Simulation of ^{137}CS radioactive contamination due to an accident in a biomass plant for energy production: the importance of Decision Support System (DSS) in the emergency planning

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Abstract: - The proposed work is aimed to demonstrate the capability of the free license code HOT SPOT to simulate a radioactive contamination and its use as possible DSS (Decision Support System) for emergency planning operations. The simulated scenario's consists in an accident to a biomass plant for energy production, where it is assumed for an entire year of energy production the use of biomass combustible , coming from the Chernobyl area (with a high ^{137}Cesium contamination). The Italian area selected for this simulation is situated in Piemonte (north of Italy) because of the high density of biomass plants present. The simulation of the radioactive contamination have been conducted with the code HOT SPOT, a free license code. The results of the simulation and data discussion will be presented in this work by the authors.

Key-Words: - Biomass, Accident, Radioactive, Contamination, Cesium, Energy, Safety, Security, DSS

1 Introduction

Nowadays the Decision Support Systems (like software) to support experts during the emergency planning operations in case of an unconventional events (like a radioactive diffusion) are one of the key safety and security issue of the new millennium. The accidents, (either intentional or natural) that cause a negative impact on environment and human health, are increasing proportionally to the needs of energy of human society. Chernobyl and Fukushima are just two examples of contaminations that have provoked short term and long term negative consequences. The DSS are necessary not only to guarantee the correct chose of safety way out that increase the safety of operators and population in case of accident but also to improve the prevention phase that is essential in an emergency planning system. The work has been developed in the context of the activities of the International Master Courses in Protection Against CBRNe events and realized by experts (the students of the Master) coming from Academic Entities and also from Minister of Interior and Ministry of Defence. According to the high cost of the DSS officially used by these Ministers, the authors decide to test free license tools to demonstrate their functionality in case of emergency. The free license code used in this work is HOT SPOT code, it was used to simulate different type of radioactive accident scenarios and the diffusion of contamination in open field. The authors, after the analysis of a real event: the ^{137}Cs contamination of pellet coming from Lithuania and used in Italy in 2009; decide to simulate a worst scenario. It consists in an accident to a biomass plant from energy production that use combustible taken in the neighborhood of Chernobyl and contaminated with ^{137}Cs because of the radioactive fallout [1-3].The geographical area considered to simulate this scenario has been an industrial area of Piemonte full of biomass plants. The HOT SPOT code has been used to simulate the radioactive diffusion due to an accident. In this paper, the scenario together with the main results of the simulations will be presented, analyzed and discussed to understand the real possibility to use HOT SPOT as DSS during the prevention and/or intervention emergency phases.

2 Problem Formulation

Large parts of north-eastern Europe have been subject to fallout of radioactive nuclides “fallout" after the Chernobyl accident. These radioactive nuclides have been deposited on the ground at concentrations highly variable from area to area depending on the weather conditions and orography [1-3].
Many years after the event, the Cs-137 remains the dominant radionuclide contamination, since it has a very long half-life (30 years) and it is characterized by a high mobility in the environment.
The cesium is "moving" in ecosystems contaminated by passing from an array to another: from the atmosphere to the water and from the water back to the plants, soils, animals, humans. If the radionuclides deposited on the ground, as a consequences of rain events, pass from the surface layers to the deeper ones becomes chemically available for roots uptake by trees. It happened after the nuclear disaster at Chernobyl, cesium has reached the deeper layers of the ground and has been “uptake” from the roots of forest trees thanks to competition mechanisms with the potassium ion, and the roots metabolize it [4].
The degree of contamination is different depending on whether and if the lands are cultivated or not. In farmlands, the continuous mixing causes the cesium homogenous distribution in various ground layers; if the land is not cultivated, the cesium has time to sink from the surface layers to the deep ones. The factors that make the ground a potential source of release are manifold: the composition of the soil in the percentage of clay and organic components, the pH, etc. . . .
Between the ground and the roots is established a balance of trade, maintained by the so-called "ionic labile pool" of ground which serves to provide bio-available elements for the roots.
For those that are its chemical characteristics, the cesium in the ground is available only in a soluble form. It is absorbed by the roots of the plants that, with a delay of a few years, achieve a certain amount of cesium in the wood of trees grown on the contaminated ground.
Because of the long half-life of cesium-137, about 30 years, it is still possible to detect the presence of radioactive material in the timber from areas affected by the Chernobyl disaster.
It has been decided to simulate the consequences of an accident in a biomass plant for energy production using combustible coming from areas situated in the neighborhood of Chernobyl. It has been choose the Italian Region of Piemonte because of its high density of biomass plants (see Figure 1).

