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EXTENSION TO CHEMICAL PRODUCTS AND BIOAEROSOLS OF THE CERES PLATEFORM USED TO EVALUATE THE ATMOSPHERIQUE DISPERSION AND HUMAN HEALTH CONSEQUENCES OF NOXIOUS ATMOSPHERIQUE RELEASES

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Abstract: The CERES platform is an operational computational tool used by CEA to assess the atmospheric dispersion, the environmental impact and the human health consequences from chemical, biological or radioactive releases. Atmospheric dispersion results have been tested by comparison with experimental data and give satisfactory. New biological and chemical impact modules have been coupled to CERES in order to deal with emergent issues. A future challenge will be to take into account the reactivity of various chemical species which could de released in the air and there interactions with the atmospheric chemistry.

***Key words**: CERES, atmospheric dispersion, impact assessment, radiological, chemical or biological releases.*

INTRODUCTION

The CERES platform is an operational computational tool used by CEA to assess the atmospheric dispersion, the environmental impact and the human health consequences from radioactive accidental or chronic releases. In order to answer emergent issues such as accidental or malevolent releases of chemical products or even the dispersion of bioaerosols, improvements of the CERES platform have been carried out recently. In particular, impact models for toxic chemical and biological agents have been developed and coupled with the atmospheric transport model which has been up-graded. The new version of the dispersion model takes into account the topography using a simple approach consistent with quick response calculations. The paper intends to present some of the major new and future capabilities of the CERES platform.

MAINLY FEATURES OF CERES

The CERES platform is an operational computational tool used by CEA to assess the atmospheric dispersion, the environmental impact and the human health consequences from radioactive and chemical accidental or chronic releases. Atmospheric dispersion is calculated by using a Gaussian puff model, which takes into account radioactive decay, soil and atmospheric boundary layer top reflexions.

In case of a crisis, the main objectives of CERES is to provide, in the first step, atmospheric and dose assessments very quickly then, in second step, improve results by using more realistic and complex input data.

A new graphical user interface coupled with geographic information system (GIS) has been developed. At each step of calculation definition, crisis or expert mode can be used. The crisis mode allows to calculate a case very quickly. For example, a very simple definition of the meteorological situation can be done in crisis mode. One direction and one velocity of the wind and the atmospheric stability are the only necessary data to run a case. In the expert mode, atmospheric evolution can be provided. In this mode, CERES is able to import automatically the meteorological data (forecast or previous data). In crisis mode, impact points are set automatically in wind axis. In expert mode, impact points can be set everywhere graphically, manually with geographic coordinates or chosen in the database.

CERES is able to calculate atmospheric dispersion with a non constant meteorology for one or several releases. It also can take account of a granulometry distribution by using a ponderate deposition velocity. Influence of relief is now taken into account in the CERES dispersion model with a simple scheme according to atmospheric stability as shown in Fig. 21. In stable atmosphere, plume axis is not deflected if the relief is below it. It is deflected by 10 meters if the relief is above. In unstable or neutral atmosphere, plume axis is deflected either half of height release (for a relief below axis) or half of height relief (for a relief above axis).

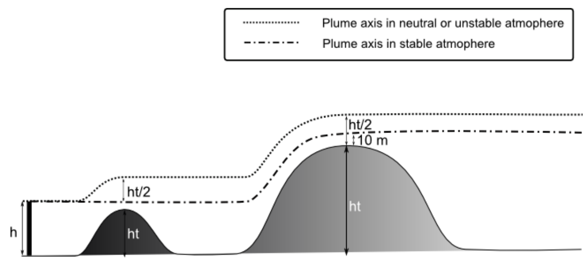
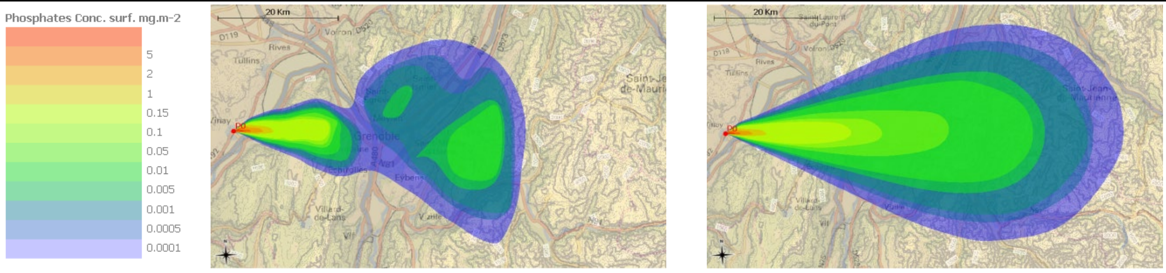


Fig. 21: Modelling of relief influence in the atmospheric dispersion

In order to compare the atmospheric dispersion results with and without relief, calculations have been performed on a hypothetical phosphate release. Atmosphere is supposed to be unstable and the wind direction varies between 250 to 270 ° with a velocity of 3 m.s^{-1}. Five hundred kilograms of phosphate are released during 1 hour. Figure 2 shows the phosphate deposition 5 hours after the beginning of release, with relief (Figure 2a) and without relief (Figure 2b). Plume goes to the first relief where the deposition is the most important. So, its axis is deflected upwards. This leads to lower deposits in the valley of the considered site. The maximum deposition is located near the release and on the reliefs. There is a factor 200 between the deposited concentration calculated taking into account or not the relief of the site.



