COMPARISON OF SOFTWARE FOR RESCUE OPERATION PLANNING DURING AN ACCIDENT IN A NUCLEAR POWER PLANT

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ABSTRACT

This work has been developed to determine proper analytical support instruments in order to improve emergency operation systems in case of accidents in a nuclear reactor. The case study analysed is in reference to an experimental nuclear fission power plant in Italy (the information about the name and location of this plant has been omitted for safety reasons). The accidental event's consequences were simulated using a free licensed software, HotSpot, and the results obtained were compared with the results obtained using ISPRA Software, the only software certified by the Italian National Institute for Environmental Protection and Research (ISPRA) for nuclear accidents. Once the reliability of HotSpot was established, the most critical incident for this reactor, as indicated by the latest revision of the National Plan on Protective Measures against Nuclear and Radiological Emergencies, was simulated. The simulation results (for areas classified with respect to limits on effective dose) were used as input in the development, through the use of the GeoMedia GIS software, of a vulnerability model that takes into account the spatial distribution of the population in the area affected by the event. In the context of emergency management, such instruments should be integrated with the systems of command & control centres for crisis management and the emergency operation centre (EOC), and made available to the entire chain of emergency management, including the field teams with handheld terminals.

Keywords: *Radiological emergency planning; ISPRA Software; HotSpot; nuclear power plant accident scenario; ground deposition.*

1. INTRODUCTION

Emergency systems planning is extremely important in order to mitigate the effects of a disaster. Proper identification of risks scenarios and information in terms of people and resources involved are fundamental for safety and security reasons (Giaimo, 2000). In addition, the quantification of possible releases of radioactive material and the scheduling of these data are necessary to start actions and countermeasures that are to be taken in order to minimise the impact on the environment and health.

Referring to nuclear emergencies, the Italian Legislative Decree No. 230/95 provides that the Department of Civil Protection (DCP), Prime Minister's Office, sign a National Emergency Plan to deal with emergencies arising from other countries. The same law requires for the prefects in the areas involved to have appropriate action plans, known as External Emergency Plans (EEP) in case of accidents at nuclear facilities in Italy. Internal Emergency Plans (IEP) are intended to identify actions to be taken by officers of the involved accident site, in case of emergency (Bomboni *et al.*, 2007).

The guidelines of DCP for external emergency planning for major accidents and hazards at nuclear installations require the establishment of three zones (Murray, 1993):

i. High impact zone: Immediately near the nuclear power plant, characterised by high lethality level for people.

ii. Damage zone: Characterised by severe and irreversible damage for people who do not take proper measures for self-protection.

iii. Attention zone: Characterised by not serious damage but critical for psychological consequences.

This work has been developed to determine proper analytical support instruments in order to improve emergency operation systems in case of accidents in a nuclear reactor. The case study analysed is in reference to an experimental nuclear fission power plant in Italy (the information about the name and location of this plant has been omitted for safety reasons). The accidental event's consequences were simulated using a free licensed software, HotSpot, and the results obtained were compared with the results obtained using ISPRA Software, the only software certified by the Italian National Institute for Environmental Protection and Research (ISPRA) for nuclear accidents. This study is aimed at determining HotSpot's suitability as a viable alternative for radiological emergency planning by evaluating its ability to produce results that are comparable with ISPRA Software.

2. SOFTWARE EVALUATED

2.1 ISPRA Software

In a nuclear/radiological accident scenario, it is important to have very quick and accurate data on the incident's impact on the surrounding area. This includes quantities such as absorbed dose, external radiation and ground contamination. In light of these considerations, ISPRA Software provides that, at the time of the emergency, the user can select an accidental event previously defined, calculated and graphically developed (incident based), and make changes to the input data in order to have a simulated event comparable with the real event. Once the type of incident has been identified, using the parameters that the system requires, the output is provided in the form of graphs and radioactivity deposition isopleth maps.

The isopleth curves are plotted with reference to a system of axes with the origin coincident with the nuclear installation, the *x*-axis coincident with the direction of the wind, the *y*-axis perpendicular to the *x*-axis, and the *z*-axis coincident with the vertical plane of the nuclear plant. The graphs in the output are used to identify radiometric contamination (Homann, 2009).