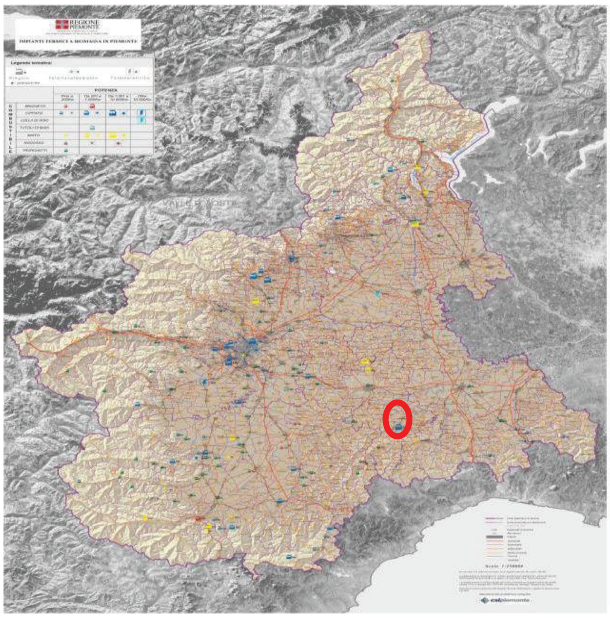

Fig.1. Map of thermic plants in Piemonte. The red box represent the selected point in which the accidents has been simulated

The biomass plant selected for the simulation has an estimated medium annual consume of 3680 m^3 of wood combustible (“cippato”). The plant is active 130 days per year and the estimated daily medium consume of wood combustible is 28 m^3 (almost 8400 Kg considering that a combustible with a medium weight of 300 Kg/m^3 and a humidity of 40%).
The height of emission point of the plant has been estimated at 15 m with a diameter of 60 cm in accordance with the real plants.
The accident scenario simulated are dispersion of ^{137}CS from chimney in different conditions

3 Materials and methods

3.1 HOTSPOT code

The HotSpot Health Physics code and HotSpot code are aimed at providing emergency response personnel and emergency planners with a fast, field-portable set of software tools for evaluating incidents involving radioactive material [5]. The software is also used for safety analysis of facilities handling radioactive materials. HotSpot atmospheric dispersion model codes are a first-order

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approximation of the radiation effects associated with the short-term (less than a few hours) atmospheric release of radioactive materials. In fact they are designed for near-surface releases, short-range (less than 10 km) dispersion, and short-term (less than 24 hours) release duration in unobstructed terrain and simple meteorological conditions. HotSpot codes involving the dispersal of radioactive material use the Gaussian model, since the adequacy of this model for making initial dispersion estimates or worst-case safety analyses has been tested and verified for many years. The HotSpot codes are continuously updated to incorporate the most current and approved radiological dose conversion data and methodologies. This code is based on the well-established Gaussian Plume Model (GPM), widely used for an initial emergency assessment or safety analysis planning of a radionuclide release. Main advantages of the Gaussian plume models are short computation time, extensive validation and broad acceptance worldwide. Virtual source terms are used to model the initial 3D distribution of material associated with an explosive release, fire release, resuspension, or user-input geometry. For evaluation of radiological scenarios, HotSpot uses the methods of radiation dosimetry recommended by the International Commission on Radiological Protection (ICRP) [6] and the US Environmental Protection Agency's (EPA) Federal Guidance Reports No. 11, 12 and 13 [7-9]. In order to simulate different meteorological conditions HOT SPOT allows the selection of the Pasquill classes.