(a) *(b)*

Fig. 22: Deposition (mg.m^{-2}) of phosphate (a) taking into account relief, (b) without taking into account relief

CHEMICAL MODEL IMPLEMENTED

In order to quickly answer emergent issues such as accidental or malevolent releases of various noxious agents, atmospheric dispersion of chemical products can be computed within CERES as it is carried out for radioactive releases. For each chemical product, the results of atmospheric dispersion are compared with health and environmental thresholds available from various databases like those of US-EPA, ATDSR or OMS… Fig. 23 shows an example of results given by CERES. Atmosphere is considered to be unstable and the wind direction varies between 90 to 110 ° with a velocity of 3 to 5 m.s^{-1}. The release of 2.5 tonnes of ammoniac during 1 hour leads to exceed several thresholds prescribed by the French Ecology ministry (SPEL = threshold of significant lethal effects, SELS = threshold of first lethal effects, SEI = threshold of irreversible effects, SER = threshold of reversible effects) or by the NIOSH (IDLH = Immediately dangerous to Life or Health) and US EPA (AEGL 2 = Acute Exposure Guideline Level).

(a)

(b)

Fig. 23: Health thresholds exceeded for ammoniac release; (a) French Ecology ministry thresholds, (b) NIOSH and US EPA thresholds

BIOLOGICAL MODEL IMPLEMENTED

To extend CERES capabilities to other applications, the situation of bioaerosols has also been considered. During their atmospheric dispersion, the mortality of the biological agents (viruses, bacteria…) is modelled by a decay rate specific to each biological agent (similarly to the radionuclides decay rate). This biological decay rate, denoted "lambda", depends on weather conditions (air temperature, hygrometry and ultraviolet radiation). It has been experimentally determined for a few weather conditions and available in the database of the Biological Impact Modelling Module (BIMM) of CERES. However, the existing experimental data do not cover all the cases which can be met during the simulations. A specific algorithm devoted to the "research for lambda coefficient" was thus developed to identify among the available experimental data the ones which approach the most the value corresponding to a given weather situation. The algorithm makes a calculation of distance in the three-dimensional environment determinated by the triplet (Temperature, Hygrometry and UV). To take into account the relative influence of each of these parameters, a preliminary evaluation of their respective weights is realized from the available data in the database.

A biological impact modelling module has also been developed in order to assess the number of infected people, lethal cases and even the secondary contamination. To calculate the health impact of the biological agents, CERES algorithm uses the NATO data (NATO Handbook, 1996) and is based on a probability distribution. For each biological agent, dose ranges are defined in five categories corresponding to "no effect", "mild dose", "moderate dose", "severe dose" and "very severe dose". Onset of illness and death after the biological exposure and secondary contamination data are also taken in the NATO data. Fig. 24 explains with an example the conceptual framework of the biological impact module. On this figure, the latency range is of 2 days. Symptomatic cases appear from day 2 to day 5 after exposure. If "onset of lethal cases" is of 1 day and "end of lethal cases" of 4 days, people who have symptoms at day 2 will die from day 4 to day 7. People who have symptoms at day 3 will die from day 5 to day 8 and so on until the last day of appearance of symptoms. On the figure, the last symptom cases appear at day 5 thus they will die from day 7 to 10. The "death range`` begin at 4 days until 10 days after the biological exposure. The total lethal cases depend on the quantity inhaled and on a possible treatment. Depending the moment the treatment is taken (before or after the beginning of symptoms), number of lethal cases can also be modified.

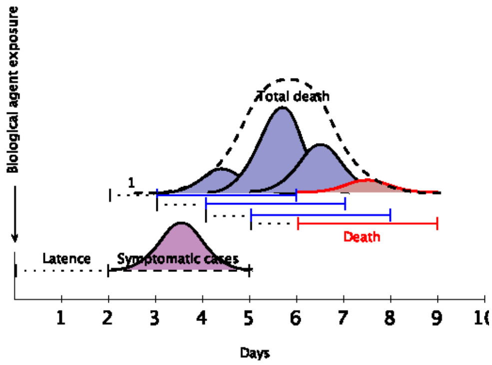


Fig. 24: A conceptual framework of biological impact

Fig. 25 shows the number of spores hypothetically aerosolised from a plane at 60 m height. In this fictitious situation, atmosphere is chosen unstable and the wind direction is 110 ° with a velocity of 5 m.s^{-1}. Release is discretized by several punctual source terms. CERES is also coupled with density population database that leads to know the number of people who could inhalate each quantity of spores.