2.2 HotSpot

HotSpot, which is available on the website of the National Atmospheric Release Advisory Center (NARAC) (NARAC, 2011), is able to provide quick approximation of the effects of radioactive substance release into the environment. In order to increase the effectiveness of the evaluation of incidents, HotSpot includes atmospheric dispersion models which are differentiated by explosion, fire or resuspension of plutonium, uranium or tritium. The general models are those used for the mix of radionuclides or other radionuclides. These models estimate the radiological impact due to the release of radioactive materials for short time periods (hours). In addition to the atmospheric dispersion models, HotSpot offers three subprograms:

i. Nuclear explosion: To evaluate the consequences of a nuclear explosion.

ii. Field instrument for detection of low-energy radiation (FIDLER): To calibrate instruments for ground-survey measurements of plutonium and provide initial screening for possible plutonium uptake in the lungs. The FIDLER program can also be applied to any instrument suitable for measuring external radiation levels and non-plutonium mixtures.

iii. Radionuclides in the workplace: To evaluate the dose of exposure for workers at risk.

The mathematical model used for the code is a Gaussian type, which is able to reproduce the emission behaviour of a virtual radiological source starting from the appropriate boundary conditions. In order to better assess the radiological effects near the drop zone, the same virtual source is used to model the initial atmospheric distribution of radiation following an accidental event (Homann, 2009). For evaluation of radiological scenarios, HotSpot uses the methods of radiation dosimetry recommended by the International Commission on Radiological Protection (ICRP) (ICRP, 2005) and the US Environmental Protection Agency's (EPA) Federal Guidance Reports No. 11, 12 and 13 (EPA, 1988, 1993, 1999).

3. CASE STUDY

3.1 Simulated Scenario

For the evaluation of the consequences of an accidental event in the reference site, the release of a set of radionuclides from a fireplace is simulated. For this case study, the release will only cover radionuclide I131. In order to analyse this scenario, ISPRA Software incident based system, known as System - C (release from a fireplace), is used, while the HotSpot subroutine that allows this assessment is "General Plume".

3.2 Results

For this study, the two software are compared in terms of the ground deposition. The boundary conditions used to define the case study with HotSpot are as shown in Table 1. The simulation was implemented using T = 240 min as the starting time. A comparison of the results obtained by the software is shown in Table 2, where the elapsed time decreases with distance in order to have a computational time delay that is acceptable.

From the results obtained, it is deduced that the two software are comparable for distance of not exceeding 1 km from the point of release. At distance of 0.2 km, the percentage of variation between the ground deposition values for both software is approximately 25%. This variation decreases with increasing distance until a minimum value of 3% is reached at distance of 0.6 km. Moving from this distance, HotSpot begins to be more conservative than ISPRA Software, providing larger ground deposition values. The variation between the two software increases to 85% at distance of 1 km.

Table 1: Boundary conditions used to define the case study with HotSpot.

Parameter	Value
Source material	I-131 8.04 d
Material at risk	3.7 x 10^{10} Bq
Damage ratio	1,000
Leakpath factor	1,000
Airborne fraction	1,000
Respirable fraction	1,000
Respirable release fraction	1,000
Effective release height	20.00 m
Wind speed (*h*=10 m)	2.00 m/s
Distance coordinates	All distances are on the "Plume Centerline"
Wind speed (*h*=*H-eff*)	2.14 m/s
Stability class	C
Respirable deposition velocity	0.30 cm/s
Non-respirable deposition velocity	0 cm/s
Receptor height	1.5 m
Inversion layer height	None
Sample time	0.010 min
Breathing rate	3.33 x 10^{-4} m^3/sec
Inner contour dose	1.00 x 10^{-7} Sv
Middle contour dose	5.00 x 10^{-8}Sv
Outer contour dose	1.00 x 10^{-8} Sv

Beyond this distance, the two software are not comparable, with the differences being significant, by an order of magnitude at distance of 1.5 km, two orders at 2 km, five orders at 3 km and seven orders at 5 km. This marked difference in response to distances greater than 1 km is justified by the basic settings of the two software. As shown in Figure 1, the trend of ground deposition values generated by ISPRA Software tends to decrease linearly for distance of up to 1 km, after which the values tend to move more quickly to zero.

