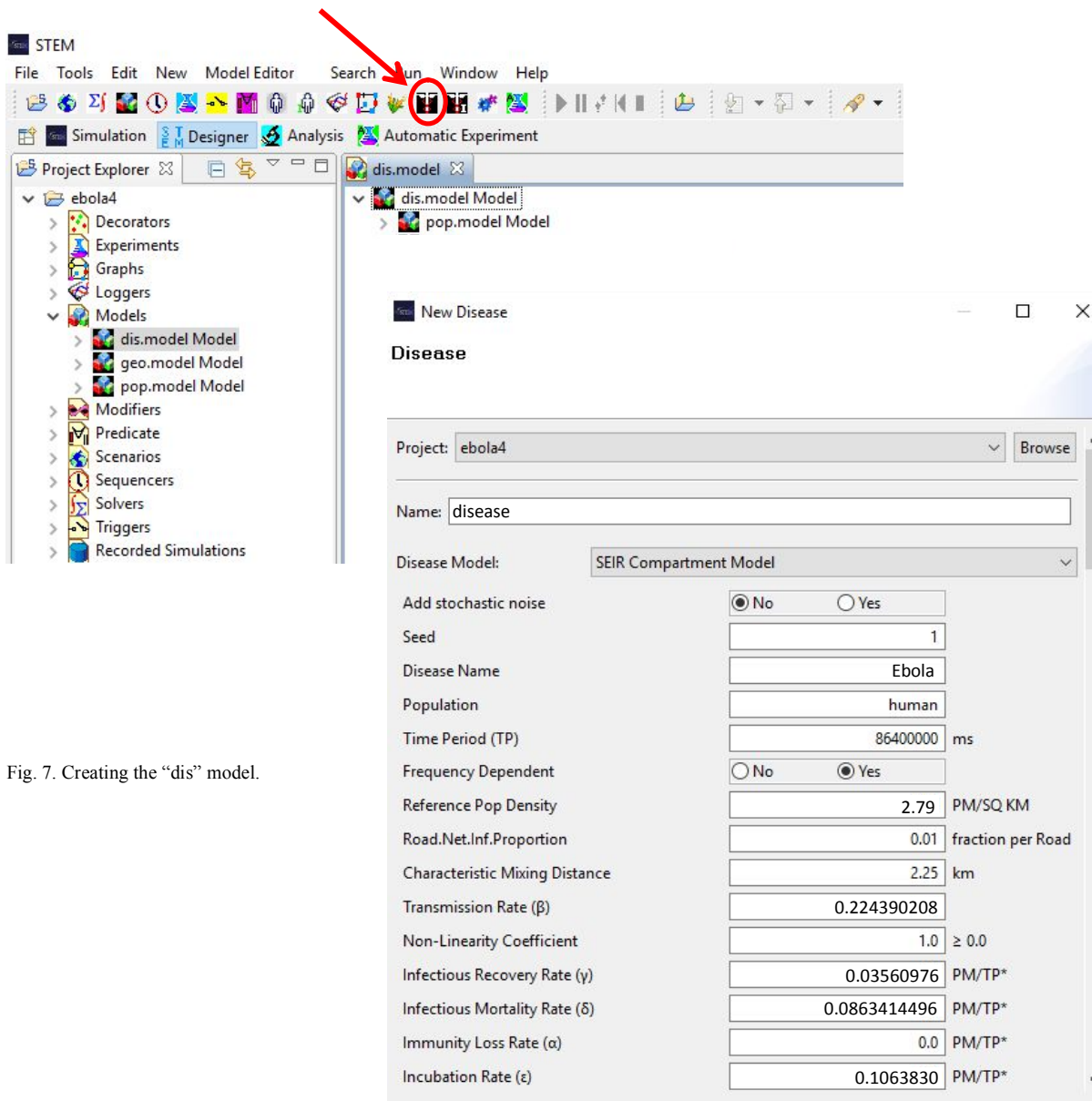
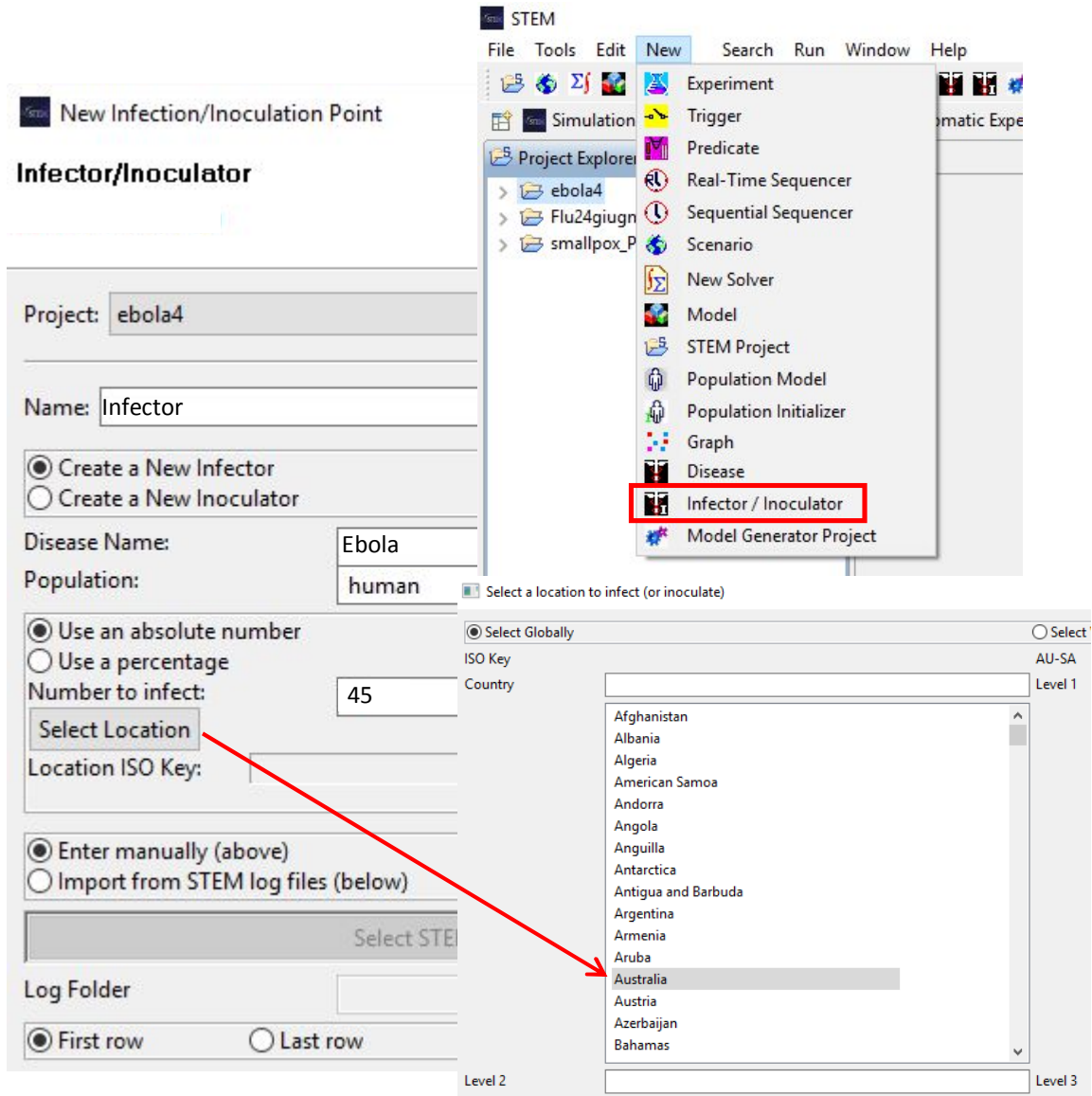


Fig. 7. Creating the “dis” model.

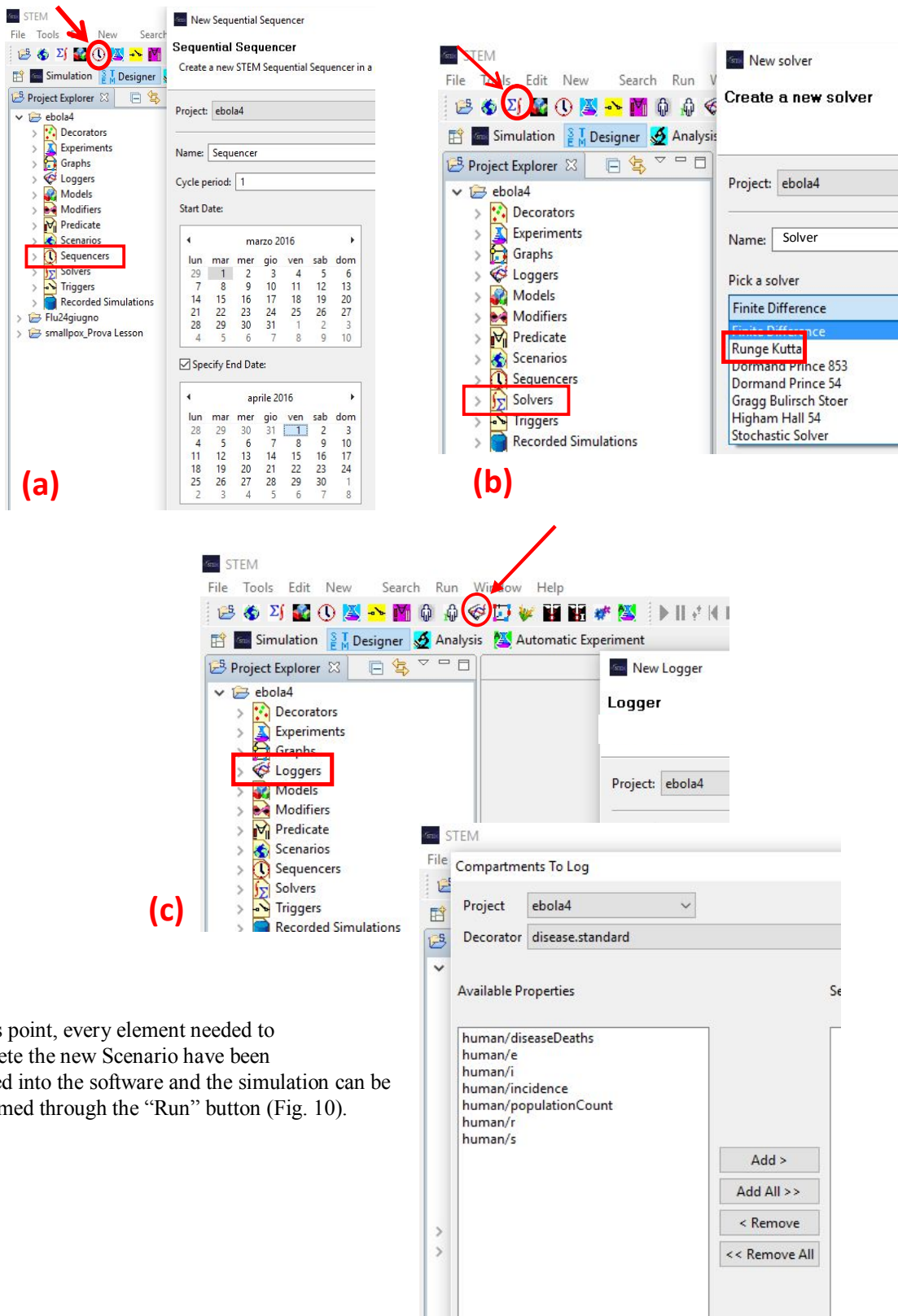
In addition is essential to create an *Infectior*, which includes the initial index cases number and the geographical location affected by the virus infection (Fig. 8).

Fig. 8. Creating the “Infector”.



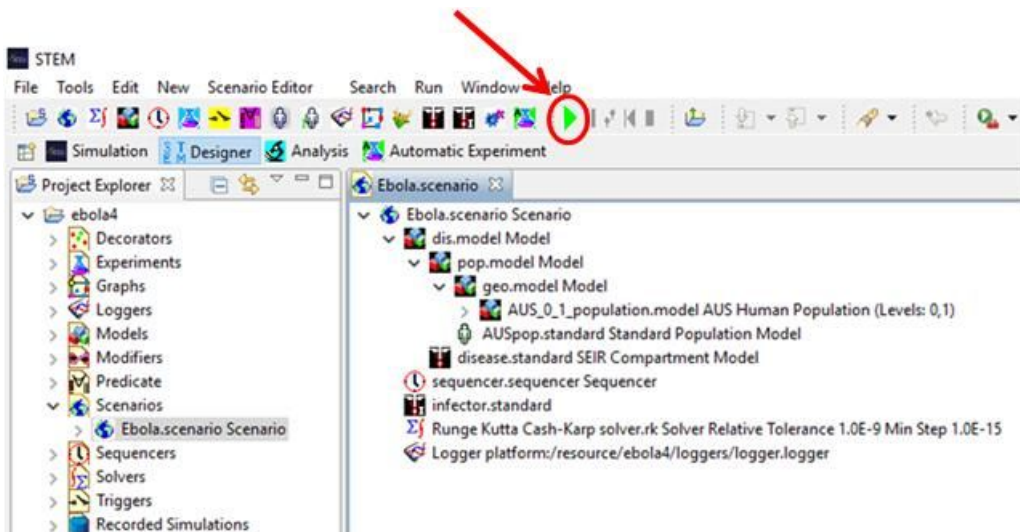
To complete the creation of the model the scenario needs a *Sequencer* (Fig. 9a) that specifies the temporal evolution of the disease indicating the beginning day and the final one of the epidemic period. Then, a *Solver* (Fig. 9b) have to be used to integrate the differential equations of the model to run. And finally, a *Logger* window (Fig. 9c) will allow to select the compartments to observe the distribution of the disease through the simulation.

Fig. 9. Creating a: (a) “Sequencer”; (b) “Solver”; (c) “Logger”.



At this point, every element needed to complete the new Scenario have been inserted into the software and the simulation can be performed through the “Run” button (Fig. 10).

Fig. 10. New Scenario completed with the “Run” button indicated.



1.4. The Australia Ebola-virus Outbreak: a STEM simulation

This STEM simulation has been performed considering a 45 number of Ebola-virus index cases isolated in Australia. The outbreak is assumed to begin in the South Australia (AU-SA) followed by a diffusion of the infectious disease during a period from the 1 March 2016 to 1 April 2016. Totally the Australia territory is populated by approximately 22 millions people with a population density of about 2.8 inhabitant/km². For the SEIR epidemic model used to perform this simulation, the Australian population was considered as constant during the all outbreak time. Consequently, there are no deaths due to outside factors as well as the births number, which is evaluated so small that can be ignored (*closed population*). Notably, all Ebola-virus cases spreading through the country were assumed to be related to human-to-human transmission and, the entire population was initially considered susceptible so that $N = S$ (where N is the *population number* and S the *susceptible individuals*). Transition rates used for this study are shown in figure 7 [36].

Results of the STEM simulation for this hypothetical case, reported a number of 129 deaths in the South Australia and just 1 death for each of the surrounding regions (AU-VI, AU-CT, AU-NS, AU-QL, AU-NT, AU-WA), with a total number of 135 *Disease Deaths* (Fig. 11, 12, 13a). Instead, no deaths subsequent to the Ebola-virus epidemic appear only in the Tasmania district (AU-TS). This land is an island situated close to the Australia south east border and, probably as a consequence of its geographical location, the virus transmission has been limited. (Such data is, in actual fact, coherent with other STEM analysis previously performed. Similarly, for example, in a STEM “Smallpox scenario” simulated in Italy, no casualties indeed, resulted in the Italian islands of Sardinia and Sicily rather than on the rest of the country, thus confirming how the geographical location has got an essential role in the spreading of an infectious disease outbreak). As expected, the outbreak due to an Ebola Virus Disease (EVD) infection is able to cause a large number of fatalities. The EVD, indeed, usually causes an acute, serious illness, which is often deadly if untreated. In this study the course of the Australian outbreak and the spread of the disease, via a SEIR epidemic model, has been used to predict the future scenario without intervention. Besides a 135 *Deaths* number, the *Recovered*

individuals resulted to be approximately only 52 people (Fig. 13c). In fact, as the *Incidence* graph results shows (Fig. 12), during the first days of the Australia EVD outbreak simulation, the disease rapidly grows. This data is coherent with the early diffusion of an infectious disease (especially by an extremely contagious and aggressive virus like Ebola) considering that, onset symptoms of the illness are common to other diseases (quite like Influenza or Malaria) thus causing diagnosis difficulties and facilitating virus spread. Moreover, specific laboratory tests, i.e., the commonly ones used (ELISA: Enzyme-linked Immunosorbent assay) to detect the antibodies against the virus (IgM/IgG), are not useful to be applied for the early diagnosis because antibodies usually do not appear within 1 or 2 weeks of illness. Other diagnosis techniques by which the existence of the Ebola-virus genes can be rapidly investigated after virus isolation (rRT-PCR: real-time reverse transcription-polymerase chain reaction), are also limited to apply if the EVD is not suspected or the patient medical history is not known. In addition, that kind of detecting analysis can be performed only in high-containment laboratories (BSL-4) because of the highly risk related to EVD infection [11].

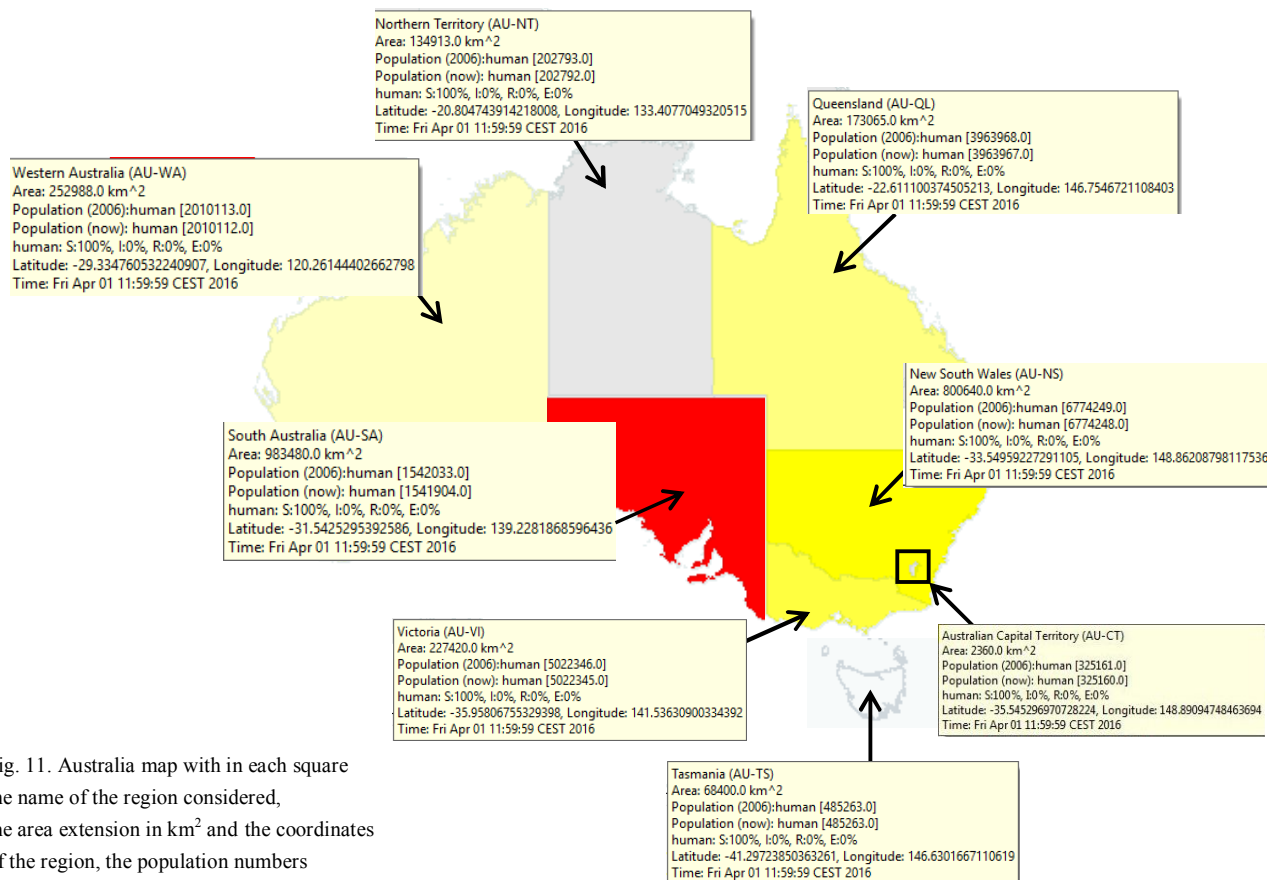


Fig. 11. Australia map with in each square the name of the region considered, the area extension in km² and the coordinates of the region, the population numbers before the disease occurred, the population numbers after the period considered that the disease occurred and the end time of the period considered.

