

PRESENTATION OF THE CERES PLATFORM USED TO EVALUATE THE CONSEQUENCES OF THE EMISSIONS OF RADIONUCLIDES IN THE ENVIRONMENT

M. Monfort, L. Patryl and P. Armand

CEA, DAM, DIF, F-91297 Arpajon, France

Abstract: The CERES application (*Code d'Évaluations Rapides Environnementales et Sanitaires*) has been developed by CEA. It is used to evaluate the consequences on human health of releases of isotopes in the environment, either for emergency planning or for safety evaluation. Various types of emissions can be simulated: atmospheric accidental emission, atmospheric emission during normal operation or emission in liquid media under normal operation.

Key words: CERES, operational tools, dispersion, radiological impact.

INTRODUCTION

The Radiological and Chemical Impact Laboratory (LIRC) of the French Atomic Energy Commission (CEA) is in charge of the development of modelling tools to evaluate the consequences on human health of releases of radionuclides or toxic chemicals in the environment, for emergency planning and for safety evaluation. In this context, the laboratory has developed the CERES application (*Code d'Évaluations Rapides Environnementales et Sanitaires*), in order that all impact calculations relative to CEA installations will be done using the same tools and methods. This application is used either for emergency situations planning or for the realization of assessment calculations within a regulatory framework, for example in the safety documents relative to nuclear installations. It helps to evaluate either the consequences of accidental situations supposed to occur on installations or the impact of routine releases from single installations or nuclear sites on their near environment.

Several emission situations can be simulated:

1. accidental releases in the atmosphere,
2. routine releases in the atmosphere,
3. routine releases in rivers.

Two versions of the CERES platform are available:

- the first one, called "emergency version" is used in order to evaluate the consequences of the emission of isotopes in the atmosphere during emergency situations. In this version (number 1 above), some options are not available in order to simplify the definition of the parameters used for the evaluation. In addition, many parameters are proposed as default values and can not be modified;
- in the second version, called "expertise version", all the modules can be used and many parameters can be modified, either if most of them are pre defined with default values.

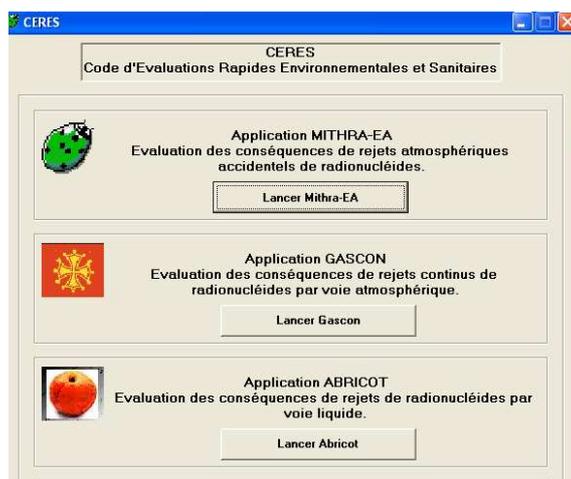


Figure 1. User Interface

DISPERSION CALCULATIONS

Accidental atmospheric releases

For accidental atmospheric releases, atmospheric transport modelling (ATM) is carried out with the Gaussian puff MITHRA model (Monfort, M. 2008). Different standard deviations equations can be used: Doury's formulas (Doury, A., 1987), function of travel time, that is the default option, or standard deviations based on Pasquill's theory: Briggs' (Briggs, G.A., 1973) or Turner's (Turner, D.B., 1964).

Following an accidental release in the atmosphere, MITHRA evaluates instantaneous ($Bq\text{m}^{-3}$) and time integrated activities concentrations ($Bq\text{sm}^{-3}$) for different points and instants defined by the user. Deposits on the ground result from mechanisms of diffusion, impaction and sedimentation and from washing out of puffs during rainy situations. The dry deposition velocity is considered independent of distance from the emission. Quite important rain leads to more significant deposits. The calculation of wet deposition velocity with distance from emission is possible by taking into account the washing out rate. These parameters combined with the diffusion parameters (release height, wind speed, vertical standard deviation) enable to evaluate the depletion coefficients and depositions. For aerosols or vapours, depletion due to dry and wet deposition is calculated. For aerosols, a dry deposition velocity of $5.10^{-3} \text{ ms}^{-1}$ is proposed (Sehmel, G.A, 1980) as default value but can be modified.