Table 2: Comparison of ground deposition results obtained using the two software.

Distance from point of release (km)	Elapsed time (min)	Ground deposition (Bq/m^2)		Delta (%)
		ISPRA Software	HotSpot	
0.1	238	$2.12x10^5$	$2.40x10^5$	13.21
0.2	236	$7.42x10^4$	$5.50x10^4$	-25.88
0.3	234	$3.18x10^4$	$2.30x10^4$	-27.67
0.4	232	$1.56x10^4$	$1.30x10^4$	-16.67
0.5	230	$9.02x10^3$	$8.00x10^3$	-11.31
0.6	228	$5.33x10^3$	$5.50x10^3$	3.19
0.7	226	$3.41x10^3$	$4.10x10^3$	20.23
0.8	224	$2.22x10^3$	$3.10x10^3$	39.64
0.9	222	$1.51x10^3$	$2.50x10^3$	65.56
1.0	220	$1.08x10^3$	$2.00x10^3$	85.19
1.5	210	$1.96x10^2$	$9.10x10^3$	-
2.0	200	$5.12x10^1$	$5.30x10^3$	-
3.0	180	$8.41x10^0$	$9.1x10^5$	-
5.0	140	$6.47x10^{-1}$	$9.1x10^6$	-

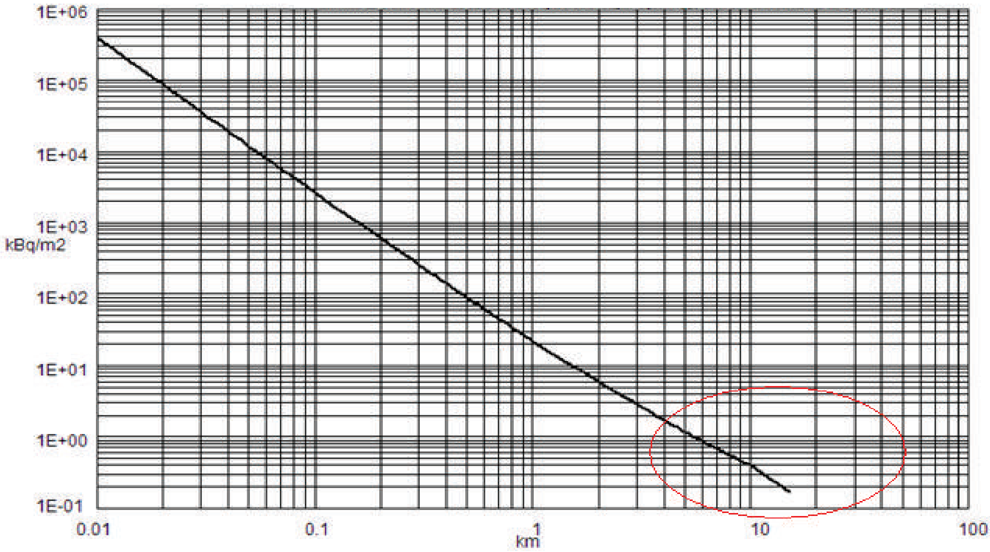

Figure 1: Trend of ground deposition values generated by ISPRA SOFTWARE for the case study.

3.3 Discussion

From the results of the case study, the HotSpot's output is comparable with that of ISPRA Software for distance of up to 1 km from the point of release. Based on this, it can be concluded that HotSpot is a viable alternative to the ISPRA SOFTWARE for radiological emergency planning for the first km, while for larger distances, it is better to use ISPRA Software11.

ISPRA Software was specifically designed to simulate nuclear power plant accident scenarios. Hence, its code was to be modelled based on real scenarios, which are processed by the system. On the other hand, HotSpot uses generic base scenarios, allowing the user to change a wide range of parameters that can have consequences on the evaluation of characteristic variables of the event (Homann, 2009).

In regards to the data in output, a limitation found when using ISPRA SOFTWARE is that there are difficulties in its graphical user interface (GUI). This is certainly a critical factor in emergency management, as the output data from the system is not real, but rather, must be further manipulated to get a picture of the real situation.