Being the disease “*Incidence*” defined as a measure of the probability of occurrence of a disease in a population (within a specified period of time), the *Infected population* number follows the *Incidence* rate. So, when the disease *Incidence* grows, the *Infected population* number (Fig. 12, 13b) arises.

As a consequence of that, *Disease Deaths* start to gradually appear (Fig. 12, 13a). Then, immediately after the early stage of the EVD diffusion, there is a relatively short period of time (from the 2nd day to, more or less the 6th day of the simulation) showing the decrease of the *Incidence* curve. Such disease progress could be related to the beginning of *Recovered individuals* who increase, as their graph curve shows (Fig. 13c), from the start till the end of the considered period of time.

However, their final number remains dramatically low if compared to the total *Disease Deaths* number, even if, being the Ebola-virus highly lethal, it does not give rise to surprise, if medical interventions are not carry out at an early stage of the disease. Interestingly, the curve of the *Exposed individuals* number (Fig. 12) constantly increases, even more during the previous described falling down phase of the *Infected individuals* number. Hereby, the *Infected population* number rapidly starts to arise again and, consequently, the *Incidence* curve increases too. Actually, because of the real data lack to compare to, it results more difficult to evaluate the effective accuracy of this simulation. Clearly, using this method, appears that although EVD is disastrous, it is possible to control and to reduce the *Infected individuals* (Fig. 13b), and keep the balanced situation. By the way, being the model assumptions quite simplified, it means to consider the simulation results to be interpreted with caution. Surely, the use of epidemic mathematical models as STEM, is very useful, and nowadays essential, to optimize the interventions needed to face with an urgent emergency quite like the EVD outbreak affecting the Central and West Africa since 2013. By evaluating and weighting the relationship between the *Susceptible*, *Exposed*, *Infectious* and *Recovered/Removed individuals* (Fig. 12) the software can help to develop adequate intervention strategies supplying vaccination, quarantine and optimization of medical delivery system.

Fig. 12. Epidemic aggregate STEM data view. Incidence rate graph is on the right, while all the compartments graph is on the left. In particular, on the left are shown *Death individuals* (light blue), *Exposed individuals* (yellow), *Infected individuals* (red), *Recovered individuals* (green).

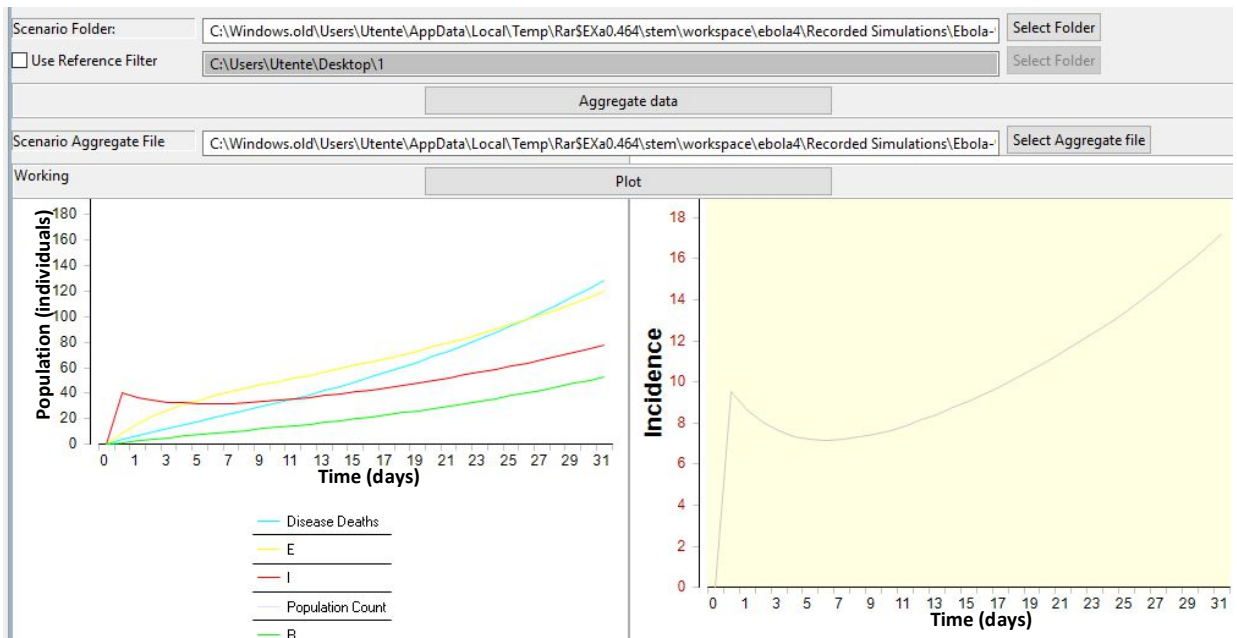
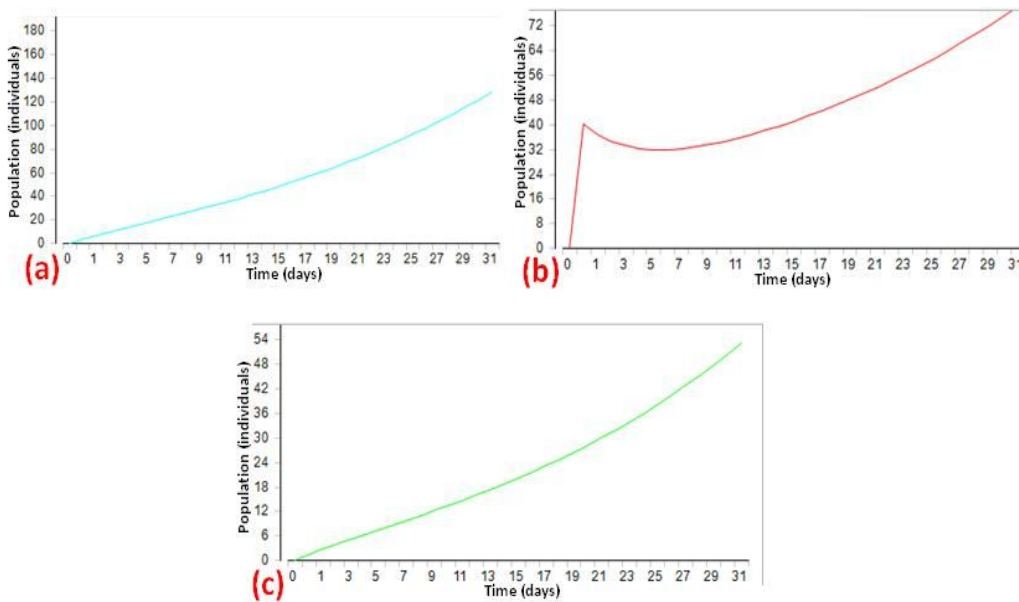


Fig. 13. (a) Disease deaths; (b) Infected people; (c) Recovered people.



1.5. The Ebola Virus

Ebola Virus Disease (EVD) is known to be a highly contagious disease with a high mortality rate [4,5]. Also known as Ebola hemorrhagic Fever (EHF), EVD originated in Sudan and Zaire in 1976. From 1976 to 2008, the total case fatality rate for EVD victims was 79% [6]. The ongoing outbreak of EVD is affecting multiple countries in Central and Western Africa [5]. Recently, beginning in December 2013 in West Africa, precisely Guinea, a new EVD outbreak spread to Sierra Leone, Liberia and Nigeria reaching in a few months an alarming diffusion becoming the largest (both by number of cases and geographical extension) and deadliest recorded so far in medical history [7]. United States, Spain, Mali and two other previously affected West African countries (Nigeria and Senegal) also have reported few cases [8]. According to the Center for Disease Control and Prevention (CDC) and World Health Organization (WHO) case reports, it is accountable for 28.646 reported cases and 11.323 deaths as of 27 March 2016 [10,35].

EVD is a viral infection caused by a virus of the family *Filoviridae*, genus *Ebolavirus*. There are five identified subspecies of the Ebolavirus:

- Ebolavirus (*Zaire ebolavirus*), EBOV;
- Sudan virus (*Sudan ebolavirus*), SUDV;
- Bundibugyo virus (*Bundibugyo ebolavirus*), BDBV;
- Taï Forest virus (*Taï Forest ebolavirus*), TAFV;
- Reston virus (*Reston ebolavirus*), RESTV.

Both EBOV and SUDV ebolaviruses proved to be highly lethal (90% for the EBOV and 50% for the Sudanese strain). The fifth ebolavirus (RESTV) is the only one that seems to be asymptomatic in humans at the moment, but it has proven it can be fatal in monkeys [5].

Ebola is transmitted through direct contact with the skin, blood or bodily fluids of an infected individual or animal and with contaminated objects [5,9].

The appearance of filoviruses and other emerging diseases is often attributed to urbanization with the concomitant invasion of animal habitats, climate change and deforestation, changing socio-economic conditions, increased global connectivity, and changes in biological characteristics of the viral species. The highest risk for emergence is being seen in tropical countries with high biodiversity and poor health care infrastructure, as was evidenced again by the EVD outbreak of EBOV in western Africa since 2013 [16].

1.5.1. Pathogenesis & Immune Response

Ebola-Virus is characterized by membrane enveloped filamentous or branched particles in the shape of a “U” a “6” or circular forms. The virions have a uniform diameter of 80 nm but vary considerably in length, with some as long as 14,000 nm (Fig. 14). The genome is a non-segmented, negative stranded RNA virus of approximately 19 kb in size and consists of seven genes transcribed in: the glycoprotein GP, which forms trimeric spikes on the Ebola virion envelope; the matrix proteins VP24 and VP40 (involved in particles formation); the RNA polymerase complex (L and VP35 proteins); the nucleoprotein NP which associates with VP30 and the RNA polymerase complex. Structurally, Ebola viruses have three layers: a surface glycoprotein layer, a lipid membrane envelope unit and an internal tubular helical nucleocapsid (Fig. 15).

The viral envelope is derived from cell membrane of the host during the budding process and it is here that the underlying viral encoded glycoproteins (GP) insert during transcriptional editing [17]. Life cycle of Ebola virus begin with the binding and attachment of virion to specific surface receptors on target cell membrane. This tropism is directed by its envelope glycoprotein (GP). The virion envelope subsequently fuses with the cellular membrane of host cells and the virus nucleocapsid is released into the cytosol resulting in viral uptake. The internalized nucleocapsid serves as a template for viral transcription and replication resulting in copying into new virus progeny genome copies. When budding off from the cell, virions can infect other cells to repeat the virus cycle. Dendritic cells, monocytes, macrophages, endothelial cells, fibroblasts, hepatocytes, adrenal-cortical cells and several types of epithelial cells support the replication of this virus.



Fig. 14. An Ebola Virus particle.

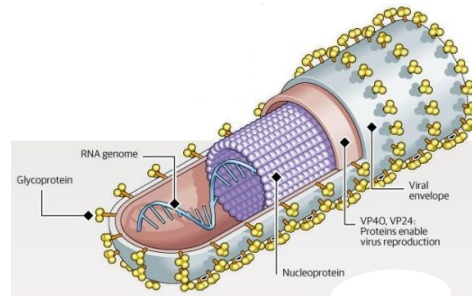


Fig. 15. Ebola virion structure.

The incubation period, that is the time interval from infection with the virus to onset of symptoms, is 2 to 21 days (with an 8 to 10 days' average). Humans are not infectious until they develop symptoms. Resultant exposure of infected cells to viral particles causes cell damage producing release of cytokines (TNF- α , IL-6, IL-8 and nitric oxide - NO -) contributing towards fever and a significant inflammatory response, lymphoid cell apoptosis and suppression of effective adaptative immune response. By doing so, the virus disables the immune system, allowing uncontrolled viral replication and dissemination and indirectly damages the vascular system that leads to hemorrhage, hypotension, thrombus and disseminated intravascular coagulation followed by shock, organ failure and death (Fig. 16) [18]. The specific antibodies formed against the viruses are directed primarily against the viral surface glycoproteins (GP). A rapid, high level, immunological response targeting the viral GP coat is thought to lead to patient survival. In contrast, patients with a defective and slow antibody response associated with increased blood concentrations of nitric oxide (NO), resulting from an inappropriate response to the virus particles, can rarely survive [19].

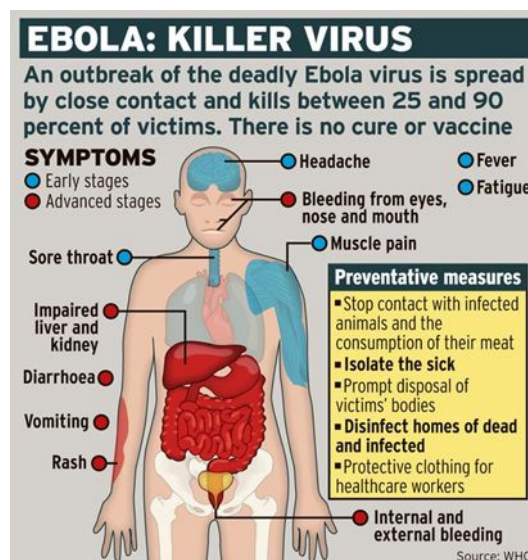


Fig. 16. Ebola Virus pathology.

1.5.2. Transmission

The exact natural reservoir host for Ebola-virus still remains unknown. On the basis of available evidence and nature of similar viruses, researchers believe that this virus is animal borne (zoonotic) and is totally dependent on its hosts for replication and overall survival. Birds, arthropods and plants are considered to be the possible reservoirs of Ebola-virus but it is not yet conclusively established as certain. Fruit bats, monkeys, great apes, duikers or pigs appear to be possible reservoirs. In particular some fruit bats species were found to be naturally infected by filoviruses remaining healthy and without showing any signs of illness: the perfect condition for the virus persistence. Unfortunately, none of the Ebola-virus strains have ever been isolated from naturally infected animals [20]. The virus that persists in the reservoir bat species, with little or no

transmission, might be sporadically activated through an appropriate stimulus like stress, co-infection, change in food sources or any, as yet unrecognized, trigger. This hypothesis would explain the sporadic nature and periodicity of filovirus disease outbreaks in Africa [21]. Secondary transmissions are known to be caused by close contact with infected patients; direct contact (through broken skin or mucous membranes) with infected blood, tissue or body fluids, or reuse and improper needle and syringe hygiene. Unsafe burials that involve direct contact with dead bodies are widely incriminated as major transmission ways. Viable Ebola-virus can persist for over 7 days on surfaces of bodies, confirming that transmission from deceased persons is possible for an extended period after death [22]. Ebola-virus has been cultured from saliva, breast milk, urine and semen of infected patients; in addition, viral RNA has been detected by RT-PCR from stool, tears and sweat and in rectal, conjunctival, vaginal and skin swabs. Infected persons can shed Ebola-virus for several weeks to months after infection. The virus also can persist in convalescent patients, suggesting that transmission may occur after that symptoms have disappeared [23]. So, contact with bodily fluids remain the most likely route of transmission, even if sometimes several patients had no direct physical contact with an infected person or known infected carcass. These observations point to other routes of transmission (e.g., human to human respiratory tract infection through droplets and aerosols) or may suggest that other, unidentified animal sources may be involved in Ebola-virus transmission to humans. However, the aerosol mode of transmission remains highly controversial [24]. Although there is strong debate on the potential aerogenic transmission of filoviruses, it should be stressed that the transmission by air is not similar to *Influenza* or other airborne infections. By the way, some researchers state that there is a distinct possibility for Ebola-virus to become airborne because of the customary and high mutation rates of negative sense RNA viruses (Fig. 17), although it is unclear if these mutations carry any fitness advantage or not [25]. Analysis of the available research suggests that the Ebola 2014 virus is currently mutating at a rate 200% to 300% higher than historically observed [26].

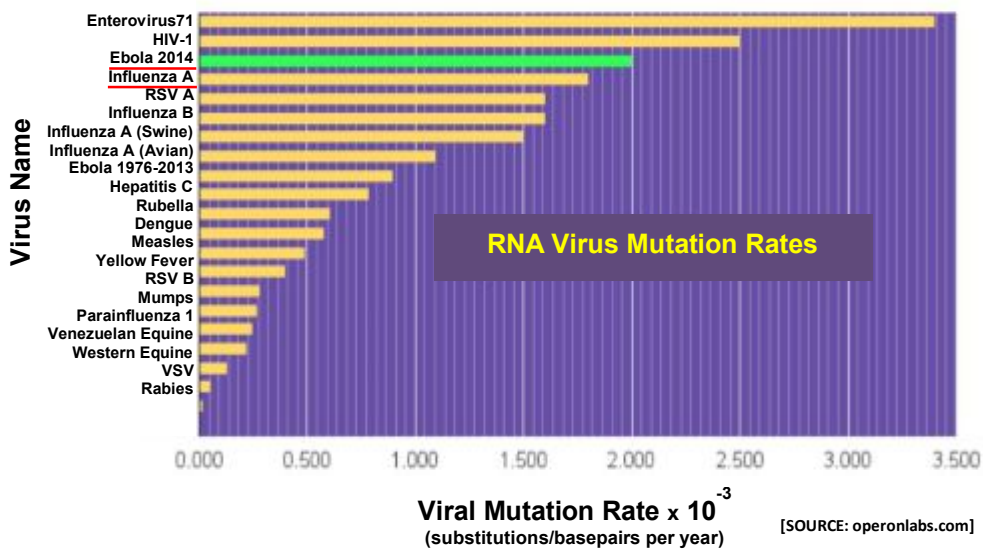


Fig. 17. Ebola-virus 2014 is mutating as fast as Seasonal Flu (Influenza A).

1.5.3. Diagnosis

Clinical diagnosis of Ebola-virus disease (EVD) is indicated after the occurrence of clusters of cases with prodromal fever, bleeding tendencies and person-to-person transmission which is frequently associated with headache, muscle pain, fatigue, nausea, skin rashes, diarrhea and loss of appetite [27]. If EVD is suspected, thorough medical history as well as any exposure to wildlife in recent past is important to investigate. Laboratory tests that may be indicative include basic blood analysis: complete blood count with differential, liver enzyme, bilirubin, creatinine levels, blood urea nitrogen and pH. Diagnosis is confirmed by:

- Isolating the virus and detecting its RNA and proteins or
- Detecting antibodies against the virus in a person's blood.

In addition, direct detection of virus particles may be undertaken using electron microscopy. Isolating virus by tissue culture (to be performed only in high-containment laboratories → BSL4: biosafety level 4, in order to reduce laboratory personnel risk of infection), detecting viral RNA by reverse-transcriptase polymerase chain reaction (RT-PCR) and antigen detection are effective early and in those who have died from the disease. Serological testing for demonstrating immunoglobulin M (IgM) and immunoglobulin G (IgG) antibodies against the virus, i.e., by enzyme-linked immunosorbent assay (ELISA) is effective late in the disease and in those who recover [28].