A specific module is used to evaluate the atmospheric dispersion of tritium and transformation from HT gas to tritiated water (Belot, Y., M. Roy and H. Métivier, 1996).

The activity emitted from the facility to the environment can be evaluated using the ERASTEM system (Comte N.), that is a box model, taking into account the transfers from the different compartments of the studied reactor (fuel, pool, containment, environment) using ventilation rates, retention, filtration and transfer coefficients.

As MITHRA is a Gaussian puff model, it can take into account releases or meteorological conditions varying with time. Radioactive decay during atmospheric transfer is calculated, using Bateman equations (Bateman, H., 1910). If the release is emitted with high temperature and speed, as it can be the case for significant fires, it is possible to evaluate a plume rise, using Briggs or Holland equations. The effective height is then used as the release emission height.

In the calculations, it is possible to take into account a wind meandering factor. This can be necessary for long duration releases, if meteorological data are not known with great accuracy. Indeed, if the release is quite long, meteorological conditions, especially wind directions, are not constant during release time and observation. The wind meandering factor increases the width of the plume; the concentrations in the wind axis are then lower. If meteorological conditions are well known, it is possible to define meteorological steps, i.e. time intervals during which meteorological data (wind speed and direction, atmospheric stability and rain) are supposed to be constant. In this situation, it is useless to use a wind meandering factor.

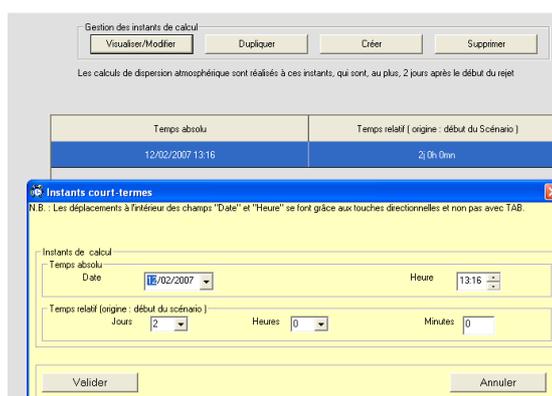


Figure 2. Meteorological Data Definition

Depending on the type of calculation, meteorological data are either observations and then came from the meteorological station located on the site (if release is ongoing, that means diagnostic calculations) or forecasts (in case of emergency situations, when the objectives are to implement the counter-measures before the releases begun) coming for example from MEDICIS system outputs described in (Achim, P., 2010).

Calculations are carried out on a gridded domain and at points defined in the data base relative to the studied site or at points whose coordinates are defined by the user.

Routine atmospheric releases

For atmospheric releases in normal situations (routine emissions), dispersion calculations are carried out with GASCON model (Guétat, P., P. Armand and M. Monfort, 2004), based on the same Gaussian puff model as in MITHRA code describes previously.

To evaluate the impact of atmospheric releases during normal operation of the plant, the meteorological data needed are the observations carried out for one or more years at the meteorological station of the site or nearby.

The variability of the weather conditions throughout the year is taken into account by associating a probability of occurrence at each triplet (wind speed, wind direction and atmospheric stability) and by summing the contribution of each one of these weather conditions to obtain the average atmospheric concentration. Thus, observations are processed statistically. They are distributed by classes of occurrence in 18 sectors of 20° width into normal diffusion associated to dry weather class (unstable atmosphere, important turbulences), normal diffusion with rain class, weak diffusion class (stable atmosphere).