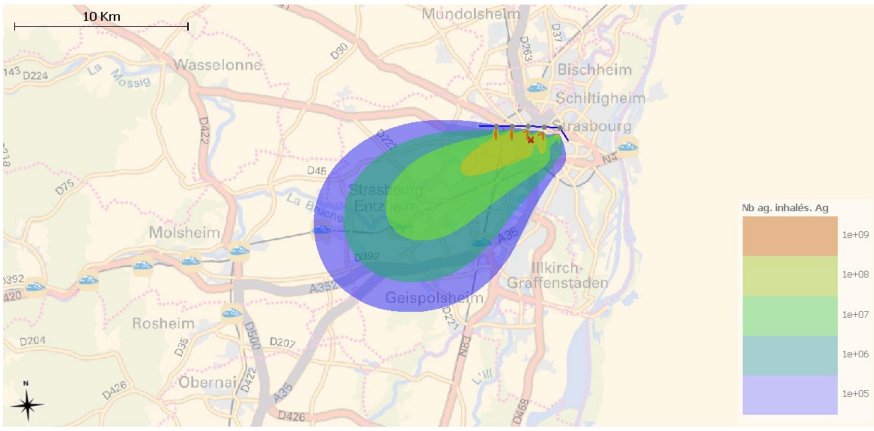


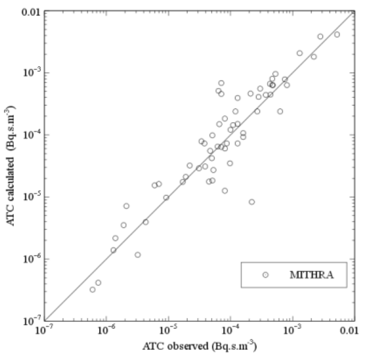
Fig. 25: Number of inhaled spores after a hypothetical release of spores by plane

VALIDATION OF ATMOSPHERIC DISPERSION MODULE OF CERES

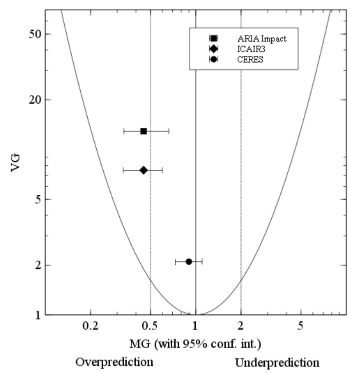
To validate the dispersion model implemented in CERES, some of results have been compared with experimental data. The selected test cases come from various tracing campaigns (Monfort et al., 2001). The results of CERES, ICAIR3 (French model from Institut de Radioprotection et de Sûreté Nucléaire) and ARIA Impact (ARIA technologies society) models have been compared with 62 measurements representing various meteorological situations (from low to high wind speeds and stable to strongly unstable atmospheres). The Atmospheric Transfer Coefficients (ATC) resulting from the measurements have been compared with the ATC calculated by CERES and by two other codes: ICAIR 3 and ARIA Impact (Fig. 26a).

CERES has the best correlation coefficient (0.9) and 71% of the calculated values are within a factor 2 in regard to the measured values. This is a very satisfactory score as CERES is quite a simple model. The geometric mean bias (MG) of 0.9 shows that CERES still tends to overestimate the concentration in air even if the vertical standard deviation have been corrected by a wind factor 1 to 3 depending on the duration of the release (a factor 3 is used for each release of more than one hour).

Fig. 26b represents the dispersion of calculated values by the geometric variance (VG) on the geometric bias (MG). The 95% confidence limits for MG are indicated by thin horizontal bars. Dotted lines represent a plus and minus factor-of-two mean bias for predictions. CERES model fits the experimental results very well even if it slightly overestimates the values and tends to underestimate the concentration in air at short distance, for the releases at elevated location and for stable situations. In the same way, CERES tends to overestimate a little bit the concentration for stable situations.



(a)



(b)

Fig. 26: (a) Comparison between measured and calculated ATC; (b) Geometric variance (VG) according to geometric mean bias (MG) for the CERES, ICAIR3 and ARIA Impact models.

CONCLUSION

The CERES platform is an operational computational tool used by CEA to assess the atmospheric dispersion, the environmental impact and the human health consequences from radioactive accidental or chronic releases. It is composed of an atmospheric dispersion module preceding several impact modules adapted to various kind of noxious C, B or R agents. Atmospheric dispersion results have been tested by comparison with experimental data and give satisfactory. A new graphical user interface with a geographical information system have also been developed in order to have very quick and detailed answers in case of a crisis. New biological and chemical impact modules have been coupled to CERES in order to deal with emergent issues. A future challenge will be to take into account the reactivity of various chemical species which could de released in the air and there interactions with the atmospheric chemistry.

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