1.5.4. Vaccine & Drug development

While several candidate treatment options are being tested, no specific chemotherapeutic or immunization strategy yet exists for Ebola-virus. Currently available vaccines and drugs are still experimental and require full testing for safety and efficacy in humans. A well-known antibody therapeutics named ZMapp™ (Mapp Biopharmaceutical, Inc. – San Diego, California, U.S.A., in collaboration with Defyrus, Inc. – Toronto, Canada) was under development: it is classified as a humanized monoclonal antibody, harvested from the serum of Ebola-infected mice with major components produced in the *Nicotiana benthamiana* strain of tobacco plant. The drug works by attacking specific proteins on the surface of the Ebola-virus, thereby reducing its virulence: it showed enough efficacies to protect chimpanzees from Ebola-virus but its use is still critical due to its slow procedure of production [29].

Another drug currently undergoing human testing is TKM-Ebola, developed by Tekmira Pharmaceuticals Corp. (Burnaby, British Columbia, Canada). TKM-Ebola is a systematically delivered, small interfering RNA therapeutic that is administered using novel lipid nanoparticle delivery technology. TKM-Ebola interrupts the genetic coding of the Ebola-virus by blocking the expression of the L proteins of the RNA polymerase of the Ebola-virus, thus hampering replication of the virus within the host cells [30].

Favipiravir, then, also called as Abigan of commercial name, is an RNA polymerase inhibitor developed by Japanese company Toyama Chemicals (a subsidiary of Fuji Film) and already under the clinical phase III as a new Influenza treatment. This new drug was quickly focused as an efficient EVD treatment at the early stage [31].

After long time efforts related to develop vaccine platform using recombinant chimpanzee adenovirus vector for Ebola vaccine, Okairos (acquired by GSK) manufactured *cAd3Ebola* vaccine (recombinant chimpanzee adenovirus serotype 3 vectored Ebola vaccine) and this candidate has been tested for clinical phase I by GSK [32].

Recently, trials using vesicular stomatitis virus (VSV) platform designed as bivalent vaccine against Ebola and Marburg viruses revealed systemic immune responses protecting animals after injection. The most advanced form using VSV for Ebola vaccine is *VSVAG-ZEBOV* vaccine developed and sponsored by the

Public Health Agency of Canada and NewLink Genetics Corporation. The *VSVΔG-ZEBOV* vaccine revealed the 100% protection efficacy in animals [33].

Despite the fact that a number of experimental treatments and vaccines for EVD are under study, primarily therapy is based on supportive care which includes balancing fluids and electrolytes to counter dehydration given by either oral or intravenous route, administering anticoagulants early in infection to prevent or control disseminated intravascular coagulation, administering procoagulants late in infection to control bleeding, maintaining oxygen status, managing nausea, fever and pain (avoid using aspirin or ibuprofen to decrease risk of bleeding), prescribing medications to treat secondary bacterial or fungal infections and minimizing invasive procedures. Treatment instituted at an early stage increases chances of patient survival [34].

1.6. Bioterrorism

The Ebola-virus is a highly virulent, single-stranded ribonucleic acid virus which affects both humans and apes and has fast become one of the world's most feared pathogens.

Although endemic in Africa, Ebola has caused worldwide anxiety and concern about its spread, including through bioterrorism. Ebola-virus is highly contagious and because of its potential aerosol and droplet transmissibility it can be a good candidate as biological warfare agent (BWA). In particular, it may inadvertently spread via droplets that are coughed or sneezed from a sick person. Subsequently, these droplets may enter the eyes, nose, or mouth of another person who is less than two meters away [12]. Due to this potential characteristic of the virus, it has also been classified as a highly potential agent of bioterrorism (category A) [13]. The high fatality rate is attributed to unavailability of a standard treatment therapy or vaccine. The disease is frightening since it is characterized by rapid immune suppression and systemic inflammatory response, causing multi-organ and system failure, shock and often death. In a world every day more interconnected, the threat of overt or stealthy bio-terroristic attacks worldwide has become a real possibility. That could generate very harmful consequences from a sanitary point of view as well as the spreading of increasing public panic. Recently, the progresses reached by science technologies and improvements on biological knowledge could be easily exploited by terrorists which nowadays can find materials and free information on internet, with the illicit aims to intentionally organize bio-terroristic attacks. On that purpose Ebola-virus can perfectly suit, even if it presents vantages and disadvantages.

For example, the Ebola-virus is capable to survive for several hours at room conditions (20-25 °C) on objects or surfaces, better if in the dark [14]. On the contrary, obtain and disseminate the Ebola-virus is quite difficult: it requires contacts with medical staff or with infected patients to collect a virus sample; moreover, the transportation and its utilization is not simple, being the risk to contract the infection quite high, especially if managed by not expert personnel. Therefore, the virus weaponization is an essential step to ensure the success of a bio-terroristic attack, but again, it implies the presence of expert virologists or genetists able to modify Ebola-virus adding to it more dangerous features which may better permit to store the virus and/or to better disseminate it. In addition, working with a so dangerous pathogen requires very expensive facilities, as well as a BSL-4 laboratory level.

By the way, it is of great concern for the International Community the recent information revealing the possibility that some terroristic organization could send some of their members as an "infected human Ebola-disease vehicle" with the intention to spread the virus into a specific population target.

However, the choice of Bioterrorists to organize an action like that is quite unlikely, first of all because of the high security levels during all the different steps of a travel (for instance in an airport), especially from countries considered at risk. Then, the contagion from person-to-person may occur only after the symptoms onset, which normally appear after an average period of 8-10 days. Afterwards, transmission routes for Ebola-

virus, are through direct contact by skin wounds or mucous membranes with blood or other body fluids or secretions [15].

1.7. Conclusions

EVD is often a devastating disease in humans as it involves the body's vascular system resulting in significant internal bleeding and multi-organ system failure. Till date, no effective prophylaxis, anti-viral treatment, or vaccination for this fatal disease is available; therefore, increasing awareness of risk factors for Ebola infection and understanding protective measures which individuals can take, is perhaps one of the most effective ways to reduce human infection and death. On that purpose, according to WHO reports, all possible measures should be undertaken to reduce exposure to Ebola-virus and prevent transmission [28]:

prevention and control, assessment of risk, surveillance and contact tracing, a good laboratory service, safe burials and social mobilization, to raise awareness of risk factors for virus infection and protective measures, to reduce human transmission (for workers using personal protective equipment – PPE), source control, to reduce the risk of wildlife-to-human transmission from contact with infected animals and the consumption of their raw meat, to dispose of trained staff using standard precautions when caring for patients as well as if working in laboratory and so on.

Besides the intrinsic risk (as already happened in Africa) related to a naturally caused outbreak of EVD, also as a consequence of a lot of underestimated factors, nowadays there is the new threat of the bioterrorism too. That consideration arises much more concern if taking into account that Ebola-virus is able to rapidly acquire mutations (Fig. 17) and the worst case scenario referring to this occurrence is the possibility for Ebola-virus to become airborne [26,24]. Fortunately, a single mutation does not necessarily mean that the virus will change its transmission route, or spreads more easily. But a high intrinsic mutation rate of Ebola-virus means that such changes may become possible in the future. That's the reason why scientific research efforts, surveillance for lethal diseases such as EVD and supporting at-risk countries to develop preparedness plans is essential. Furthermore, tools and strategies to face with hazardous threat Bio Warfare Agents (BWA), must be absolutely improved. On that purpose, the availability of mathematical epidemiologic models, quite like STEM, can be also a useful help, as the analysis represented in this study tried to demonstrate.

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2. CHEMICAL SCENARIO: It is 25 of June 2016, at the end of Angelus of Pope Francis all people leave Saint Peter Square. The estimated number of people present on site is 500.000. Your team is on duty in at Fire fighter operational center and the threat level for terrorist attack is very high for the Jubilee.

2.1. Scenario Assessment

It is the 25 of June 2016, at the end of Angelus of Pope Francis, more or less at 12.00 A.M., all people leave Saint Peter Square. The estimated number of people present on site is 500.000.

This is the year of Jubilee. For the Catholic Church the Jubilee is the year of the remission of sins, reconciliation, conversion and of sacramental penance. It is also called the Holy Year and it is the period during which the Pope grants a plenary indulgence to the faithful who goes to Rome to make particular religious practices.

For this reason, everyone's attention has turned to this great event in which thousands of people from all over the world come to Rome.

What better setting to hit?

The alert level for terrorist attacks is very high.

The day is very hot, there is sultry, confusion, ideal conditions for possible CBRN attacks, in particular chemical attacks.

2.2. Event description

At the end of the celebration of Angelus, during the outflow of the crowd, a police unit calls the operational center and informs us about strong chemical smell, many people falling down and many other have the following symptoms: eye irritation, tearing, vision loss, nasal irritation, coughing and choking, drooling and salivation.

We suspect a terrorist attack with the use of chemical weapon or an incidental release of a toxic industrial substance (TIC).

It is immediately activated an “Emergency Plan” (PE) considering that the Fire fighter operational center is already on site. So, using the Provincial Command Operative Center VVF it is possible to promptly inform:

- The Prefecture of Rome
- Ministry of Interior-CON (National Operative Center)
- Lazio Regional Directorate (VVF)
- Police Headquarters
- Vatican Gendarmerie
- Emergency 118

It's time to act.

2.3. Chemical Release prediction: use of Decision Support Software

In order to predict and manage this kind of events, it will be useful to use DSSs (Decision Support Software) that are interactive software-based systems intended to help decision makers to identify, solve problems and make decisions from a combination of field data, documents and personal knowledge.

A good DSS is mostly composed by a:

- Database system that stores a large quantities of relevant data related to the class of problems for which the software has been designed;

- Model base management system which transforms data from the Database into information that is useful in decision making;
- Dialog generation and management system which is an intuitive and easy-to-use interface in order to help users, who are not usually computer- trained, to better utilize the software.

Using DSSs could contribute to the improvement of risk identification and management but it is key to underline that these software are simply general recipes for approaching specific decisional situations, so they need reinterpretation, refinement, adaptations and additions in order to face the disaster. In practice DSS is only a tool which could help a decision maker to evaluate the process during a disaster [1].

As for facing this kind of emergency it is key first to collect as much field information as possible; we are talking about of what, when and where the disaster happened (basic information) in order to make an initial evaluation. Now, as for using a DSS, it is necessary to integrate the initial evaluation with the meteorological information (wind intensity and direction, temperature and air stability). Only in this way it is possible to make a good Hazard Prediction, a Release Area Assessment and a useful disaster's Management.

Because the reduction and mitigation of the effects of such disasters is mainly dependents from the first actions, a CBRN decision maker needs to have clear in mind first which is the involved area. As for this, one of the most important DSS output is the "hazard zone plot" where it is possible to identify the incident area (location of the intentionally created CBRN event), the release area (initially affected by the release of a CBRN hazard), the contaminated area (where the CBRN agent is actually present) and finally the hazard area (where unprotected personnel and material may be affected by the agent).

Depending on the information available, it is possible to define different hazard areas. In particular:

- Simplified Hazard area: when a decision maker has only basic information about the disaster (what, where and when) and few meteorological data;
- Detailed Hazard area: it is possible to better predict the involved area using more data (wind direction and speed, stability and temperature);
- Enhanced Hazard Area: where, in addition to the information reported in the previous point, a decision maker has additional information about the source that has been released (quantity, type of release, etc) and additional meteorological data.

The more detailed are the information available, the more the predicted hazard area it will be similar to the actual (real) hazard area (see Figure 1).

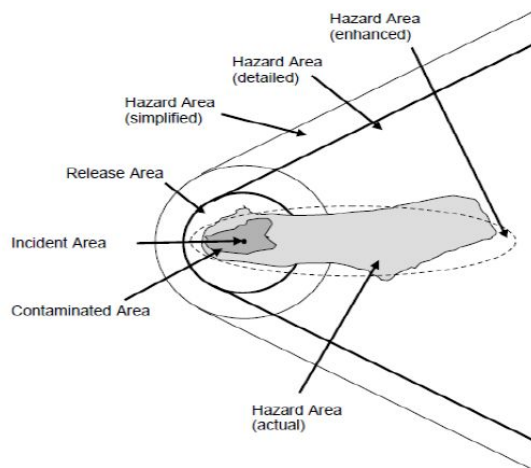


Fig. 1. Areas involved in a CBRN release.

As for facing a chemical release it will be useful, especially when there is few information available, to use the WISER software. Thanks to this tool, that it is based on Emergency Response Guide 2012, it is possible to make a simplified or a detailed prediction.

If a decision maker knows more details about the release (additional meteorological data, type of release, quantity, etc) it will be possible to make an enhanced prediction using ALOHA Software.

2.3.1. Simplified prediction

It is the 25 of June 2016 and we are on duty at the Fire fighter operational center in order to contrast some possible terrorist attack in Rome. At the end of Angelus of Pope Francis, more or less at 12:30 A.M, a police unit locates in Saint Peter Square, calls the center and informs us about a strong smell and the people's symptoms. They also reports a trailer located in Paolo VI street with a tank with a leakage of chemical substance and sends to us a tank picture where it is possible to identify a UN number that characterize the substance inside the tank.

Taking into account the people's symptoms and the UN identification number (1005) the team identifies the chemical substance: it is AMMONIA.

Using the information reported above and the Italian Air Force weather forecast, our team decides to make a simplified prediction using WISER and the ERG 2016 in order to give the first indications to the police unit.

The simplified prediction it has been realized following the steps reported below.

The first step is to open the WISER software and click to "Known Substances" in order to search for a substance within WISER's database (see Figure 2).

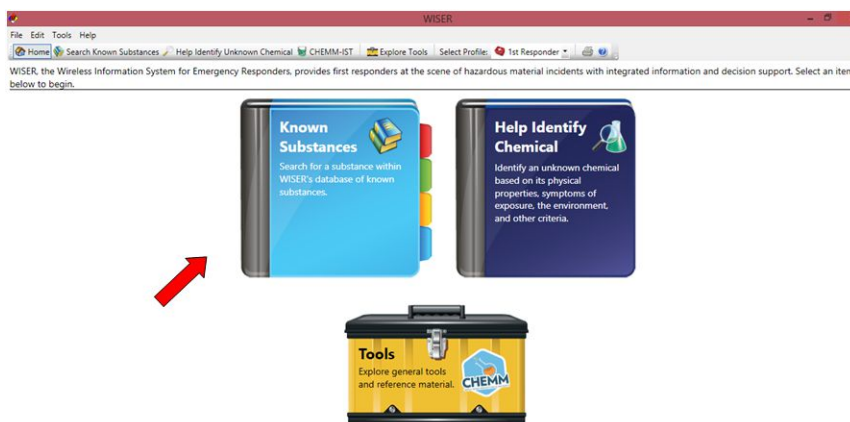


Fig. 2. WISER: Known Substances option.

We are dealing to a chemical disaster, so it is necessary to select "Chemicals" in the window named "Known substances". Now it is possible to search Ammonia by the name or the UN number. We decide to choose the second option as indicated by the arrow in Figure 3.

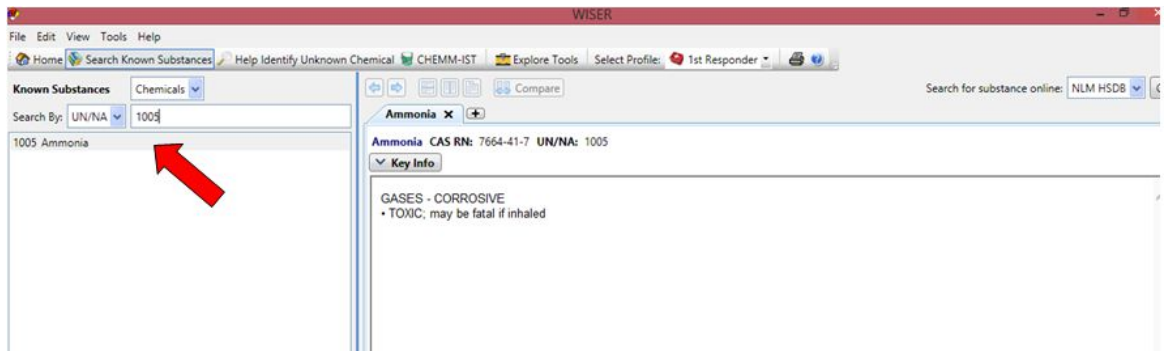


Fig. 3. WISER: Substance identification.

After the identification, it is possible to manage the ammonia release using the information listed in the window “Key Info”. As reported in the Figure 4, it is possible to acquire information about: ammonia identification, protective equipment clothing, critical signs and symptoms, protective distance as reported by the ERG 2012, protective distance map, firefighting procedures, reactivities/incompatibilities and treatment overview.

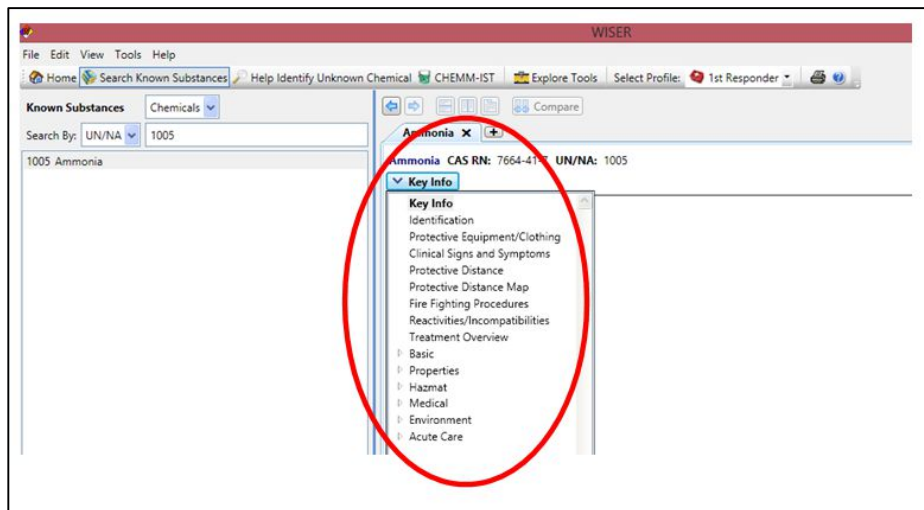


Fig. 4. WISER: Key info.

Although all these information are important, the first aspect to deal is the identification of the protective distance map in order to identify the involved area and to inform the police unit on where it is unsafe to stay. This is a key action to take in place in order to reduce the people contamination.

As for this, it is necessary to select the key info option named “Protective Distance Map” (Figure 5).