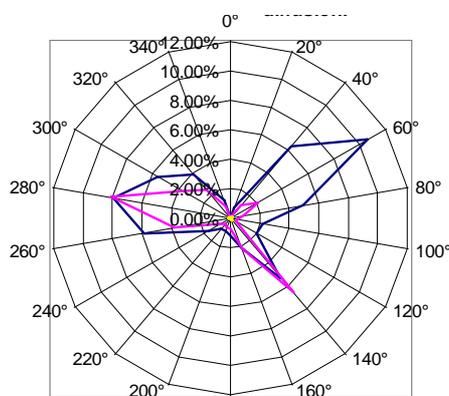


Figure 3. Wind rose

As rain increases atmospheric turbulences, the situation of stable atmosphere with rain is not taken into account because it appears not to be very realistic.

During a single calculation, it is possible to evaluate the global activity concentrations and deposits due to several emissions points.

GASCON provides average activity concentrations (Bqm^{-3}) and dry and wet depositions ($\text{Bqs}^{-1}\text{m}^{-2}$) at different points defined by the user and on a gridded domain.

Routine liquid releases

For normal release in rivers, dispersion calculations are carried with the ABRICOT model (Guétat, P., 2004). A homogeneous and immediate dilution is assumed. The water activity depends on the quantity emitted and on the river flow.

ABRICOT can take into account the fact that the drinking water, the fishing water or the water used to irrigate crops come from groundwater, pond or is used after purification. Coefficients representing dilution phenomena and sedimentation or adsorption on the suspended matter can be used to take into account of contributions of water and sedimentation. These factors depend on the site and the isotopes studied.

If the water used come from groundwater, it is necessary to take into account the retention of the isotopes in the alluvia that involve a transfer time during which radioactive decay occurs. These phenomena are simulated using a distribution coefficient between water and sediments, the distance between the river and the intake point and the water speed in the alluvia.

If releases occur in a pond, the renewal of water is evaluated by considering the relative volume of the pond to its annual throughput exit. The volume activity in the pond is calculated using:

- dilution in the pond, due to rain and sources,
- sedimentation,
- radioactive decay,
- renewal of the water of the pond.

In the case of passage through a sewer, deposits on the suspended matter are taken into account using a distribution coefficient function of the isotope and the mass of suspended matter.

IMPACT ASSESSMENT

Impact evaluations are performed for groups of population. It is possible to take into account the fact that all the food is not locally produced or that people move during their life. It is necessary to define the time percentage spent in different places, the percentages of consumption of products of garden, fruits, and cereals as well as livestock products coming from different locations. The characteristics of various groups can be different but for a given group, these characteristics are identical whatever the age, except for diet habits. These diet habits used in calculations correspond to the food potentially impacted by the releases, i.e locally produced food. All the data (diet habits, crops...) are defined in a data base characteristic of the site but they can be modified for sensitivity studies.

The consequences, expressed in terms of effective dose or dose to the thyroid, including all the exposure pathways described below, are then estimated.

In case of atmospheric emission, the exposure pathways simulated are:

- immersion in the plume, which leads to an internal exposure by inhalation and an external exposure by irradiation,
- presence on the deposits, which leads to an external exposure by irradiation,
- consumption of plants, for which the activity results mainly from the deposits of aerosols and rainfall (direct way) but also from the transfers starting from the ground (root uptake), and which leads to an internal exposure by ingestion,
- consumption of animal products (meat and milk), from animals which have consumed contaminated food.

In case of tritium emission, the exposure ways are slightly different:

- the immersion in the plume leads to an internal exposure by inhalation and skin-passage,
- as the tritium is a pure β transmitter, it does not lead to an external exposure by the deposits; because of the mobility of tritium in the ground, the effect of accumulation in the ground is very weak and is neglected,
- it leads to a contamination by inhalation and by ingestion after transfer through the food chain.

In case of liquid emission, the exposure pathways simulated are:

- inhalation due to activity due to deposits resuspension, due to walk or agricultural work near deposits,
- presence on the deposits, which leads to an external exposure by irradiation,
- ingestion of water,
- ingestion of fishes,
- consumption of plants, for which the activity results mainly from the deposits of aerosols from irrigation but also from the root transfers, and which leads to an internal exposure by ingestion,
- consumption of animal products (meat and milk), from animals which have consumed contaminated food.