3.1.1 Pasquill Classes used in HOT SPOT

Meteorologists distinguish several states of the local atmosphere: A, B, C, D, E, F. These states can be tabulated as a function of weather conditions, wind speed and time of day. According to the stability class, the attack can result in a wide spectrum of lethal effects. Therefore, the potential terrorist will certainly consider those, just as it happens by war-planners, so that the lethal effects are maximized. The stability of the atmosphere depends on the temperature difference between an air parcel and the air surrounding it. Therefore, different levels of stability may depend on the temperature difference between the air Parcel and the surrounding air. [10-15]

The stability classes used for this work are referred to Pasquill – Gifford stability [10]. Stability classes A, B, and C refer to daytime hours with unstable conditions. Stability D is representative of overcast days or nights with neutral conditions. Stabilities E and F refer to night time, stable conditions and are based on the amount of cloud cover. Thus, classification A represents conditions of the greatest instability, and classification F reflects conditions of the greatest stability.

3.2 BUONDARY CONDITIONS SELECTED

The authors, expert in simulation of unconventional events [16-24], choose the model "General Plume" to simulate the accident that is ideal for the radioactive release from a chimney [17,18,23]. After that the principal boundary conditions has been uploaded in the GUI (Graphical User Interface) of the software (see Figure 2).

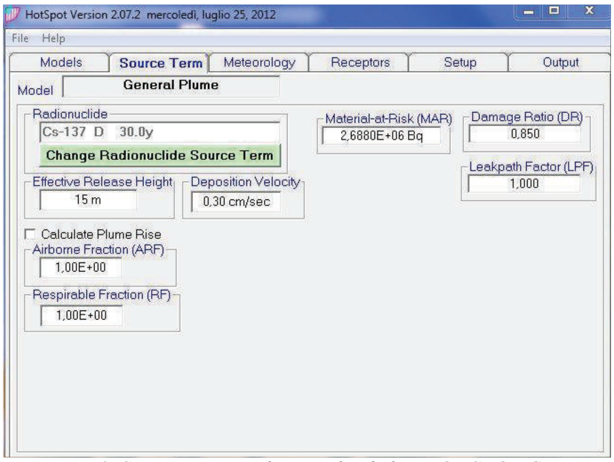

Fig.2. Source term condition uploaded in HOT SPOT GUI

In order to estimate the contamination values of ^{137}Cs in the wood has been considered the data from a sector study of University of Pavia [25]. The maximum level of contamination detected have been 320 Bq/Kg for combustible wood ("cippato") and 40000 Bq/Kg for ashes. The combustion of wood generates 85% of volatile substances, the 14% of carbon and the 1% of ashes so in the simulation the authors consider only the activity of combustible wood as value of contamination. The reality, as reported in [26], the use of ashes is considered the worst for human health, but it is not considered in this work.

The accident scenarios simulated have been two. In table 1 are reported the two different meteorological conditions:

Scenario	*Wind speed (at 15 m)*	*Stability Class*	*Wind Direction*
1	3 m/s	C	225 (from SW)
2	0,5 m/s	D	225 (from SW)

Tab. 1. Meteorological conditions

For both the scenarios, the height of the emission point is 15 meters and the sampling times has been fixed at 30 minutes. The DFC library used is the FGR 11 that allows to include the phenomena of reflection on ground and resuspension of particulate [23]. The value of the mean respiratory flux has been fixed at 3,33 x 10^{-4} m^3/s (as described for a population with a medium intensity activity). The values of TEDE (Total Effective Dose Equivalent) as sum of equivalent dose for each organs in the body (both for external and internal deposition) have been added together with the values of radioactivity on the ground (see Figure 3).

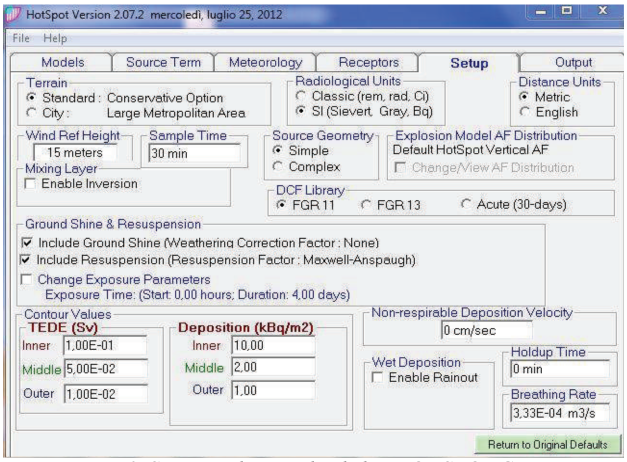

Fig.3. Setup condition uploaded in HOT SPOT GUI

The boundary conditions foresee also three different bands: internal, medium and external, that are graphically represented as three different zones of the plume in the contaminated zone. The TEDE and the ground deposition represent the values of highest interest for an analysis on radioactive particulate contamination. The last boundary condition selected has been the modality "compass" on data output that allows a representation of all the area potentially involved during the contamination in accordance with wind variation [17,18,23].