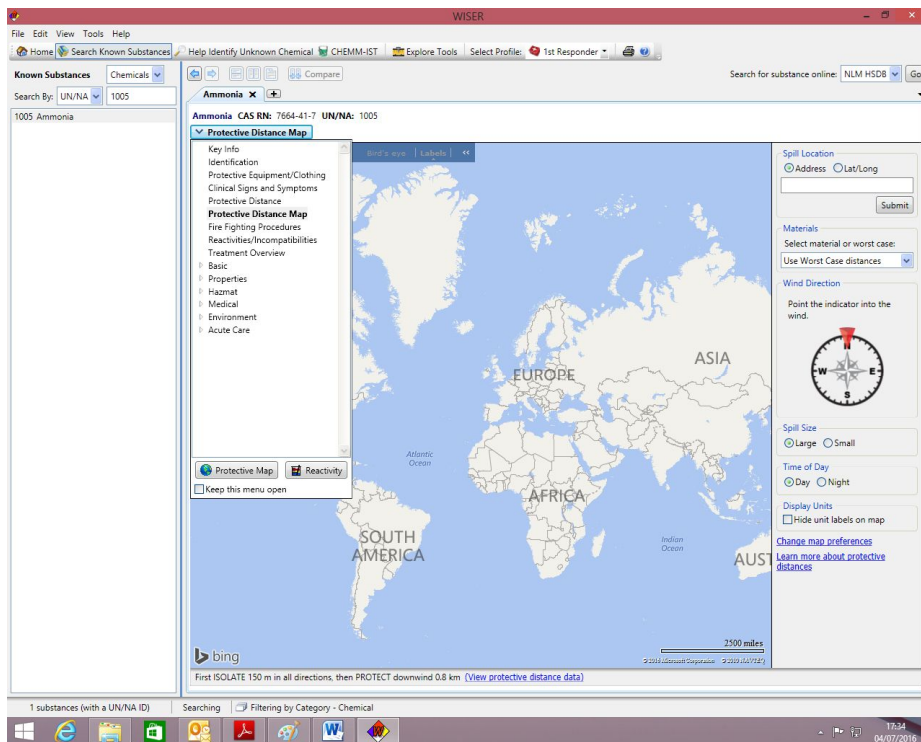


Fig. 5. WISER: Protective distance map.

This section shows, on a map, the initial isolation and protective action distances. Distances are obtained from the Emergency Response Guidebook (ERG) 2012. These are areas likely to be affected during the first 30 minutes after materials release and could increase with time (Figure 6).

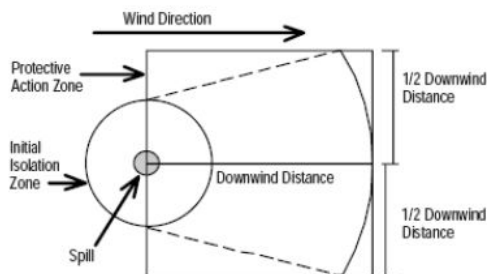


Fig. 6. WISER: Protective distance map output.

In order to obtain our distance protective maps it is necessary to fill all the gaps requested by the software as reported below (see Figure 7):

- Spill location, address: Paolo VI Street, Rome;
- Select material or worst case: it is better to choose “the worst case distance” option because we are not completely sure if it is pure ammonia or a solution;
- Wind direction compass: 280° (direction derived from the Italian Air Force weather forecast);
- Spill size: Large spill (because we don’t know the real leakage entity);
- Time of day: Day.

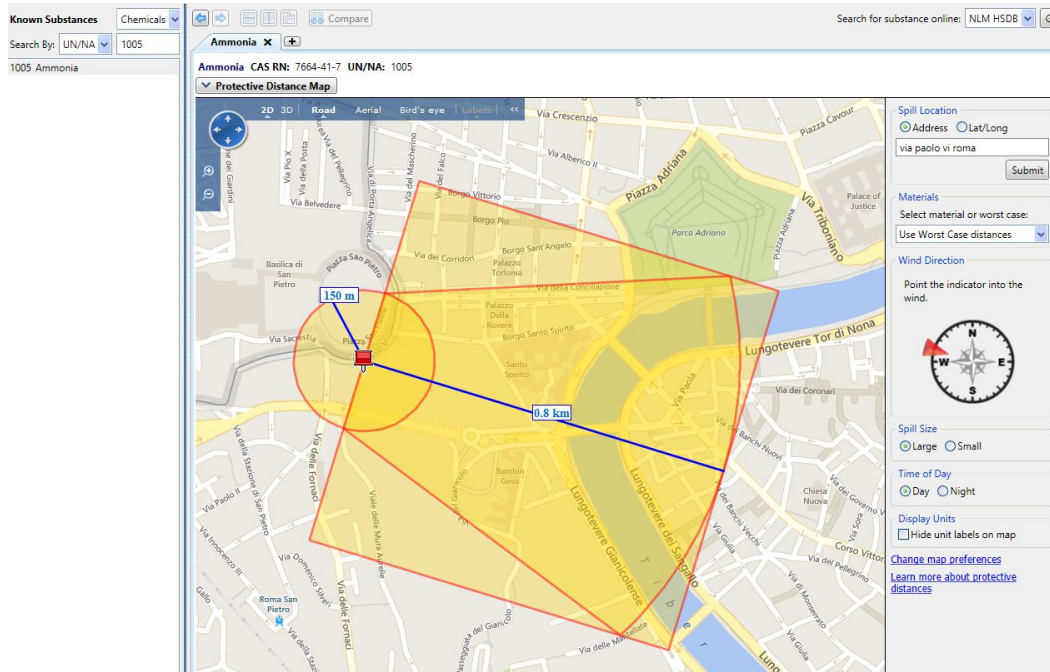


Fig. 7. WISER: Final output of the Protective distance map (simplified prediction).

As we can see in the previous figure, WISER gives us the first indication about the initial isolation zone (circle around the spill point with a radius equal to 150 m) and the protective action zone that is a square with a side equal to the downwind distance (0.8 km) that starts from the spill point. The orientation of the protective distance maps depends from the downwind direction that has been reported in the software.

This are the first information that a decision maker has to deliver to the first responders in order to avoid the spread of the contamination and to know where it is not safe to stay or operate.

In order to realize the protective distance map, WISER use the information listed in ERG 2012 that are also reported in the key info option named “Protective distance”. As we can see, the distance information reported in the protective distance map derives from table pictured in Figure 8 (underlined in red).

Ammonia

Ammonia CAS RN: 7664-41-7 UN/NA: 1005

Protective Distance

IF THERE IS A FIRE, or IF A FIRE IS INVOLVED, go directly to the [ERG guide page](#) and use the evacuation information shown under PUBLIC SAFETY.

[View protective distances overlaid on a map](#)

Initial Isolation and Protective Action Distances							
ID No.	NAME OF MATERIAL	Small Spills (From a small package or small leak from a large package)			Large Spills (From a large package or many small packages)		
		First ISOLATE in all Directions	Then PROTECT persons Downwind during		First ISOLATE in all Directions	Then PROTECT persons Downwind during	
			Day	Night		Day	Night
1005	Ammonia, anhydrous	30 m	0.1 km	0.2 km	150 m	0.8 km	2.0 km
	Anhydrous ammonia	100 ft	0.1 mi	0.1 mi	500 ft	0.5 mi	1.3 mi
3318	Ammonia solution, with more than 50% Ammonia	30 m	0.1 km	0.2 km	150 m	0.8 km	2.0 km
		100 ft	0.1 mi	0.1 mi	500 ft	0.5 mi	1.3 mi

Fig. 8. WISER: Protective distance from ERG 2012.

Because of the last Emergency Response Guide update it has been done during the current year (ERG 2016), our team decides to verify the information listed in this last version in order to validate our prediction.

Talking about initial isolation and protective action distances in case of Ammonia release, the ERG 2016 reports, in Table 1, only indication concerning a small spill (Figure 9).

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TABLE 1 - INITIAL ISOLATION AND PROTECTIVE ACTION DISTANCES

			SMALL SPILLS (From a small package or small leak from a large package)				LARGE SPILLS (From a large package or from many small packages)			
ID No.	Guide	NAME OF MATERIAL	First ISOLATE in all Directions	Then PROTECT persons Downwind during		First ISOLATE in all Directions	Then PROTECT persons Downwind during			
			Meters (Feet)	DAY	NIGHT	Meters (Feet)	DAY	NIGHT		
				Kilometers (Miles)	Kilometers (Miles)		Kilometers (Miles)	Kilometers (Miles)		
1005	125	Ammonia, anhydrous	30 m (100 ft)	0.1 km (0.1 mi)	0.2 km (0.1 mi)	Refer to table 3				
1005	125	Anhydrous ammonia								

Fig. 9. ERG 2016 Table 1: Ammonia initial isolation and protective action distances.

Considering large spill, the ERG 2016 refers to Table 3 (Figure 9) where it is possible to contemplate different kind of large spill that depends from the quantity release and wind intensity. We will analyze this case in the detailed prediction.

2.3.2. Detailed prediction

After the first police unit report, our team receives a meteo update on site from CBRN Fire Fighter Unit. They report:

- Wind direction 280° and wind intensity 2 m/s or 7.2 km/h;

- Temperature 30 °C;
- Humidity 50 %;
- Cloud coverage completely cover 8/8.

The police unit also confirms the substance identification with detector CHEM PRO 100: now we are more confident that it is Ammonia.

Thanks to this information it is possible to make a detailed prediction.

Due to the WISER architecture and considering the software refers to ERG 2012, the detailed prediction output it will be equal to the protective distance map that has been obtained making a simplified prediction (Figure 7) because this last already contemplate the only meteorological information that can be introduced (wind direction).

Indeed, in order to obtain a new protective distance map considering the update news, it could be necessary to replace the materials option “Use the Worst Case distance” with the option “UN 1005 – Ammonia anhydrous” because we are now more confident about the substance. Nevertheless, the WISER output it is the same because pure Ammonia anhydrous already represents the worst case.

On the other hand we are now able to implement our prediction using the information reported in the Table 3 of the ERG 2016 (Figure 10).

TABLE 3 - INITIAL ISOLATION AND PROTECTIVE ACTION DISTANCES FOR LARGE SPILLS FOR DIFFERENT QUANTITIES OF SIX COMMON TIH (PIH in the US) GASES										
	First ISOLATE in all Directions		Then PROTECT persons Downwind during							
			DAY			NIGHT				
	Meters	(Feet)	Low wind (< 6 mph = < 10 km/h)	Moderate wind (6-12 mph = 10 - 20 km/h)	High wind (> 12 mph = > 20 km/h)	Low wind (< 6 mph = < 10 km/h)	Moderate wind (6-12 mph = 10 - 20 km/h)	High wind (> 12 mph = > 20 km/h)		
	km	(Miles)	km	(Miles)	km	(Miles)	km	(Miles)	km	(Miles)
TRANSPORT CONTAINER	UN1005 Ammonia, anhydrous: Large Spills									
Rail tank car	300	(1000)	1.7	(1.1)	1.3	(0.8)	1.0	(0.6)	4.3	(2.7)
Highway tank truck or trailer	150	(500)	0.9	(0.6)	0.5	(0.3)	0.4	(0.3)	2.0	(1.3)
Agricultural nurse tank	60	(200)	0.5	(0.3)	0.3	(0.2)	0.3	(0.2)	1.3	(0.8)
Multiple small cylinders	30	(100)	0.3	(0.2)	0.2	(0.1)	0.1	(0.1)	0.7	(0.5)

Fig. 10. ERG 2016. Table 3: Ammonia initial isolation and protective action distances for large spills.

Considering that there is a leakage from a draining valve of a tank which can be considered similar to an highway truck or a trailer and a wind intensity of 7.2 km/h (low wind), it is possible to plot a new protective distance map with a first isolate distance equal to 150 m and a protective downwind distance equal to 0.9 km (Figures 10 and 11).

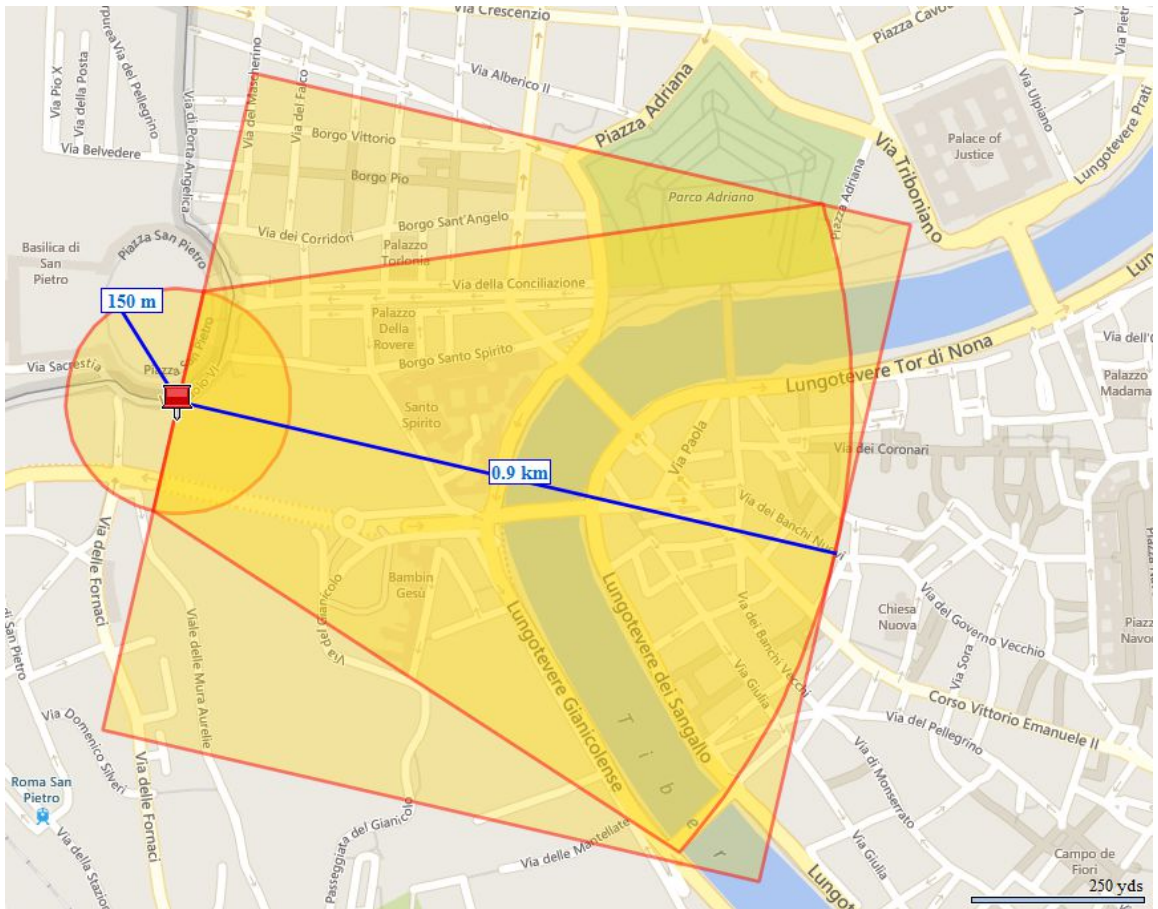


Fig. 11. Detailed protective distance map obtained using ERG 2016 data.

In conclusion, the detailed prediction that has been made using ERG 2016 thanks to the update news, it is similar to the previous one (simplified) except for the protective downwind distance that is 0.1 km longer than the simplified.

2.3.3. Enhanced prediction

Although the simplified and detailed prediction can be considered an excellent instrument to direct the first responders efforts in order to manage the disaster, now we have enough data to make a more realistic prediction. As for this we can use ALOHA software that gives us an enhanced prediction as output.

The most important ALOHA software improvement with respect to WISER software it is given by the possibility to insert inside more detailed source information (type of release, quantity, leakage dimension) and meteorological conditions in order to obtain a more realistic involved area.

The first step is to open ALOHA software (Figure 12).

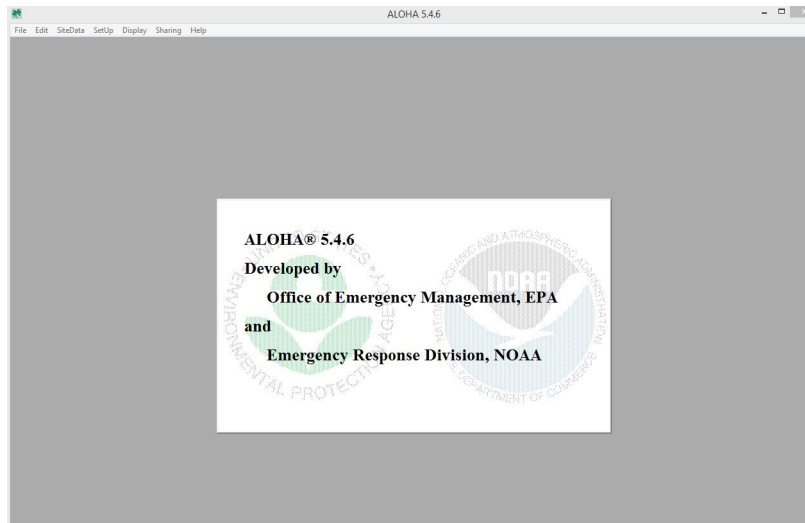


Fig. 12. ALOHA homepage.

As for reaching our goal, we must insert location data, chemical data, atmospheric data and source data inside the text summary (Figure 13).

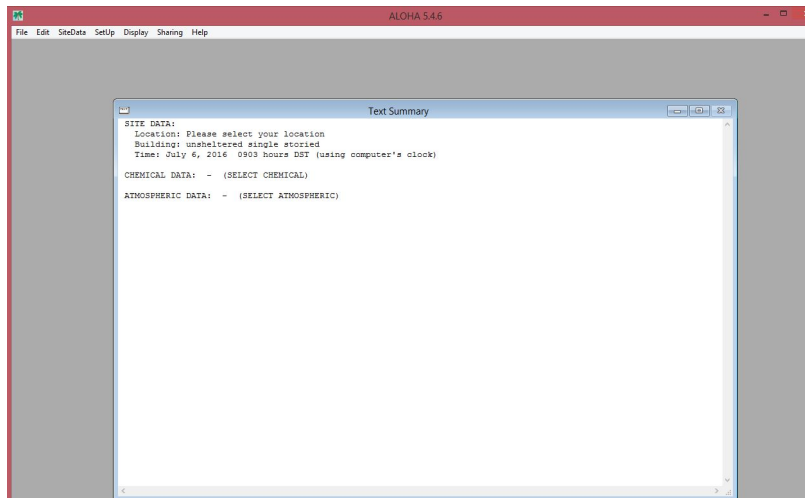


Fig. 13. ALOHA text summary.

The first information that we must insert is the location data using the “Site-data” option (underlined in red in Figure 14). Because ALOHA software includes as default location only USA site, we must add our address.

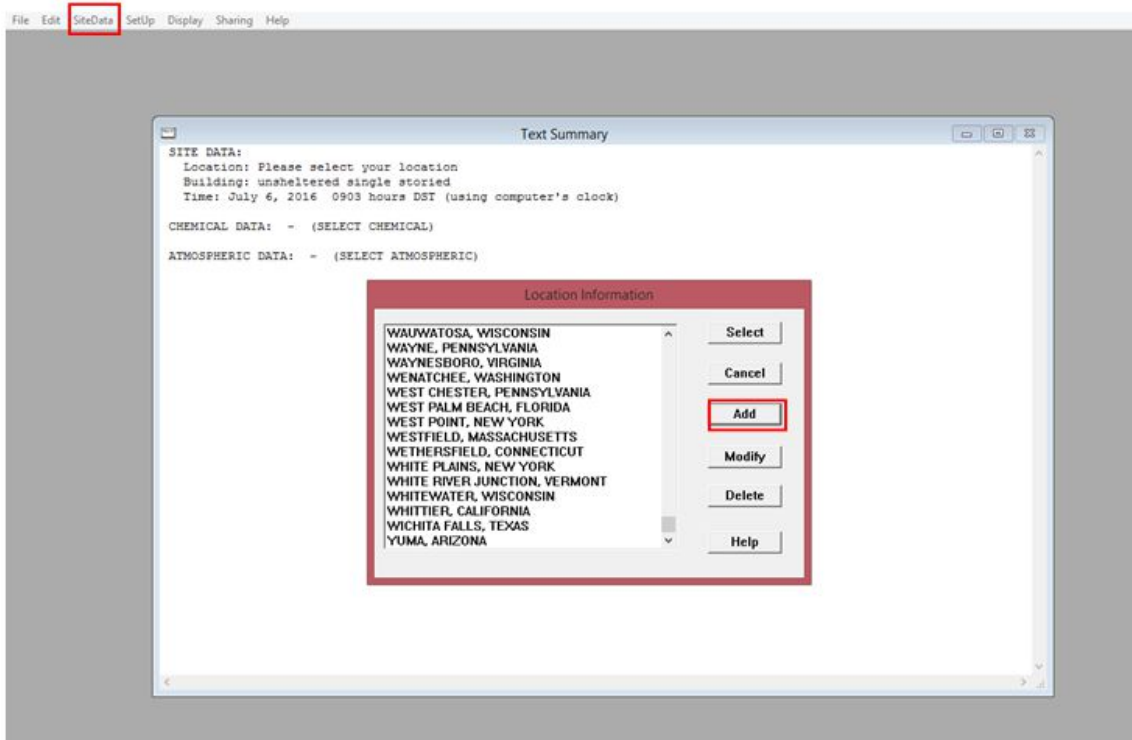


Fig. 14. ALOHA: Add location data.