Results are available as tables and graphs, giving as an example the contribution of the isotopes or the contribution of the exposure pathways to the dose. The entire hypothesis and the main parameters of the scenario are indicated with the results.

For accidental releases, in the table presenting the results, a colour code indicates whether the intervention levels for radiological emergencies defined by decree (Arrêté du 20/11/2009) (see *Table 1*) are reached for short-term impact (i.e. taking into account irradiation by the plume and the deposits, integrated on maximum 48 hours, and dose due to inhalation).

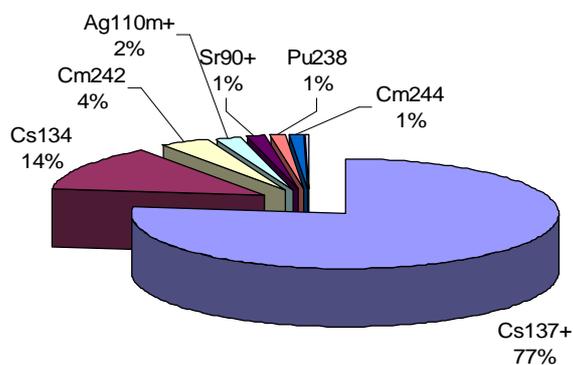


Figure 4. Graph of result

Table 1. Intervention levels for public

Dose	Action of protection
50 mSv – effective dose	Evacuation
10 mSv – effective dose	Sheltering
50 mSv – thyroid dose	Iodine prophylaxis

The paragraphs below describe the assumptions used for the different pathways.

For this evaluation of the external exposure due to the plume passage, evaluated only for atmospheric releases, dose coefficients come from the Federal Guidance Report n°12 (Eckerman, K.F. and J.C. Ryman, 1993). For accidental releases, the dose rate during the plume passage is accessible. The dose coefficients for the external irradiation by the deposits also come from the Federal Guidance Report n°12. For atmospheric releases, internal exposure results from the activity inhaled during the plume passage, without protection for accidental scenarios. Dose coefficients come from the decree of September 1, 2003 (Arrêté du 01/09/2003) or from ICRP publications (ICRP, 1995). The dose to thyroid is presented only for accidental situations when at least one iodine isotope is present in the results.

In accidental situation, the breathing rates correspond to a moderate physical activity. They come from ICRP 66 (ICRP66) and are $1.2 \text{ m}^3\text{h}^{-1}$ for adults, $0.9 \text{ m}^3\text{h}^{-1}$ for 10 years old children and $0.3 \text{ m}^3\text{h}^{-1}$ for 1-2 years old children. For atmospheric normal releases, breathing rates, also coming from ICRP66, were calculated using the volume of air inhaled daily, according to different activities, i.e. integrating periods of awakening (work, leasures) and sleep. They are thus weaker than in accidental situation; they are respectively $0.96 \text{ m}^3\text{h}^{-1}$ for adults, $0.64 \text{ m}^3\text{h}^{-1}$ for 10 years old children and $0.22 \text{ m}^3\text{h}^{-1}$ for 1-2 years old children. For liquid releases, inhalation occurs during work or walk near deposition. Then the breathing rates considered correspond to a moderate physical activity.

Transfer mechanisms of isotopes to the plants, then to animals are used to evaluate doses due to t to ingestion of crops and animal products.

DATABASE - RESULTS

CERES has a database containing the characteristics of about 600 isotopes (dose coefficients, transfer coefficients from soil to plants, from plants to animals...).

Several databases containing environmental characteristics of CEA nuclear sites (installations, height of release, source term, environmental measurements points, met data, diets ...) exist.

Atmospheric results can be visualized on a map, using the MapInfo system. All results are stored in a specific database in order to be used again if need.