4 Problem Solution

4.1 Results of Accident Scenario 1

The first result analyzed (figure 4) is the general plume graph (represented in a polar coordinate system with the origin in the release point). It is a picture of the plume at the end of the observation period (30 minutes).

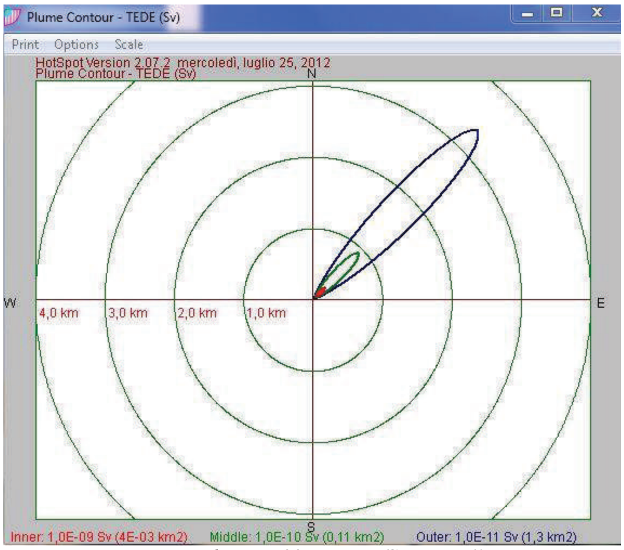

Fig.4. Plume at 30 minutes (Scenario 1)

In the figure 5 it is represented the variation of equivalent dose (in Sievert) with the distance from the release point. The "receptor height" has been fixed at 1,5 meter (the breathable zone of a medium height zone) and so it is evident that the maximum of dose value is calculated at 100 meters from the release point.

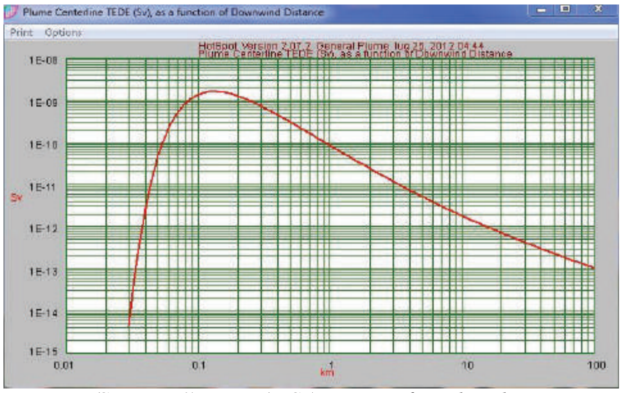

Fig.5. (Scenario 1) TEDE (in Sv) variation from the release point (height of 1,5 meters)

In the figure 6 the variation with the distance of the ground deposition values is showed.

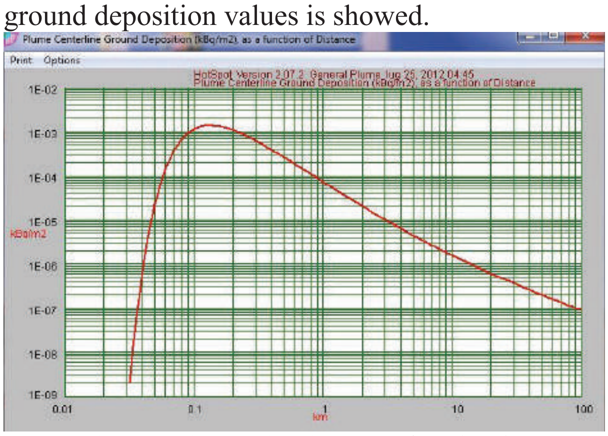

Fig.6. (Scenario 1) TEDE (in Sv) variation from the release point (ground level)

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The table 2 show all the output values from HOT SPOT.