As for this, we can use Google Heart in order to find the location data necessary to fill all the gaps in the windows reported in Figure 15.

The entering data are:

- Country name: Rome
- Location: Via PAOLO VI;
- Location not in U.S.;
- Approximate elevation : 38 m;
- Latitude: 41° 54' N;
- Longitude: 12° 27' E;
- Offset from standard locale time to GMT: -2 hours;
- Standard time.

Location Input

Enter full location name:
Location is

Is location in a U.S. state or territory ?
☐ In U.S. ☒ Not in U.S.

Enter approximate elevation
Elevation is ☐ ft ☒ m

Enter approximate location

	deg.	min.	
Latitude	<input type="text" value="41"/>	<input type="text" value="54"/>	<input checked="" type="radio"/> N <input type="radio"/> S
Longitude	<input type="text" value="12"/>	<input type="text" value="27"/>	<input checked="" type="radio"/> E <input type="radio"/> W

Foreign Location Input

Country name:

Offset from local STANDARD time to GMT: hours
(eastern hemisphere is a negative offset)

Is current model time standard or daylight savings time ?
☒ Standard Time ☐ Daylight Savings Time

Fig. 15. ALOHA: release point input.

After that we must set date and time as specified in Figure 16.

File Edit **SiteData** SetUp Display Sharing Help

Location... Ctrl+L
Building Type...
Date & Time... Ctrl+E

Date and Time Options

You can either use the computer's internal clock for the model's date and time, or set a constant date and time.

☐ Use internal clock ☒ Set a constant time

Input a constant date and time :

Month	Day	Year	Hour	Minute
<input type="text" value="6"/>	<input type="text" value="25"/>	<input type="text" value="2016"/>	<input type="text" value="12"/>	<input type="text" value="30"/>
(1 - 12)	(1 - 31)	(1900 - ...)	(0 - 23)	(0 - 59)

Fig. 16. ALOHA: data and time option.

The second information requested by ALOHA in the substance type. Using the “Setup/Chemical” option (Figure 17), it is possible to select AMMONIA inside the ALOHA chemicals database (Figure 18) .

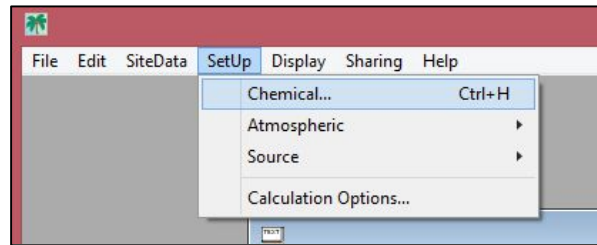


Fig. 17. ALOHA: Setup/Chemical option.

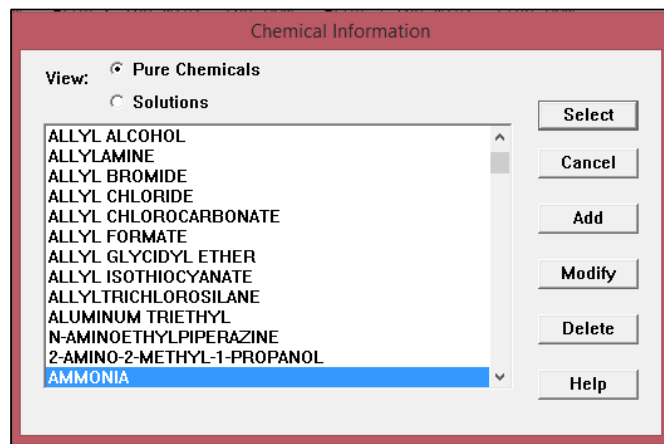


Fig. 18. ALOHA: Chemical Information.

Now it is possible to insert the atmospheric data by means the “Setup/Atmospheric/User input” option (Figure 19).

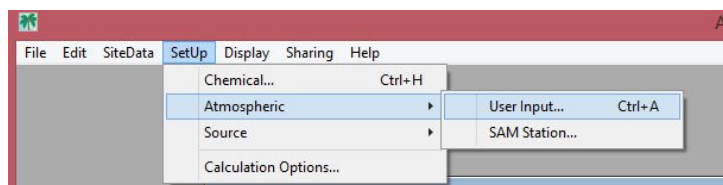


Fig. 19. ALOHA: Setup/Atmospheric/User input option.

Because we are making an enhanced prediction, ALOHA software requests a lot of meteorological data. Thanks to the weather update on site we can insert all the atmospheric information useful to reach our business. In particular (Figure 20 a-b):

- Wind speed: 2 m/s;
- Wind is from 280 °;
- Measurement Height above the ground is 3 meters (because most SAM stations are mounted on a 3-meter stand);
- Ground roughness is *Urban or Forest* (because the city is a type of terrain with high roughness and high turbulence);
- Cloud cover: *complete cover* (10/10);
- Air temperature is 30 °C;
- Stability class is *C - Slightly Unstable* (Stability represents a different degree of turbulence in the atmosphere. Usually when there is moderate or strong solar radiation and the wind is weak, the atmosphere is considered unstable. Instead when solar radiation is relatively weak or absent and also the wind is weak the atmosphere is considered stable (usually in the night). Finally relatively strong wind speeds and moderate solar radiation are associated with neutral stability. ALOHA uses the stability class table (from A-very unstable to F-stable) to automatically choose the stability class that best represents the atmospheric conditions. In this case, ALOHA chooses a D class (neutral). Because this last is characterized from strong wind (much more than 2 m/s), we have decided to override it in order to insert the more suitable stability class C);
- *Inversion present* (inversion is an atmospheric condition that can trap pollutant gases below the inversion height, causing high ground level concentrations. It is usually present when there is not strong solar radiation as our case study);
- Humidity : 50%.

Atmospheric Options

Wind Speed is : ☐ knots ☐ mph ☒ meters/sec

Wind is from :

Measurement Height above ground is: ☒ ☐ OR ☐ enter value : ☐ feet ☒ meters

Ground Roughness is : ☐ Open Country ☒ Urban or Forest OR ☐ Input Roughness [Zo] :

☐ Open Water

Select Cloud Cover : ☒ ☐ ☐

☐ complete cover ☐ partly cloudy ☐ clear OR ☐ enter value : [0 - 10]

Fig. 20a. ALOHA: Atmospheric options.

Fig. 20b. ALOHA: Atmospheric options.

The last setup step is to set the source characteristics by means of “Setup/source/tank” option. We decided to use this option because we are dealing with a leakage from a tank (Figure 21).

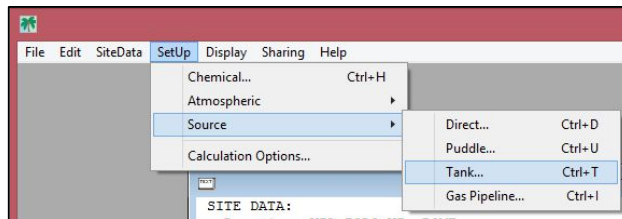


Fig. 21. ALOHA: Setup source characteristics

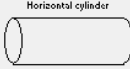
In order to obtain the ALOHA source characteristics output we must fill the following information in the windows reported in the Figures 22 (a, b, c, d, e, f):

- Tank type and orientation: *Horizontal cylinder*;
- Tank diameter: *1.5 meters* (estimated by the picture);
- Tank length: *3 meters* (estimated by the picture);
- Tank volume: *5.30 cubic meters* (calculated by ALOHA);
- Enter state of the chemical: *Tank contains liquid*;
- Temperature within the tank: *Chemical stored at ambient temperature*;
- Percentage full by volume: *85%* (we don't know how much the tank is full, so we decide to deal with the worst case: full tank);

- Liquid volume is *4.51 cubic meters* (derived from the percentage full by volume);
- Mass in the tank is *2.96 tons* (derived from the percentage full by volume);
- Type of tank failure: *Leaking tank, chemical is not burning as it escapes into the atmosphere*;
- Shape that best represents the shape of the opening through which the pollutant is exiting: *Circular opening* (because this is a leakage from a valve);
- Opening diameter: *1 centimeters* (estimated draining valve diameter for our type of tank);
- Leak through a hole or short pipe/valve: *short pipe/valve*;
- The bottom of the leak is at *0.1 meters* (we don't have this information but usually the draining valve is located in the bottom of the tank. This is the worst case).


Tank Size and Orientation

Select tank type and orientation:



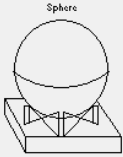
Horizontal cylinder

☒



Vertical cylinder

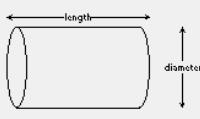
☐



Sphere

☐

Enter two of three values:



diameter

length

volume

☐ feet ☒ meters

☐ liters ☒ cu meters

Fig. 22a. ALOHA: Setup source characteristics - tank size and orientation

Chemical State and Temperature

Enter state of the chemical:

☒ Tank contains liquid
☐ Tank contains gas only
☐ Unknown

Enter the temperature within the tank:

☒ Chemical stored at ambient temperature
☐ Chemical stored at degrees ☐ F ☒ C

Fig. 22b. ALOHA: Setup source characteristics - chemical state and temperature.

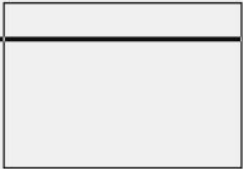
Liquid Mass or Volume

Enter the mass in the tank OR volume of the liquid

The mass in the tank is: ☐ pounds
☒ tons[2,000 lbs]
☐ kilograms

OR

Enter liquid level OR volume



The liquid volume is: ☐ gallons
☐ cubic feet
☐ liters
☒ cubic meters

% full by volume

Fig. 22c. ALOHA: Setup source characteristics - liquid mass or volume.

Type of Tank Failure

Scenario:
Tank containing a pressurized flammable liquid.

Type of Tank Failure:

☒ Leaking tank, chemical is not burning as it escapes into the atmosphere
☐ Leaking tank, chemical is burning as a jet fire
☐ BLEVE, tank explodes and chemical burns in a fireball


Potential hazards from flammable chemical which is not burning as it leaks from tank:

- Downwind toxic effects
- Vapor cloud flash fire
- Overpressure (blast force) from vapor cloud explosion

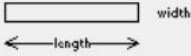
Fig. 22d. ALHOA: Setup source characteristics - type of tank failure.

Area and Type of Leak

Select the shape that best represents the shape of the opening through which the pollutant is exiting



☒ **Circular opening**



☐ **Rectangular opening**

Opening diameter:

☐ inches
☐ feet
☒ centimeters
☐ meters

Is leak through a hole or short pipe/valve?


☐ Hole

☒ Short pipe/valve

OKCancelHelp

Fig. 22e. ALOHA: Setup source characteristics - Area and type of leak.

Height of the Tank Opening



The bottom of the leak is:

☐ in ☐ ft ☐ cm ☒ m

above the bottom of the tank

OR

% of the way to the top of the tank

OKCancelHelp

Fig. 22f. ALOHA Setup source characteristics - Height of the tank opening.

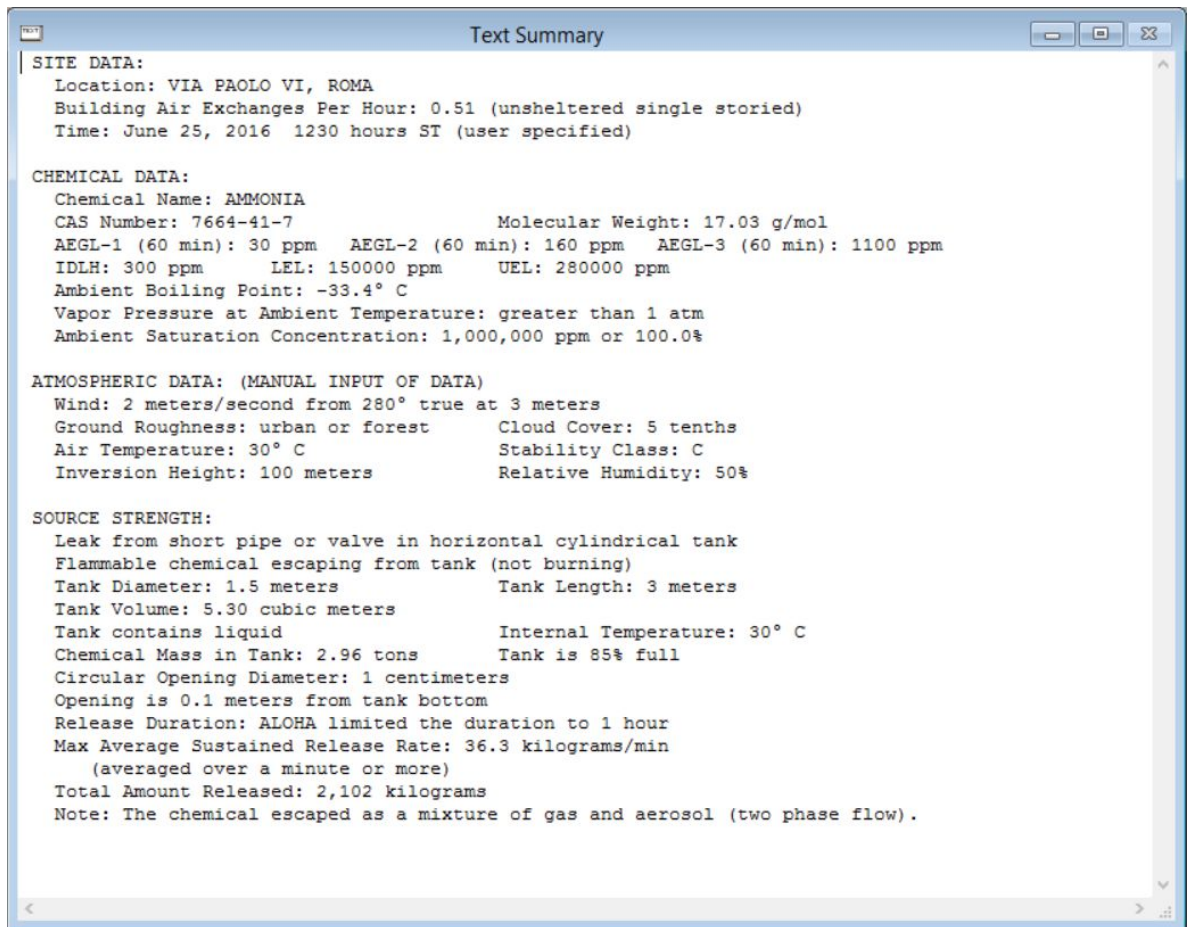


Fig. 23. ALOHA – Text summary.

At the end of this work ALOHA shows, in the “text summary” window, all the information necessary to make the enhanced prediction (Figure 23). At this point it is possible to display the threat zone using the “Display/Threat Zone” option (Figure 24).

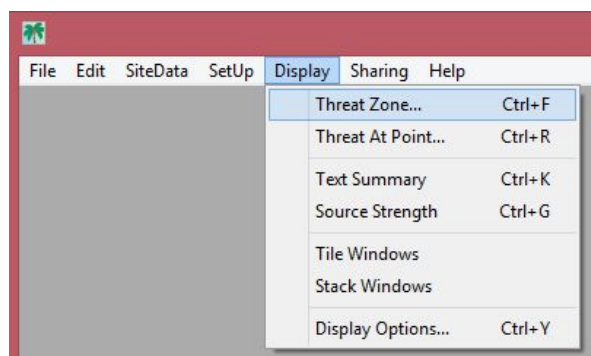


Fig. 24. ALOHA – Display/threat zone option.

ALOHA can model multiple hazards; if a toxic chemical is released without fire, there will be a vapor cloud. The hazards associated with the vapor cloud will depend on the release conditions and the chemical that is released. In this case, asking ALOHA to display a threat zone, the Hazard To Analyze dialog box appears in order to specify which hazard ALOHA has to model. In this case we want to know a *Toxic Area of Vapor Cloud* that is the predicted area where the ground-level toxic vapor concentration may be hazardous (Figure 25).

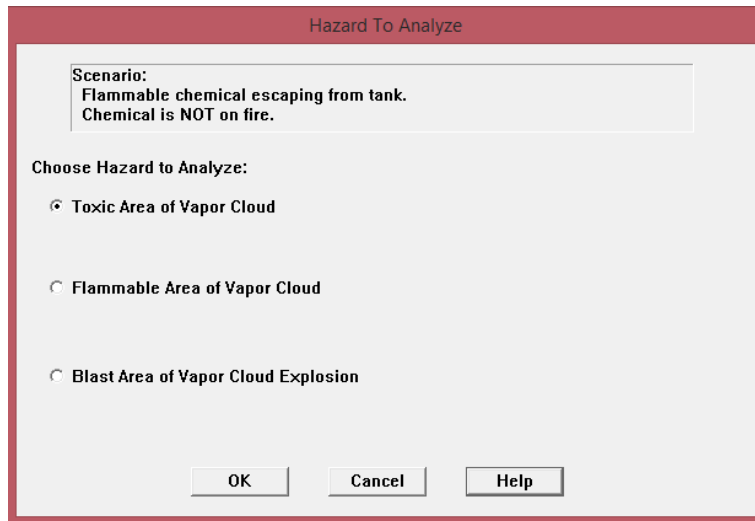


Fig. 25. ALOHA: Type of hazard to analyze.

Modelling a chemical release in ALOHA in order to assess the toxicity threat, it is necessary to choose one or more toxic Levels of Concern (LOCs). A toxic LOC indicates what level (threshold concentration) of exposure to a chemical could hurt people if they breathe it in for a defined length of time (exposure duration). Toxic LOCs also may be referred to as exposure limits, exposure guidelines, or toxic endpoints.

We decide to choose ALOHA's default toxic AEGLs LOC values. These are the best public exposure LOCs available because they undergo a rigorous review process, have multiple exposure durations and are designed as guidelines for nearly all members of the general public (Figure 26).