Regarding the update of the libraries of the two software, HotSpot's library is constantly updated automatically with the latest X-ray doses and methods of conversion, and these libraries are available on the internet. Updating of ISPRA SOFTWARE libraries needs to be conducted by typing manually from the different sources.

In order to ensure proper implementation of the algorithms, HotSpot automatically launches a review of the software, so that every module is compared with a series of cases in its database to verify the correct functionality. Each default scenario is simulated and its results are compared with the results documented. This ensures that the software is properly installed and that all algorithms are operational.

4. INTEGRATION WITH GEOMEDIA FOR RESPONSE OPTIMISATION

Once HotSpot's simulated scenarios were validated with reference to the current EEP Test Site, the most critical incident for this reactor as defined by the latest revision of National Plan on Protective Measures against Nuclear and Radiological Emergencies (DCP, 2010) is simulated. The results obtained with this simulation are then processed with Intergraph Corp's GeoMedia GIS software, which is used to demarcate territorial zonings of the risks linked to demographic factors, drawing on data accessible via spatial data infrastructure (SDI). This is used to identify a model of vulnerability for the area in question, taking into account the real distribution of the population in the territory.

A further step in ensuring good emergency planning is to provide an update of the data contained in the EEP, which was last revised in the year 2000. Several significant differences were found between the data in the EEP and SDI. The most significant difference is related to demographic data, for which there was an increase in the population at an average rate of 42.5% in the area surrounding the test site for up to a distance of 5 km. In addition, demographic analysis was performed for up to a distance of 10 km from the centre (Figure 2). The road infrastructure network was also analysed to ensure proper identification of the roads to be used for emergencies and proposals for new ones.

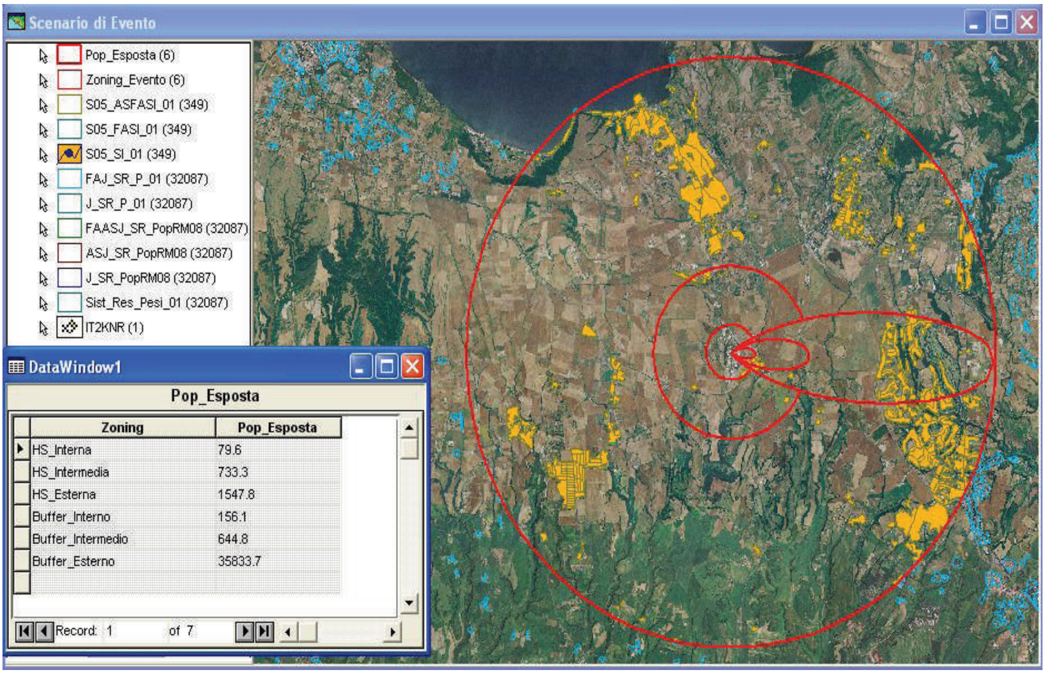

Figure 2: HotSpot analysis results presented on a GeoMedia map.