DISTANCE km	T E D E (Sv)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Bq-sec)/m3	GROUND SURFACE DEPOSITION (kBq/m2)	GROUND SHINE DOSE RATE (Sv/hr)	ARRIVAL TIME (hour:min)
0,010	0,0E+00	0,0E+00	0,0E+00	0,0E+00	<00:01
0,030	4,4E-15	1,5E-03	2,2E-10	0,0E+00	<00:01
0,070	5,0E-10	1,5E+02	3,6E-04	7,2E-13	<00:01
0,100	1,4E-09	3,9E+02	1,1E-03	2,2E-12	<00:01
0,200	1,3E-09	3,6E+02	1,1E-03	2,2E-12	00:01
0,300	7,3E-10	2,1E+02	6,2E-04	1,2E-12	00:01
0,400	4,5E-10	1,3E+02	3,9E-04	7,7E-13	00:02
0,500	3,0E-10	8,7E+01	2,6E-04	5,2E-13	00:02
0,600	2,2E-10	6,3E+01	1,9E-04	3,7E-13	00:03
0,700	1,7E-10	4,7E+01	1,4E-04	2,8E-13	00:03
0,800	1,3E-10	3,7E+01	1,1E-04	2,2E-13	00:04
0,900	1,0E-10	3,0E+01	8,9E-05	1,8E-13	00:05
1,000	8,6E-11	2,4E+01	7,3E-05	1,5E-13	00:05
3,000	1,2E-11	3,4E+00	1,0E-05	2,1E-14	00:16
5,000	5,2E-12	1,5E+00	4,4E-06	8,8E-15	00:27
10,000	1,8E-12	5,2E-01	1,5E-06	3,1E-15	00:55
20,000	7,0E-13	2,0E-01	6,0E-07	1,2E-15	01:51
40,000	3,0E-13	8,5E-02	2,6E-07	5,1E-16	03:42
60,000	1,9E-13	5,3E-02	1,6E-07	3,2E-16	05:33
80,000	1,3E-13	3,8E-02	1,2E-07	2,3E-16	07:24

Tab.2. (Scenario 1) Output value from HOT SPOT

4.2 Results of Accident Scenario 2

The Accident Scenario 2 presents a variation in meteorological conditions (the stability class D has been uploaded in this case). It has been selected to analyze variation between 2 stability classes very different. In the figure 7 the general plume is showed.

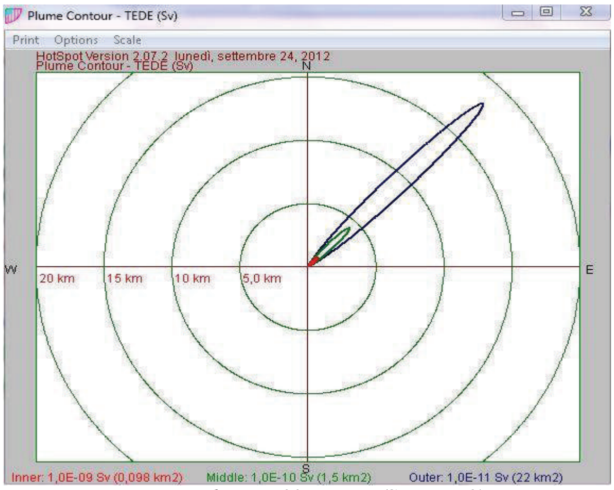

Fig.7. Plume at 30 minutes (Scenario 2)

Moreover, the figure 8 and 9 show, respectively, the ground deposition with a receptor height of 1,5 meters (breathable area) and at ground level.

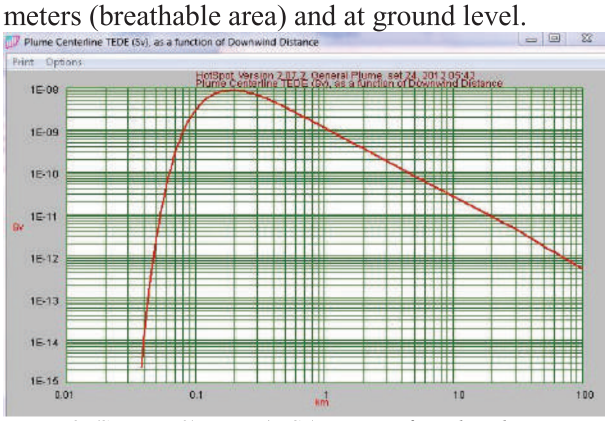

Fig.8. (Scenario 2) TEDE (in Sv) variation from the release point (height of 1,5 meters)