Toxic Level of Concern

Select Toxic Level of Concern:

Red Threat Zone

LOC: AEGL-3 (60 min): 1100 ppm

Orange Threat Zone

LOC: AEGL-2 (60 min): 160 ppm

Yellow Threat Zone

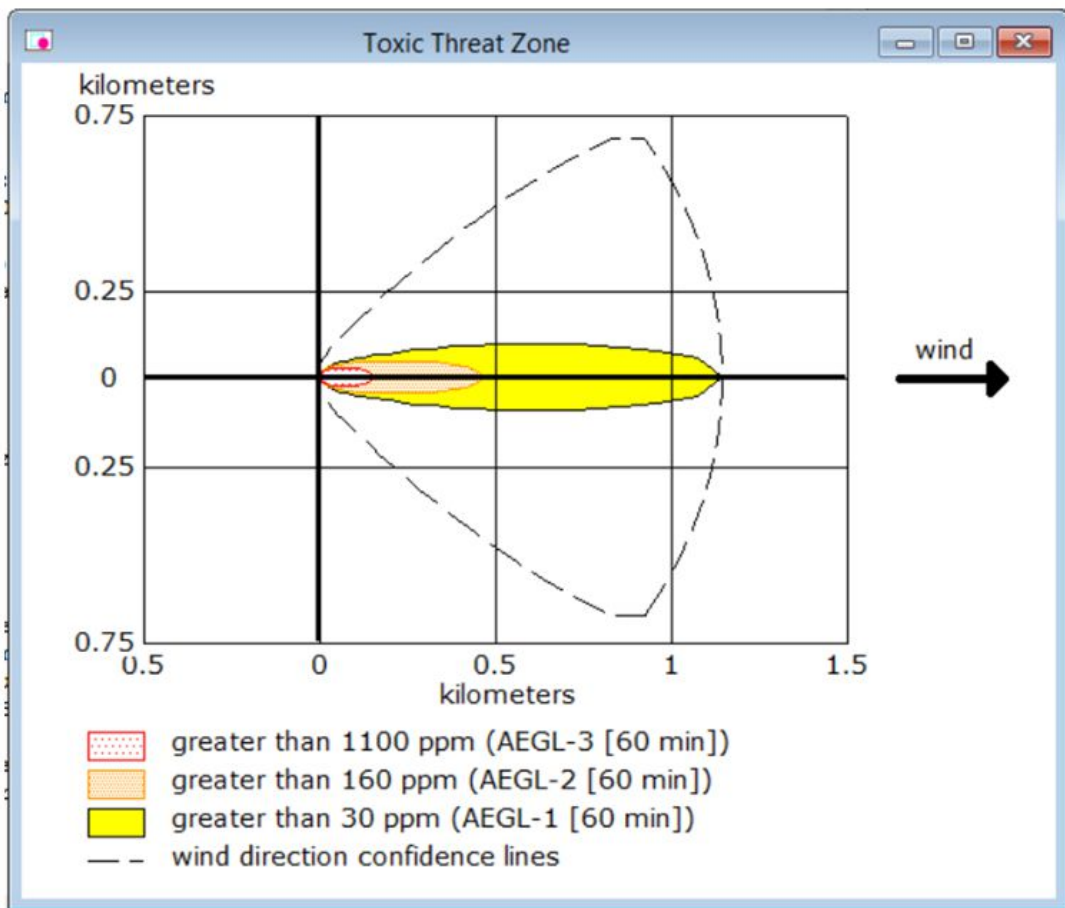
LOC: AEGL-1 (60 min): 30 ppm

Fig. 26. ALOHA: Toxic level of concern.

Modelling a toxic vapor cloud scenario in ALOHA with the default public exposure guidelines as toxic LOCs, the threat zone estimated will be the one pictured below (Figure 27). The red, orange, and yellow threat zones indicate the areas where the ground-level pollutant concentration is predicted to exceed the corresponding LOC at some time in the hour after the release begins. Typically, the "-3" public exposure guideline values are used for the most hazardous (red) threat zones, because they represent the threshold concentration above which health effects may be life threatening. In detail, AEGLs estimate the concentrations at which most people will begin to experience health effects if they are exposed to a hazardous chemical for a specific length of time.

The three AEGL limits reported in ALOHA software are [2] :

- AEGL-3 is the airborne concentration of a substance above which it is predicted that the general population could experience life-threatening health effects or death;
- AEGL-2 is the airborne concentration of a substance above which it is predicted that the general population could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
- AEGL-1 is the airborne concentration of a substance above which it is predicted that the general population could experience notable discomfort, irritation, or certain asymptomatic non sensory effects. These effects are not disabling and are transient and reversible upon cessation of exposure.



THREAT ZONE:

Model Run: Heavy Gas

Red : 152 meters --- (1100 ppm = AEGL-3 [60 min])

Orange: 466 meters --- (160 ppm = AEGL-2 [60 min])

Yellow: 1.1 kilometers --- (30 ppm = AEGL-1 [60 min])

Fig. 27. ALOHA – Toxic Threat zone.

Although this last is the final output of the enhanced prediction, we need a more realistic hazard zone representation in order to better manage the terroristic attack. As for this, ALOHA permits to export its prediction in a Google Earth file.

The Figure 28 shows the bi-dimensional toxic threat zone.

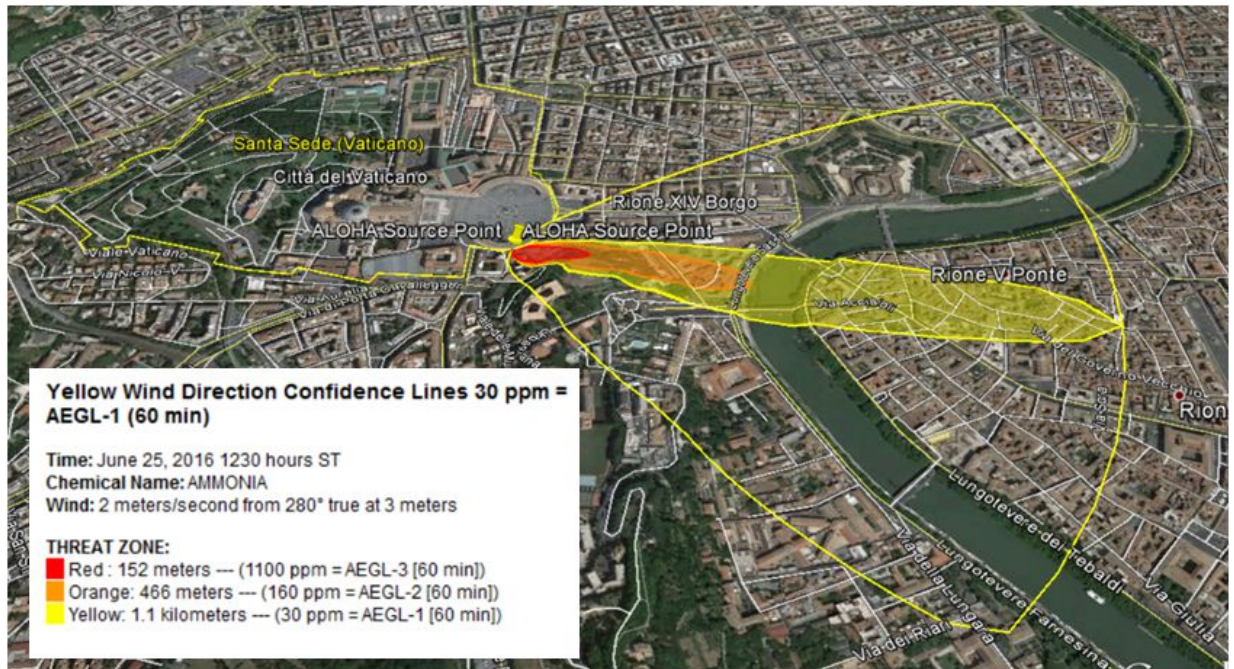


Fig. 28. GOOGLE EARTH – bi-dimensional Toxic Threat zone.

Although a bi-dimensional prediction is a good instrument that shows clearly which are the hazard zones, it doesn't consider the presence of obstacles mostly due to the buildings placed all around the release point.

A more realistic toxic cloud picture can be done using the three-dimensional Google Earth option (Figure 29).

Looking for the three-dimensional representation it is clear how much it is important to consider this obstacles in order to direct our personnel inside the hazard zone as best as possible.



Fig. 29. GOOGLE EARTH – three-dimensional Toxic Threat zone.

2.4. Consequence management action

After the chemical release prediction, it's time to manage a disaster giving all the necessary information to the competent authorities and above all to the responders that are directly involved in the accident.

The first action is to inform the competent authorities about the ammonia release in Paolo VI street that has induced a substance plume. This last has a 280° downwind direction that identifies the most dangerous zone. The authorities must also know that the hazard zone could cover, in an hour, a distance of 1.1 kilometres (AEGL 1) where the most dangerous zone (AEGL 3), in which the general population could experience life-threatening health effects or death, has an extension of 0.152 kilometres from the release point. Although the downwind direction identifies the most severe zone, authorities have to ban to the people to transit or stay in a circle with a radius of 1.1 kilometres and centre in the release point. This is due to avoid a spread of contamination considering every possible wind direction changes.

Immediately, for security reasons, has been established, in agreement with the Vatican Gendarmerie, to transfer by helicopter the Holy Pope to the Castelgandolfo summer residence. At the same time we must send, in Paolo VI street, a specialist's team, which is dressed with all personnel protective equipment (PPE), to eliminate the tank leakage in order to reduce the substance dispersion.

As for guiding first responders as soon as is possible, it may be useful to use the guide ERG 2016 which is a manual that can help us to quickly identify emergency response procedures in order to manage the accidents. It is key to underline first that this guide is useful during the critical first 30 minutes so we don't have much time.

The ERG 2016 is an user-friendly instrument because inside it is possible to find all the information necessary to deal a disaster by means the name or the substance ID number. In our case, using the ID number, we can consult the orange section where it is possible to find information about health effects, fire and explosion conditions, protective clothing, evacuation procedures and first aid actions.

As for dealing with the substance, we must to know first how it could harm people health. Using the ERG 2016 and WISER key info options, we notice that the ammonia is hazardous by all routes (dermal, ingestion, inhalation), in fact, when it is liquid, it is capable of burning the skin, causing permanent eye damage, or corroding the digestive tract upon contact. In addition when it is gas, it can cause severe eye damage, pulmonary edema and even death from spasm, inflammation and edema of the larynx.

So, due to the ammonia contamination, responders, that are involved in the area, must be dressed with personnel protective equipment (PPE). In particular first responders, who operate mostly in the downwind direction, must wear first breathing apparatus (SCBA) and protective clothing composed of butyl rubber, natural rubber, neoprene, nitrile rubber or polyvinyl chloride to prevent skin and eyes contact. This PPE must be Level A, that is the highest level of protection.

At this point we have the plume prediction, we know how much the ammonia could be dangerous and our first responders know which kind of PPE are necessary to manage the disaster. So it's time to evacuate all the people in the area. Although we could consult the evacuation procedure that has reported in the ERG 2016 green section, we can use our enhanced prediction because it is more detailed than the one proposed by ERG. In this last are reported the same first isolate and downwind protective distances that are observed during the detailed plume prediction.

So, thanks to the enhanced prediction, which has been made using ALOHA, we can manage this evacuation in a good way. Looking for the three-dimensional plume representation (Figure 29) it is easy to understand that it is impossible to evacuate people through Conciliazione Street, even if it is the biggest street. In the simulation, indeed, there isn't a direct substance presence covering Conciliazione Street, nevertheless it is very close to the involved area.

As for this, that way could be also contaminated by an ammonia concentration that can probably cause long-lasting adverse health effects or an impaired ability to escape. The health effect could be also lethal considering some software errors prediction and the wind instability in term of direction.

So, we must immediately inform the first responders about the plume direction and dispersion in order to evacuate people in the right direction. In our case it is better to direct the crowd, that it is located in St. Peter Square, through the streets in the left side moving away from St. Peter Square (San Peter Colonnade, Porta Angelica Street, Mascherino Street). The same evacuation procedure has to be followed by the people situated in Conciliazione Street moving through Rusticucci Street, Dell'Erba Street and Traspontina Street. To quickly inform the crowd about this evacuation procedure we decide to use the St. Peter Square's audio system.

In addition, considering the wind direction instability, this people must be transported as far as possible in a safe zone where there are operators, fully equipped and ready to decontaminate all the people. We are talking of about 500.000 persons, so it is key to limit the spread of fear in order to avoid other dangerous situations.

In addition to the evacuation procedure, first responders must to carry out the first aid actions. In particular they must:

- move victims to fresh air if it is possible;
- give artificial respiration device if victim is not breathing;
- do not use mouth to mouth method;
- if victim has ingested or inhaled the substance, give artificial respiration device with the aid of a pocket mask equipped with a one –way valve or other proper respiratory medical device;
- administer oxygen if victim's breathing is difficult;
- remove and isolate contaminated clothing and shoes;
- in case of contact with liquefied gas, thaw frosted parts with lukewarm water;
- keep victim warm and quiet.

Contaminated people must be transported to the safe zone, along the upwind direction and outside the hazard zone, in order to receive decontamination and the necessary medical care.

For sure, talking about ammonia decontamination, the use of water is advisable.

The most important action in order to decontaminate and help the victims are the following:

- remove all clothing and place they in a labeled durable 6-mil polyethylene bag (removal of clothing, at least to the undergarment level, will reduce victim's contamination by 85%).
- If clothes have been exposed to contamination, then care must be taken when undressing to avoid transferring chemical agents to the skin (i.e. any clothing that has to be pulled over your head should be cut off instead of being pulled over).
- If exposure to liquid agent is suspected, cut and remove all clothing and wash skin immediately with soap and water.
- If exposure to vapor only is certain, remove outer clothing and wash exposed skin with soap and water.
- Cover all open wounds with plastic wrap prior to performing head to toe decontamination Particular attention should be made to open wounds because ammonia is readily absorbed through abraded skin.
- Flush the exposed skin and hair with plain water for 2 to 3 minutes then wash twice with mild soap. Rinse thoroughly with water. Be careful not to break the patient/victim's skin during the decontamination process.
- Flush exposed or irritated eyes with plain water or saline for at least 15 minutes by tilting the head to the side, pulling eyelids apart with fingers, and pouring water slowly into eyes. Remove contact lenses if easily removable without additional trauma to the eye. If a corrosive material is suspected or if pain or injury is evident, continue irrigation while transferring the victim to the Support Zone.
- Do not irrigate eyes that have sustained frostbite injury
- Scraping with a wooden stick, i.e. a tongue depressor or popsicle stick, can remove bulk agent.
- If water supplies are limited, and showers are not available, an alternative form of decontamination is to use absorbent powders such as flour, talcum powder, or Fuller's earth.
- Victims should be kept warm and quiet; any activity subsequent to exposure may increase the likelihood

of death.

After the contamination it is necessary to verify if there is already substance presence by means a Gas Detector that detects ammonia gas. If there is still contamination, it is necessary to repeat the previous procedure.

After these decontamination and first medical care actions, if necessary, it is possible to transport the victims from the hospitals.

Another important aspect to deal when the situation is under control, is the first responders decontamination. As for this they must:

- wash PPE using soap and water solution and a soft brush. It is important always to move in a downward motion (from head to toe), to make sure to get into all areas, especially folds in the clothing and to wash and rinse (using cold or warm water) until the contaminant is thoroughly removed;
- remove PPE by rolling downward (from head to toe) and avoid pulling PPE off over the head;
- remove the SCBA after other PPE has been removed;
- place all PPE in labeled durable 6-mil polyethylene bags.

At the end, the regional authority for the environmental protection (ARPA) was involved in order to assess the possible contamination in air and water (Tiber river).

Conducting all these actions in a right way it may be useful in order to reduce the accident magnitude, the spread of contamination and to save a lot of victims involved [3,4].

References

- [1] CDR Lembo Raffaele and Eng. Secchi Alberto Amsicora, 2014; Study of a DSS for the management of CBRNe events in civil and defence scenarios;
- [2] AEGL architecture. Retrieved from: <http://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/resources/acute-exposure-guideline-levels-aegls.html>.
- [3] ERG 2016: Emergency Response guide; U.S. Department of Transportation (Canada).
- [4] Key info Retrieved from WISER software.

1. RADIOLOGICAL SCENARIO: FUKUSHIMA.

1.1. Introduction

Atmospheric plume modelling for Fukushima Dai-ichi nuclear accident posed an extremely complex problem due to the rapidly changing meteorological conditions (e.g., on and off-shore wind directions, precipitation events), Japan's complex topography, and the variety and number of reactor units experiencing problems over an extended time period. During the response period only limited radiological and meteorological data were available, information about the conditions of the reactors were partial. [1]

The pattern of release was complex, both temporally and spatially. Significant release began on 12 March and the rate of release varied considerably over the following week, this was due to particular events, such as hydrogen explosions, venting and leakage from both the reactors and the containment systems. The release was complex, as mentioned above, also spatially because it occurred from different locations (unit 1-3), at dissimilar heights and with quite disparate characteristics because the responses of the emergency systems were different. [2]

This simulation is performed using HotSpot, this algorithm is design to simulate radionuclide release that happens in few hours. The simulation ran with the data from March, 15 because the emission was higher than the ones from the previous days, we need to underline also the role of the rain, that helped to deposit the radionuclide on the Japanese soil.

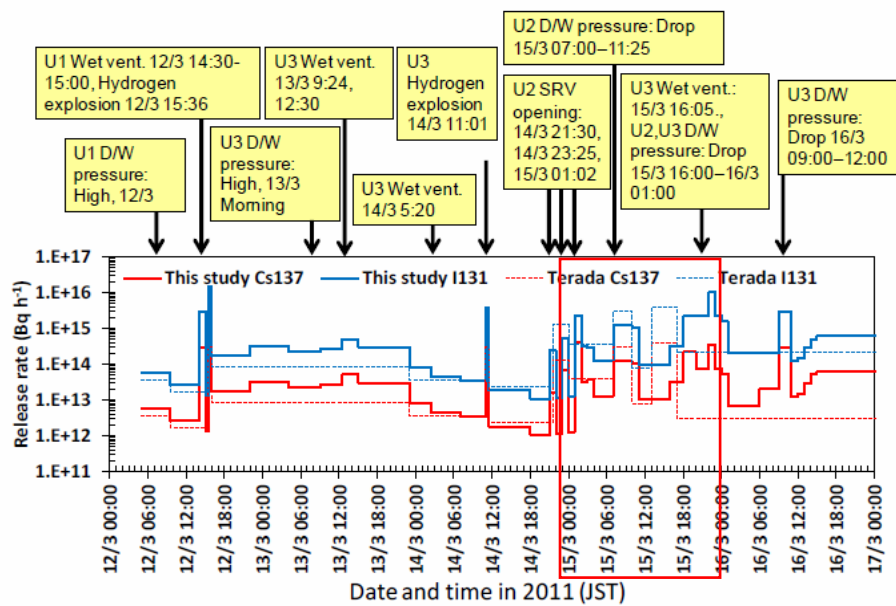


Fig. 1. Temporal changes in release rate of total 131I and 137Cs from 12 March to 17 March 2011 reconstructed in G. Katata et al. (solid lines) and Terada et al. (2012) (dashed lines). The recognized events in the reactors (Prime Minister of Japan and His Cabinet, 2011; TEPCO, 2011) are shown above the figure [3]

Table 1. Emission rates (Bq per hours) from Fukushima Daiichi NPP over the period March 15th 2011 [3]

Release period (Japan standard time)	Release duration (h)	137Cs	Release height (m)
15/3 00:00–15/3 01:00	1	1,3E+12	20
15/3 01:00–15/3 02:00	1	3,8E+14	20
15/3 02:00–15/3 03:00	1	3,1E+13	20
15/3 03:00–15/3 04:00	1	3,6E+13	20
15/3 04:00–15/3 07:00	3	3,9E+13	20
15/3 07:00–15/3 10:00	3	3,6E+14	20
15/3 10:00–15/3 11:00	1	1,0E+14	20
15/3 11:00–15/3 16:00	5	5,0E+13	20
15/3 16:00–15/3 18:00	2	6,6E+13	20–120
15/3 18:00–15/3 20:00	2	4,4E+14	20–120
15/3 20:00–15/3 22:00	2	1,5E+14	20–120
15/3 22:00–15/3 23:00	1	3,3E+14	20–120
15/3 23:00–16/3 00:00	1	7,3E+13	20–120
		2,1E+15 (Bq)	
		total 137Cs release on March 15th	

Data from G. Katata et al., are reported above [3], the table just report the emission rates (Bq per hours) from Fukushima Daiichi NPP on March 15th 2011. The last line shows the total emission of 137Cs (Bq) took place on March 15. This amount has been included in HotSpot as a source term in the simulation of the release of a single day.