As shown in Figure 3, using dynamic queries cascade (piping) and the functional attributes of GeoMedia, the calculation of risk zoning is updated near-real-time via the calculation of scenarios using HotSpot with changing meteorological parameters. This update is then automatically propagated to the common operational picture (COP) through GeoMedia's web-services.

With reference to nuclear risks, and the technical apparatus and organisation envisaged by the Italian national regulations, the proposed system can ensure that users have updated, highly interoperable maps. This can allow for increased efficiency in coordinating inter-agency transactions between the control centre (provided by the IEP), DCP and other agencies responsible for emergency management. It also provides the ability to increase situational awareness for the teams in the field with handheld terminals.

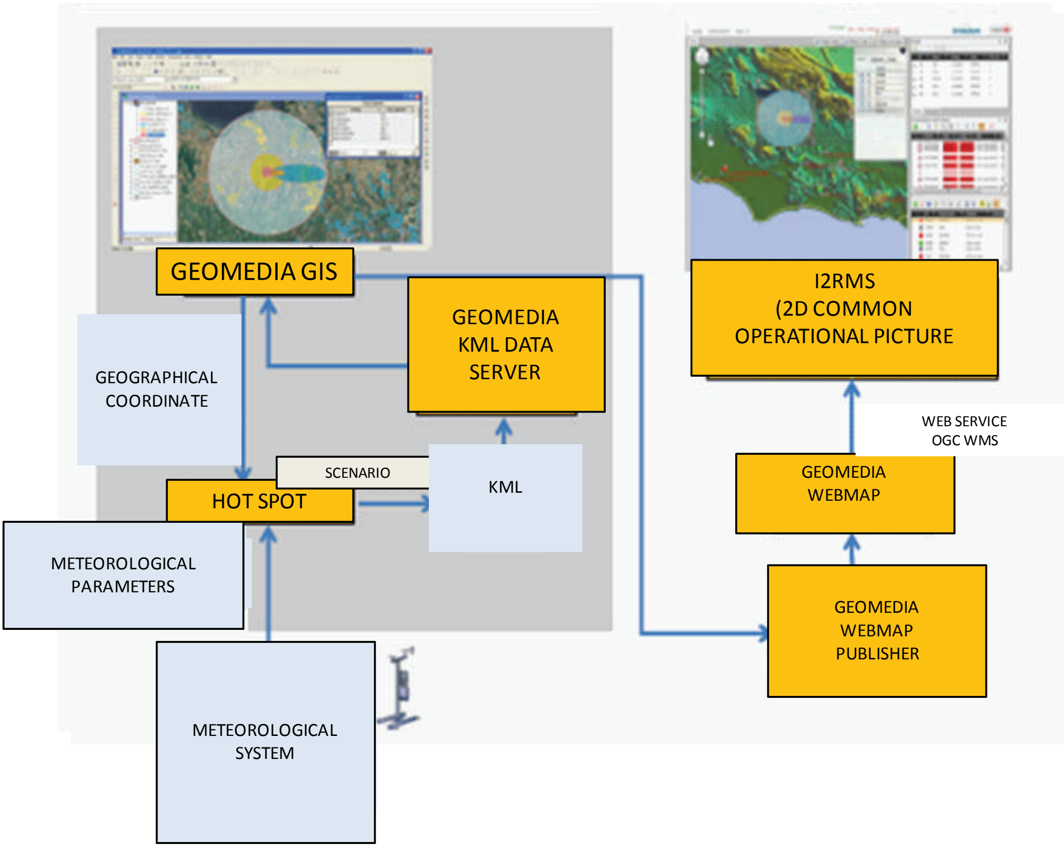

Figure 3: Integration of HotSpot with GeoMedia's geoworkspace for near-real-time calculation of scenarios and risk zoning, and updating to the COP.

5. CONCLUSION

The use of HotSpot as an alternative to ISPRA Software has highlighted a number of advantages such as being "free license", ease of use and wide variety of simulated scenarios. While it has an inaccurate definition of results at large distances in cases of dispersion and ground deposition scenarios, it does provide advantages in terms of a large variety of options for defining a scenario, clear and detailed visualisation of results, updating of radioprotection limits, self-verification of operations, and integration with GIS. Based on this, it can be concluded that HotSpot is a good alternative to ISPRA Software for radiological emergency planning.

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