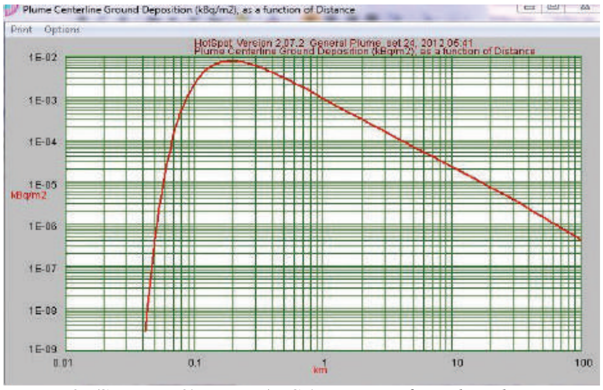

Fig.9. (Scenario 2) TEDE (in Sv) variation from the release point (ground level)

4.3 Results and Analysis

The comparison between the two different scenarios shows that the plume area of Scenario 2 are wider than the one in Scenario 1 and the plume is extended in a larger surface but the contamination values are negligible for this second scenario.

The results of the simulations show that the maximum value of contamination is detected at a distance of 130 meters from the release point (and is 9,61 x 10^{-6} mSv for the Scenario 1). The maximum value of ground contamination is lower than 1 Bq/m^2 (Scenario 1) and 10 Bq/m^2 (Scenario 2).

The figure 10 shows a projection of the possible fallout in case of accident (in the worst scenario in absence of wind). Taking into account the prevalent wind in the considered area, the fallout zone can been delimited by two red lines (see figure 10).

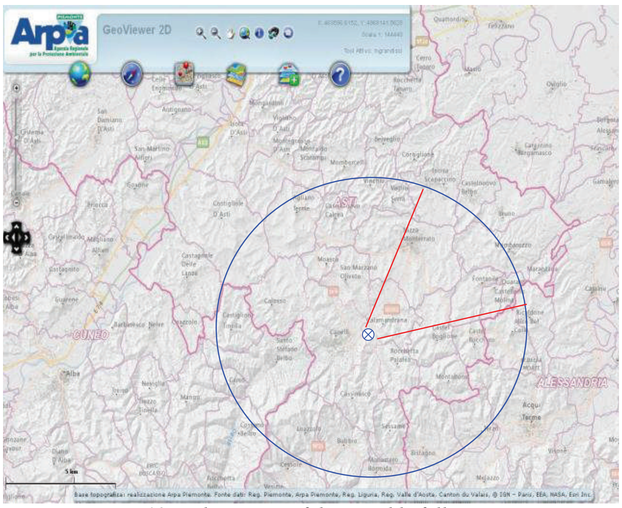

Fig.10. Delimitation of the possible fallout zone

The cumulative dose obtained is $6x10^{-2}$ Sv/year, that is a value lowest than the one imposed by Italian Law [27,28].

5 Conclusion

The simulation of the event and the evolution of the plume was realized through the hotspot software. This software takes into account the weatherconditions, the wind direction, the stack height, respiration, but does not take into account the topography of the area, the presence of buildings and / or obstacles to the advancement of the plume and the presence any updrafts .

In the case that we have examined the area is flat and free of large buildings. Furthermore, the area is near the sea and it is not characterized by abnormal movements of air. According to that, the simulations improved should be closer to the reality. It should be said that the simulations performed with the software do not always consider all the parameters and variables that could affect the evolution of the plume. The authors can affirm that the software can be used as a useful DSS to assist the decision maker, but cannot fully replace it. In case of an accident, however, the real measurements should be carried out to verify the goodness of the simulated data.

Considering an event as the accident described, since the dose values calculated are very low (around an order of magnitude lower than the LAW limit), the approximations and the margin of error due to the simulation should not significantly alter the final results. At the conclusion of this study, we can say, with a good degree of reliability, that scenarios as the one proposed would constitute events without any radiological significance for the population and for the workers.

The Hot Spot code could certainly be used also in the processes of:

- Prevention;
- Risk planning;
- Support the decision-making process during the accidental events.

The future development of this work will be compare the HOT SPOT output with an event with a high magnitude and compare the results.

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