We are going to consider meteorological conditions, the group concluded that the radioactive material transported on March 15 was the major contributor to contamination in Fukushima prefecture.

During the major radionuclide emission periods from the accident in 15 March 2011, rainfall events took place over central-eastern Japan. It is well-known that most aerosols and water-soluble gases are washed out by a rainfall. Continual rainfall occurred between 17:00 hours on March 15 and 04:00 hours on March 16 in northern Fukushima. Thus, radionuclides in the air were washed out by the rainfall. Most of the radionuclides were deposited on March 15 in Fukushima.

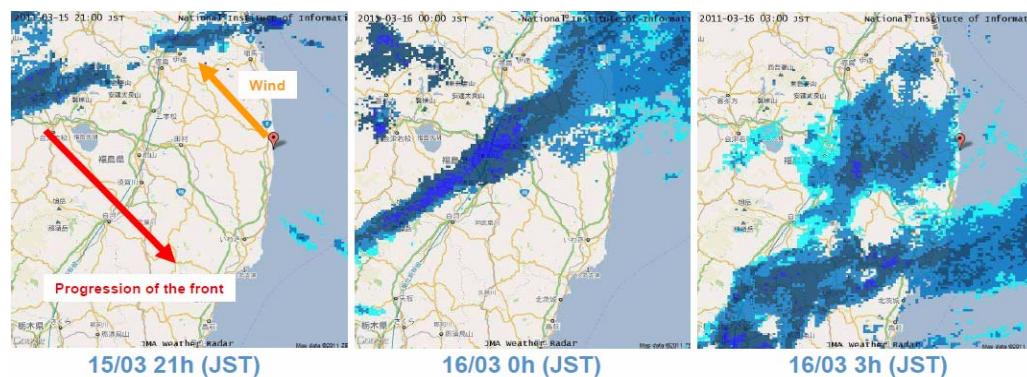


Fig.2. Progression of a rain-snow front between 3/15 & 3/16 towards the nuclear site. At the same time, explosion of reactor unit 2 and radioactive releases occur. [4]

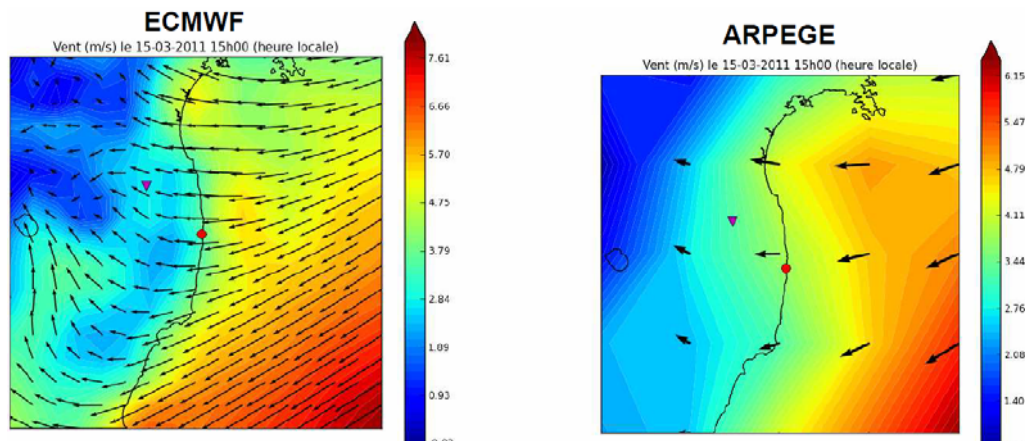


Fig. 3. Wind speed (m/s) 15:00 hours on March 15th [4]

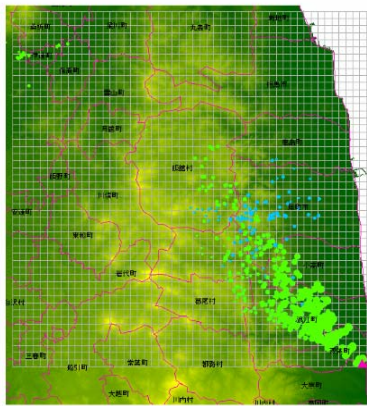


Fig. 4. Radionuclides deposition [5]

The wind direction is shown in the figure above. The South – East direction is evident from this picture by trajectory estimation from wind directions and velocities on March 15. The green circles represent dry deposit, blue circles the wet ones.

1.2. HotSpot Simulation

The HotSpot Health Physics codes were created to provide emergency response personnel and emergency planners with a fast, field-portable set of software tools for evaluating incidents involving radioactive material. The software is also used for safety-analysis of facilities handling nuclear material. HotSpot codes

are a first-order approximation of the radiation effects associated with the atmospheric release of radioactive materials. The HotSpot codes are designed for short-term (less than a few hours) release durations. Users requiring radiological release consequences for release scenarios over a longer time period (e.g., annual wind-rose data) or users requiring more sophisticated modeling capabilities (e.g., complex terrain; multi-location real-time wind field data; etc.), are directed to such capabilities through other types of software.

We choose the General Plume model.

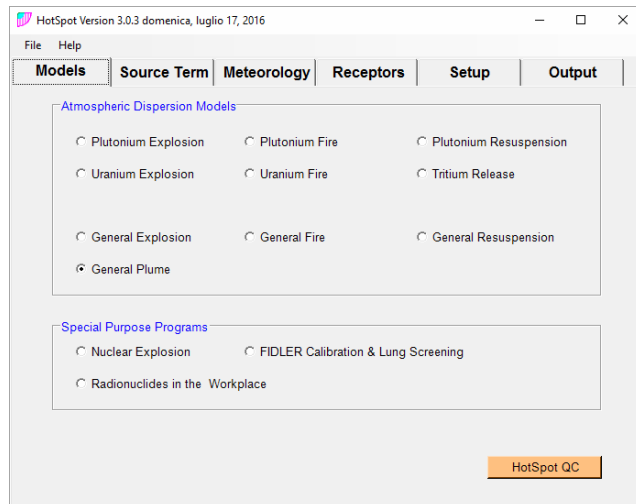


Fig. 5. HotSpot – first view

We implement the simulation with Caesium-137, data inserted in the algorithm were taken from previous figures and tables.

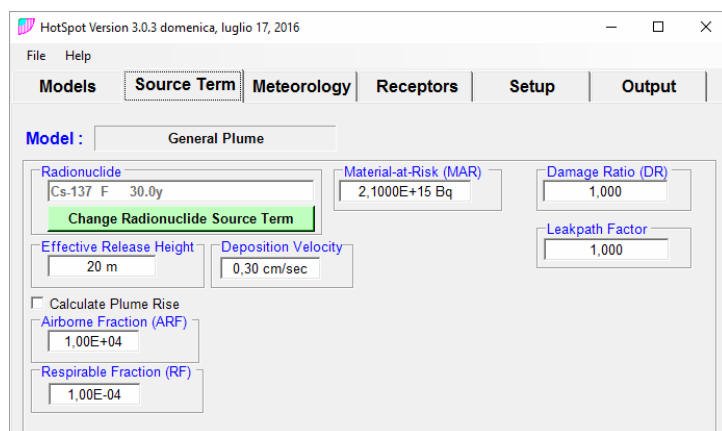
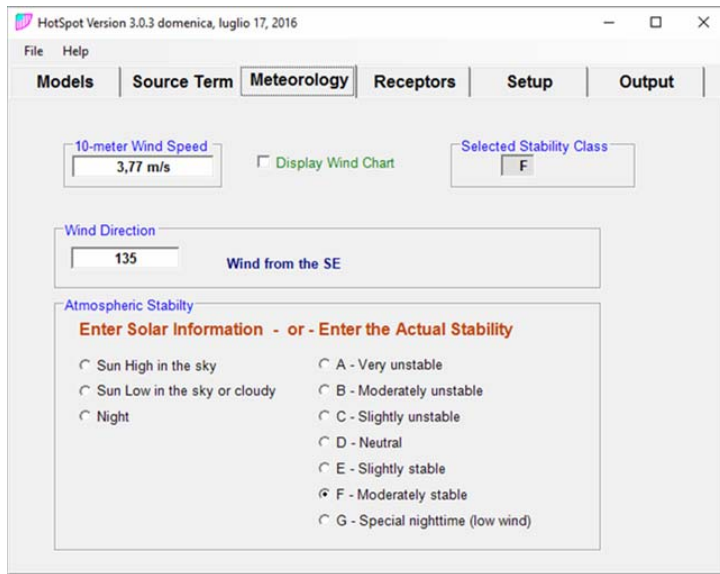


Fig. 6. HotSpot – second view



HotSpot Version 3.0.3 domenica, luglio 17, 2016

File Help

Models | **Source Term** | **Meteorology** | **Receptors** | **Setup** | **Output**

10-meter Wind Speed: 3,77 m/s ☐ Display Wind Chart Selected Stability Class: F

Wind Direction: 135 Wind from the SE

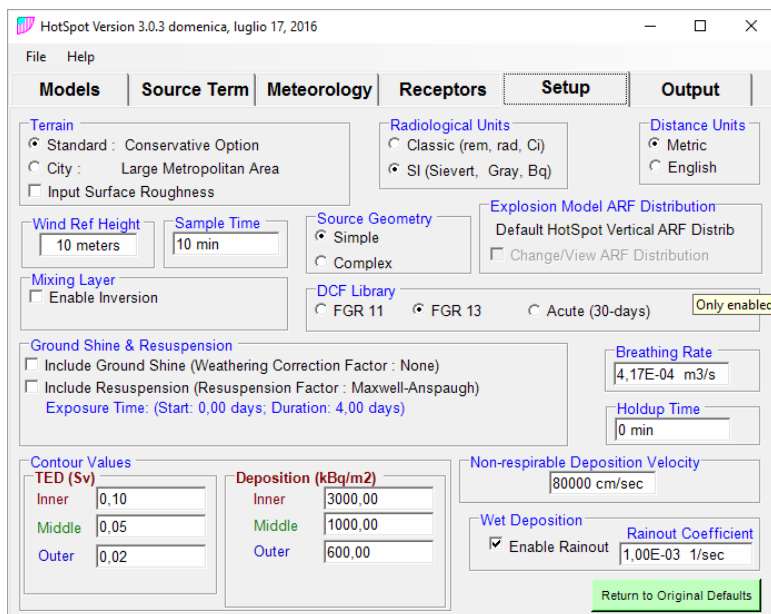
Atmospheric Stability

Enter Solar Information - or - Enter the Actual Stability

☐ Sun High in the sky
☐ Sun Low in the sky or cloudy
☐ Night

☐ A - Very unstable
☐ B - Moderately unstable
☐ C - Slightly unstable
☐ D - Neutral
☐ E - Slightly stable
☒ F - Moderately stable
☐ G - Special nighttime (low wind)

Fig. 7. HotSpot – third view



HotSpot Version 3.0.3 domenica, luglio 17, 2016

File Help

Models | **Source Term** | **Meteorology** | **Receptors** | **Setup** | **Output**

Terrain
☒ Standard : Conservative Option
☐ City : Large Metropolitan Area
☐ Input Surface Roughness

Radiological Units
☐ Classic (rem, rad, Ci)
☒ SI (Sievert, Gray, Bq)

Distance Units
☒ Metric
☐ English

Wind Ref Height: 10 meters Sample Time: 10 min

Source Geometry
☒ Simple
☐ Complex

Explosion Model ARF Distribution
 Default HotSpot Vertical ARF Distrib
☐ Change/View ARF Distribution

DCF Library
☐ FGR 11 ☒ FGR 13 ☐ Acute (30-days) Only enabled

Mixing Layer
☐ Enable Inversion

Ground Shine & Resuspension
☐ Include Ground Shine (Weathering Correction Factor : None)
☐ Include Resuspension (Resuspension Factor : Maxwell-Anspaugh)
 Exposure Time: (Start: 0,00 days; Duration: 4,00 days)

Breathing Rate
 4,17E-04 m3/s

Holdup Time
 0 min

Contour Values

TED (Sv)		Deposition (kBq/m2)	
Inner	0,10	Inner	3000,00
Middle	0,05	Middle	1000,00
Outer	0,02	Outer	600,00

Non-respirable Deposition Velocity
 80000 cm/sec

Wet Deposition
☒ Enable Rainout **Rainout Coefficient**
 1,00E-03 1/sec

[Return to Original Defaults](#)

Fig. 8. HotSpot – fourth view

The output data are shown below.

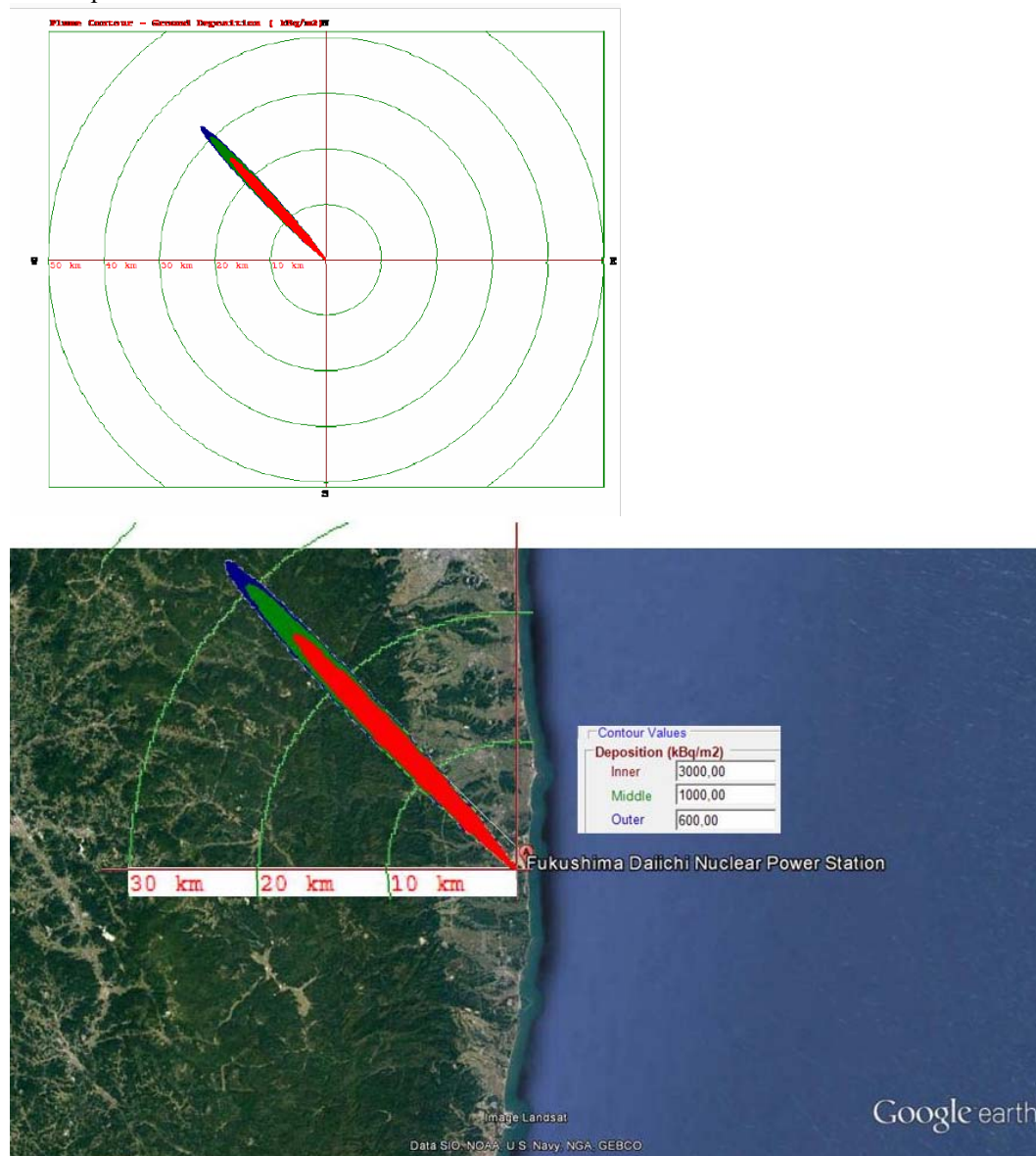


Fig. 9, 10. Ground deposition on the with screen and geolocalized

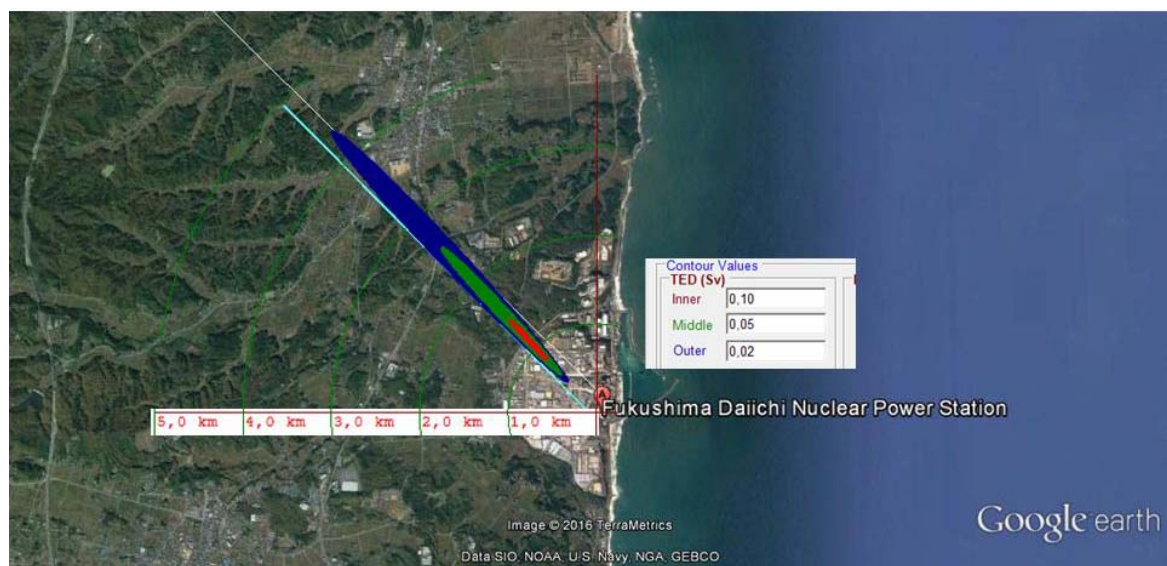
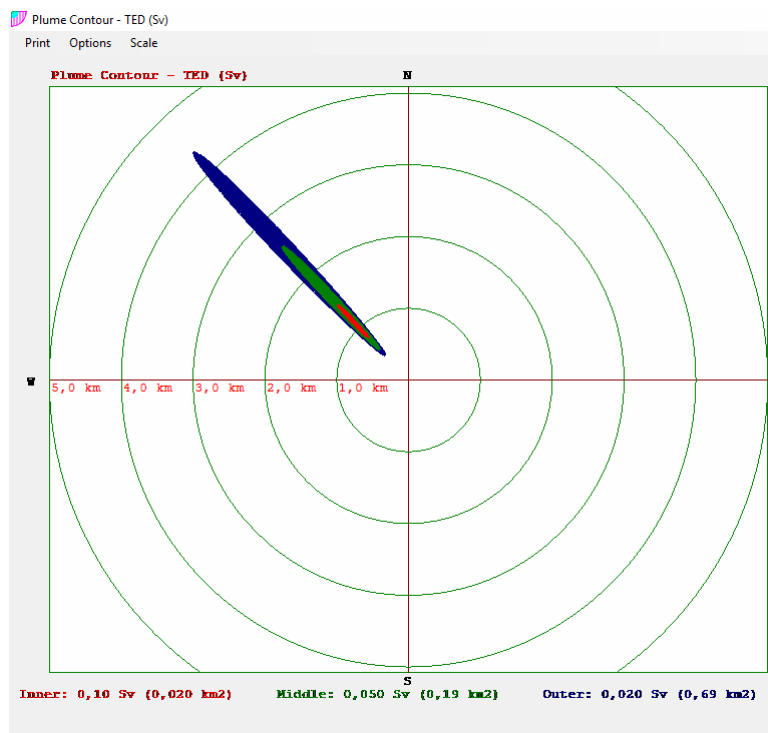