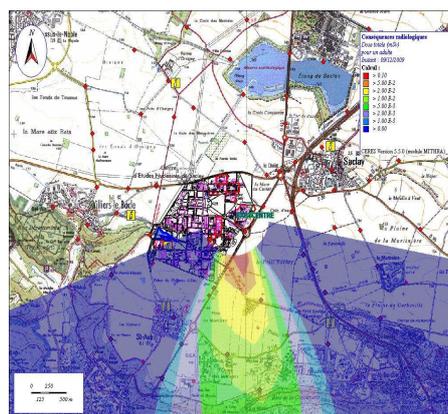


Figure 5. Radiological consequences: total dose (mSv)

VALIDATION OF THE APPLICATION

Results obtained with Doury's parameters have been validated by comparison with experiments of atmospheric tracing. MITHRA atmospheric dispersion results were compared with those obtained by SIROCCO2 assessment code developed by the French Support to Nuclear Safety. According to the assessment results, due to lack of experimental data available, the validation carried out until now only consists of comparison exercises between the results provided by various models. In addition, studies results carried out previously with a plume model were compared to results obtained with MITHRA. The results obtained with the two codes are similar, in particular with regard to short-term calculations. However, in the event of height release, in stable situation, results provided by MITHRA are higher than those provided by the plume model. This difference is due to the well known non accuracy of plume model in these situations (LeGrand, J. and D. Manesse, 1982).

REFERENCES

- Achim, P. 2010: An operational meteorological forecast system at mesoscale for radiological and chemical assessment. HARMO'13, 1-4 June, Paris (France)
- Arrêté du 1^{er} septembre 2003 définissant les modalités de calcul des doses efficaces et des doses équivalentes résultant de l'exposition des personnes aux rayonnements ionisants. Journal Officiel de la République Française.
- Arrêté du 20 novembre 2009 portant homologation de la décision n°2009-DC-0153 de l'Autorité de Sûreté Nucléaire du 18 août 2009 relative aux niveaux d'intervention en situation d'urgence radiologique. Journal Officiel de la République Française du 18 décembre 2009.
- Bateman, H, 1910: Cambridge Philosophical Society, volume 16, page 423.
- Belot, Y., M. Roy, H. Métivier and al, 1996: Le tritium, de l'environnement à l'homme, IPSN, Les éditions de physique, ISBN : 286883-275-X.
- Briggs, G.A., 1973: Diffusion estimation for small estimations. Environmental Research Laboratories, Air Resources Atmosphere Turbulence and Diffusion Laboratory, NOAA, annual report, report ATDL-106.
- Comte, N., L. Bourgois, J.P. Bourion – Organisation et schéma de calcul de conséquences radiologiques en situation accidentelle au CEA de Saclay : logiciel SENTINEL. Technical Document.
- Doury, A. 197: Le vademecum des transferts atmosphériques. Rapport DSN 440.
- Eckerman, K.F. and J.C. Ryman, 1983: External exposure to radionuclides in air, water and soil. Federal Guidance Report 12-EPA 402-R-93-081.
- Guétat, Ph, 2004: Calcul d'impact radiologique d'un rejet liquide en situation normale. Formulaire du logiciel ABRICOT-CEA. Technical Document.
- Guétat, Ph., P. Armand and M. Monfort, 2004: Calcul d'impact radiologique par voie atmosphérique en situation normale. Technical Document.
- ICRP66, 1994: Human respiratory tract model for radiological protection.
- ICRP, 1995: Age-dependant doses to members of the public from intake of radionuclides.
- LeGrand, J. and D. Manesse, 1982: Modèle IPSN pour le calcul simplifié de la dispersion atmosphérique des rejets accidentels. Rapport CEA-R-5170.
- Monfort, M., 2004: Comparaison des résultats du code MITHRA de dispersion atmosphérique avec ceux fournis par le code SIROCCO implanté dans l'application SENTINEL. Technical Document.
- Monfort, M., 2008: Description des modèles de la suite de codes MITHRA-EA destinée à l'évaluation de la dispersion atmosphérique et des conséquences radiologiques de rejets accidentels de radionucléides. Note technique. Technical Document.
- Sehmel, G.A, 1980: Particle and gas dry deposition: a review. *Atm Env* Vol 14, pp 983-1011.
- Turner, D.B., 1964: A diffusion model for an urban area, *J. Appl. Meteorol*, 3,1, 83.