Fig. 11, 12. Total Effective Dose on the with screen and geolocalized

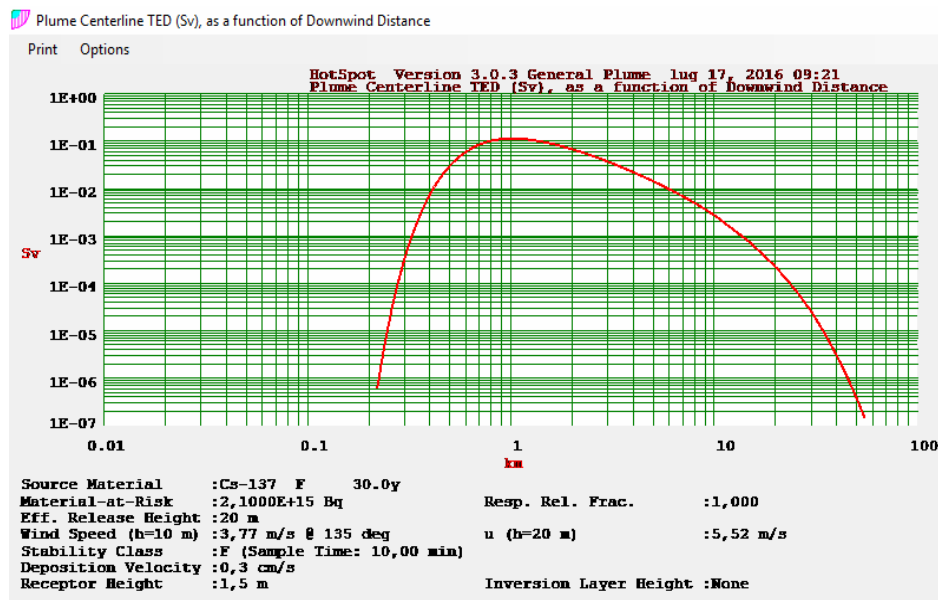
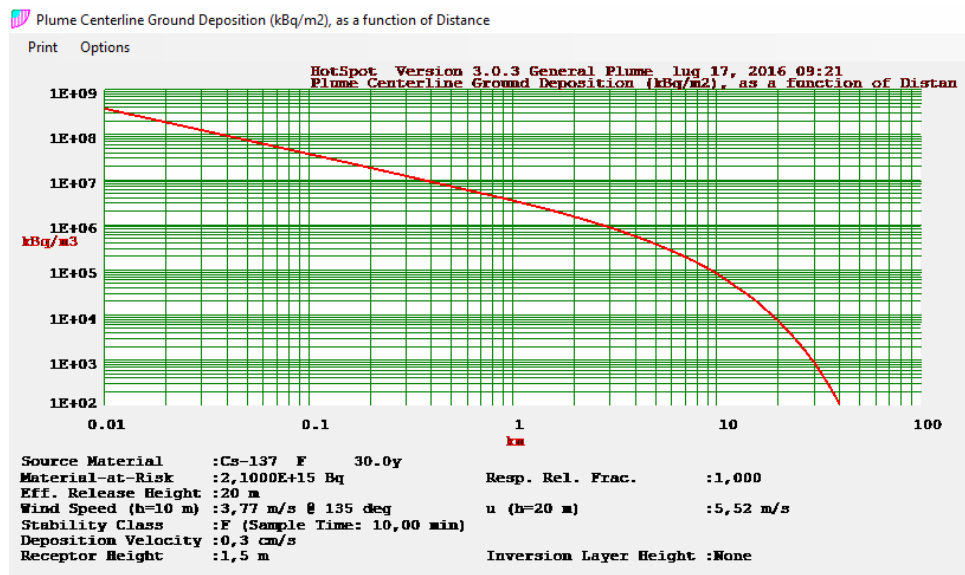


Fig. 13, 14. Ground deposition and TED as a function of distance

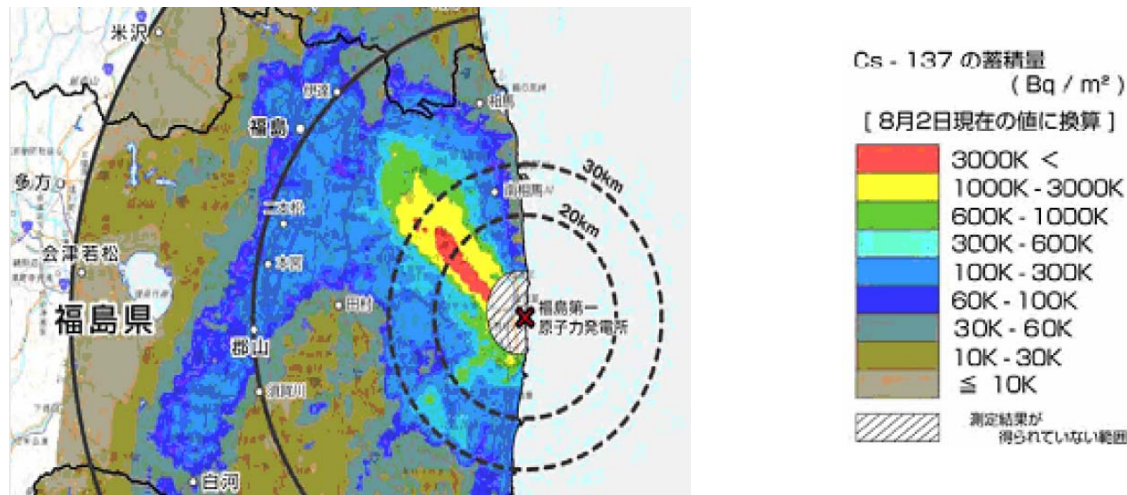


Fig. 15. The dispersion of radionuclides (15 March 2011) described through an aerial view by US-DOE/NSA and MEXT [6]

As is shown by the figure above the simulation ran through HotSpot is similar to the real contamination. Hence, the workgroup can confirm the validation of the algorithm used by HotSpot, for the 15 March of 2011, referring to the boundary condition described above. The simulation has a tight plume if compared with the real one, because, as mentioned before, the wind direction and, in general the weather condition, usually are changing really fast. HotSpot simulation is based on a short time radionuclide release, in real conditions we have a longer release that spread the contamination in wide area.

Finally it should be specified that the HotSpot Total Effective Dose calculated is underestimated. The total effective dose that people would have assumed, indeed, is greater than that shown in the simulation because only the ^{137}Cs has been considered in respect of all radionuclides released and are not inserted in the software source term released from March 12th to March 14th.

1.3. Preparedness of Advisor of Decision Makers

In our opinion advisors need to know basics of radiological and nuclear, including previous events (incidents but also terroristic attacks with orphan sources), the civilian uses of this type of energy (production of electricity but also medical purposes), the agencies and the facilities that use them, the emergency plans.

The “perfect” advisor should know the emergency systems, have the capability to work in team with, for example, team manager, radiological and safety manager, instrumentation specialists, public relations, and persons trained in relevant technical and medical disciplines. At this moment a technical assessment activity of the event goes on in order to better evaluate its evolution and to alert at appropriate levels every organization having a role in preparedness and response arrangements. So, a rapid evaluation of the radiological situation shall be made. This is an essential step because a detailed scenario’s analysis and of its magnitude and consequences ensure the best protective measures to be taken, and preparations of the various personnel and organizations that might be called upon to respond efficiently and to mitigate any consequences for human life and health and the environment. [7]

The DSS’ (decision support systems) help the advisors to support their decision but it’s not a substitute of the advisor. It’s necessary to remarks that dss are based on an algorithm and it can make some mistakes. The advisor needs to avoid these mistakes and his/her knowledge is compulsory to do that. Even some data can

rapidly change, for example the wind direction variate frequently, Fukushima accident is a good example: in this case the advisor needs up-to-date and reliable information in order to make a good decision (i.e. the evacuation of some areas that can be contaminated).

Referring to the accident, as mentioned before the information on the event were not public during the first phase of the emergency, this may be due to two reasons. The former was the Japanese government's lack of an integrated system for crisis management, and above all its weak decision-making mechanisms, including the question of leadership; the latter was its lack of an information-management system within the context of decision making (i.e., a system for sharing information between the site and headquarters, and the methods of processing the data needed for decision making). [8]

The independent investigation commission makes seven recommendations, only six of them were reported, the ones that fit with the role of the advisors and decision makers at different levels (i.e. TEPCO, agencies, national authorities):

1. Monitoring of the nuclear regulatory body by the National Diet (A permanent committee to deal with issues regarding nuclear power must be established in the National Diet in order to supervise the regulators to secure the safety of the public.)

2. Reform the crisis management system (A fundamental reexamination of the crisis management system must be made. The boundaries dividing the responsibilities of the national and local governments and the operators must be made clear.)

3. Government responsibility for public health and welfare (Regarding the responsibility to protect public health, the following must be implemented as soon as possible:

- a. A system must be established to deal with long-term public health effects including stress-related illness. Medical diagnosis and treatment should be covered by state funding. Information should be disclosed with public health and safety as the priority, instead of government convenience. This information must be comprehensive, for use by individual residents to make informed decisions.

- b. Continued monitoring of hotspots and the spread of radioactive contamination must be undertaken to protect communities and the public. Measures to prevent any potential spread should also be implemented.

- c. The government must establish a detailed and transparent program of decontamination and relocation, as well as provide information so that all residents will be knowledgeable about their compensation options.)

4. Monitoring the operators (TEPCO must undergo fundamental corporate changes, including strengthening its governance, working towards building an organizational culture which prioritizes safety, changing its stance on information disclosure, and establishing a system which prioritizes the site. In order to prevent the Federation of Electric Power Companies (FEPC) from being used as a route for negotiating with regulatory agencies, new relationships among the electric power companies must also be established—built on safety issues, mutual supervision and transparency.)

5. Reforming laws related to nuclear energy (Laws concerning nuclear issues must be thoroughly reformed.

- a. Existing laws should be consolidated and rewritten in order to meet global standards of safety, public health and welfare.

- b. The roles for operators and all government agencies involved in emergency response activities must be clearly defined.

- c. Regular monitoring and updates must be implemented, in order to maintain the highest standards and the highest technological levels of the international nuclear community.

- d. New rules must be created that oversee the backfit operations of old reactors, and set criteria to determine whether reactors should be decommissioned.)
6. Develop a system of independent investigation commissions (A system for appointing independent investigation committees, including experts largely from the private sector, must be developed to deal with unresolved issues, including, but not limited to the decommissioning process of reactors, dealing with spent fuel issues, limiting accident effects and decontamination) [9]

1.4. Health Issue

The two important radionuclides emitted (because of the dose) are Caesium-137 and Iodine-131, both beta emitter. The differences between them are the half-life and the target organs. For Cs-137 the half-life is about 30 years and it hasn't target organs, it just delivers a dose to the whole body over many years following the release. The I-131 has a shorter half-life (about 8 days) but it accumulates itself in the thyroid, for this reason it is also known in medicine for radiation therapies (thyroid cancer) and diagnostic scanners.

The doses of these radionuclides are in the ranges of 100 to 500 petabecquerels (10-15 Bq) for the Iodine-131 and 6 to 20 PBq for the Caesium-137. If we compare these data, from UN Committee, with the ones from Chernobyl, the former are significantly lower by a factor of about 10. Wind and water discharges a lot of radioactivity in the Pacific Ocean: the wind direction, in the first phases, was from West to East and the liquid used to refrigerate the reactors was directly released in the sea. The precise movement of radionuclides in the ocean is difficult to assess by measurements alone, but a number of oceanic transport models have been used to estimate the oceanic dispersion. Another important factor for the health issue is that the people were promptly evacuated after the accident: this type of action can be carried out because of direct measurement or using models that can predict the plume, such as hotspot. [2]

HotSpot Table Output - Blocco note

File Modifica Formato Visualizza ?

Exceeds Outer Dose Out To : 4,2 km

FGR-13 Dose Conversion Data - Total Effective Dose (TED)

DISTANCE	T E D	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Bq-sec)/m3	GROUND SURFACE DEPOSITION (kBq/m2)	GROUND SHINE DOSE RATE (Sv/hr)	ARRIVAL TIME (hour:min)
km	(Sv)				
0,030	0,0E+00	0,0E+00	1,3E+08	2,5E-01	<00:01
0,100	0,0E+00	0,0E+00	3,7E+07	7,4E-02	<00:01
0,200	3,4E-08	1,7E+04	1,8E+07	3,7E-02	<00:01
0,300	3,3E-04	1,7E+08	1,2E+07	2,4E-02	<00:01
0,400	7,6E-03	3,9E+09	9,0E+06	1,8E-02	00:01
0,500	3,0E-02	1,5E+10	7,1E+06	1,4E-02	00:01
0,600	6,0E-02	3,0E+10	5,9E+06	1,2E-02	00:01
0,700	8,5E-02	4,3E+10	5,0E+06	1,0E-02	00:02
0,800	1,0E-01	5,2E+10	4,4E+06	8,7E-03	00:02
0,900	1,1E-01	5,8E+10	3,9E+06	7,7E-03	00:02
1,000	1,1E-01	5,8E+10	3,5E+06	6,9E-03	00:03
2,000	6,8E-02	3,4E+10	1,5E+06	3,0E-03	00:06
4,000	2,2E-02	1,1E+10	5,5E+05	1,1E-03	00:12
6,000	9,7E-03	4,9E+09	2,7E+05	5,3E-04	00:18
8,000	5,0E-03	2,5E+09	1,4E+05	2,9E-04	00:24
10,000	2,8E-03	1,4E+09	8,3E+04	1,6E-04	00:30
20,000	2,2E-04	1,1E+08	7,5E+03	1,5E-05	01:00
40,000	3,0E-06	1,5E+06	1,1E+02	2,1E-07	02:00
60,000	5,1E-08	2,6E+04	1,8E+00	3,7E-09	03:01
80,000	1,0E-09	5,1E+02	3,7E-02	7,3E-11	04:01

Fig. 16. Table output of HotSpot simulation

As shown above the total effective dose (TED) do not represent a hazard for the human beings.

For the reasons above radiation was never expected to have any measurable effect on the general population, the UN Committee estimated that no person in Fukushima prefecture would be exposed to more than 10 mSv in their entire life. In the short term, no deterministic health effects due to radiation exposure after the FDNPS accident were observed among members of the public and none are expected in the long term because the doses were far below the threshold values for such effects, as mentioned above.

Is evident that other effects, not related to the radiation, on health (psychological and social) were expected after the earthquake and the subsequent flooding (caused by tsunami). [2]

The main problem with cesium-137, which is present in the form of salts, is its high water solubility. Cesium-137 ions are readily distributed in the body, and especially in the muscle tissues. The biological half-life is 110 days. This means that half of the cesium-137 has been excreted again after 110 days.

Iodine tablets (composed of potassium iodide) are distributed in the vicinity of nuclear power plants so that the iodine reserves in the body will be saturated with stable iodine in the case of a nuclear accident, and thus the subsequent uptake of iodine-131 will be avoided. These tablets should only be taken in the event of an emergency (follow instructions from the local authorities), since the amount of potassium iodide to be used is in the mildly toxic range. Fresh milk products should be avoided as an additional precaution, since milk contains a significant amount of bound iodine, and the cows will have remained in the pasture as the iodine-131 was spreading through the environment.

Ionizing radiations has sufficient energy to strip away electrons from atoms or to break some chemical bonds. This can affect living cells of all tissue of a whole body.

There are three modality of irradiation:

1. External irradiation exposure: radiation is emitted from a source external to the body, radiation penetrates the body and causes a dose of ionizing radiation.
2. Internal contamination: After inhalation, ingestion or absorption in blood stream of radioactive material.
3. External contamination: Radioactive material in form of dust, powder or liquid comes in contact with a person's skin, hair or clothing. Can lead to internal contamination if radioactive material gets into body (e.g. rubbing eyes or eating with contaminated hands)

Cells have the ability to repair damage. If the damage is severe enough they can die (apoptosis or necrosis) or they not die but simple mutated. The mutated cell reproduce and thus perpetuates the mutation, this could be a beginning of a malignant tumor. Sensitivity of the organs correlate with the relative sensitivity of the cells from which they are composed. Blood forming cells were one of the most sensitive cells. Muscle and brain cells were relatively insensitive to radiations. The most sensitive organs are the blood forming organs and the gastrointestinal system. Tissues and organs radiosensitivity are influenced by two factors: radiosensitivity of its cells and importance to overall organism

There are several factors that affects whole body sensitivity: Total Dose, Type of Cell, Type of Radiation, Age of Individual, Stage of Cell Division, Part of Body Exposed, General State of Health, Tissue Volume Exposed, Time Interval over which Dose is Received.

Biological effect of radiation can be stochastic and deterministic:

Stochastic effect: Current thinking is that stochastic effect occurrence follows a linear no-threshold hypothesis. This means that although there is no threshold level for these effects, the risk of an effect occurring increases linearly as the dose increases, but severity harm is independent of the dose. This effect occurs due to the ionizing radiation effect of symmetrical translocations taking place during cell division. Examples of stochastic effects are cancer and hereditary defects such as Down syndrome.

Deterministic effect: only occur once a threshold of exposure has been exceeded. The severity of deterministic effects increases as the dose of exposure increases. They are caused by significant cell damage or death. Examples of deterministic effects are: Skin erythema, cataract, sterility, kidney failure, teratogenesis. Because of an identifiable threshold level, appropriate radiation protection mechanisms and occupational exposure dose limits can be put in place to reduce the likelihood of these effects occurring.

Threshold value may differ in different persons and depends on dose delivery mode: single high dose is most effective; fractionation increases threshold dose in most cases significantly (remarkable differences between acute exposure and chronic exposure); decreasing the dose rate increases threshold in most cases.

Table 3. Signs and Symptoms of Acute Radiation Sickness in the Three Phases after Exposure.*		
Prodrome, According to Exposure Level	Latency†	Illness‡
Mild (1 to 2 Gy) Vomiting; onset, 2 hr	Duration, 21–35 days; lymphocyte count, 800–1500/mm ³	Fatigue, weakness; mortality, 0%
Moderate (2 to 4 Gy) Vomiting, mild headache; onset, 1–2 hr	Duration, 18–35 days; lymphocyte count, 500–800/mm ³	Fever, infections, bleeding, weakness, epilation; mortality, ≤50%
Severe (4 to 6 Gy) Vomiting, mild diarrhea, moderate headache, fever; onset, <1 hr	Duration, 8–18 days; lymphocyte count, 300 to 500/mm ³	High fever, infections, bleeding, epilation; mortality, 20–70%
Very severe (6 to 8 Gy) Vomiting, severe diarrhea, severe headache, high fever, altered consciousness; onset, <30 min	Duration, ≤7 days; lymphocyte count, 100 to 300/mm ³	High fever, diarrhea, vomiting, dizziness, disorientation, hypotension; mortality, 50–100%
Lethal (>8 Gy) Vomiting, severe diarrhea, severe headache, high fever, unconsciousness; onset, <10 min	No latency; lymphocyte count, 0 to 100/mm ³	High fever, diarrhea, unconsciousness; mortality, 100%

* Data are adapted from the International Atomic Energy Agency.²⁰

† Lymphocyte counts in the latency phase represent the range of values that may be seen 3 to 6 days after radiation exposure.

‡ Mortality estimates are for patients who do not receive medical intervention.

Fig. 17. Signs and symptoms of acute radiation sickness in three phases after exposure [10]

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