Using the FOCON96 computer program for the analysis of Release Authorization Requests

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1 Introduction

In France, the authorization for releases of gaseous radioactive effluents to a nuclear installation operator is done in accordance with a regulatory procedure, after seeing a file produced by the operator (Release Authorization Request (DAR) and an impact analysis describing the consequences of the requested releases on the public and the environment). The competent departments at the IPSN (Nuclear Protection & Safety Institute) then analyze the impact study, and the IPSN submits a reasoned opinion to the authorities about whether or not the file presented is satisfactory with respect to regulatory constraints, good practices and methodology of estimating the impact.

The releases authorization procedure was modified in 1995, so that many operators need to request a renewal of their authorization. Subsequently, the IPSN was faced with a large number of files to be analyzed (about 15 every year since France has about 150 nuclear installations in service), necessitating to have a methodology of quality for evaluating the impact of gaseous radioactive releases. To be able to handle this workload, the IPSN developed the FOCON96 computer program.

This paper presents the French regulatory context and the FOCON96 program. Thus, it starts with a summary of the regulatory background and describes the authorization procedure, the main outlines of the models used and the calculated indicators, with special emphasis on atmospheric dispersion aspects. The functions and the method of using FOCON96 are then presented, as well as the prospects for foreseeable changes after four years of operation.

2 French legislative and regulatory context

2.1 Legal background

The following paragraphs mention the main legislative and regulatory texts governing a request for authorization of releases by an operator.

The August 2, 1961 law N. 61-482 is the main legislative basis for the release authorization request procedure, in which the operator submits requests for releases for the approval of the public authorities (ministerial decrees).

The June 20 1966 decree N. 66-450 fixes public exposure limits and specifies that exposure of persons and the number of persons exposed to ionizing radiation must be as low as possible, within the limit of the maximum values defined in the regulations.

The May 4 1995 decree N. 95-540 is the regulatory basis for release authorization requests, by making all releases subject to authorization by the Ministries of Health, Industry and Environment. The decree specifies that the request must include the conditions and the composition of the effluents, as well as the consequences on the public and all the compartments of the environment ; deposition of aerosols or dust and transfers by various vectors (particularly the food chains) must be evaluated. The DSIN (Nuclear Installation Safety Directorate) is responsible for investigating the file.

2.2 Release authorization requests: practical aspects

The operator of a basic nuclear installation that will release gaseous radioactive effluents sends his request to the DSIN, which sends it to the Ministries of Health and Civil Safety for an opinion. The request and the corresponding opinions will then be sent to the Prefect of the department in which the effluents will be released. Then, the Prefect consults the competent departments at the Prefecture and initiates a public inquiry on the authorization request, according to methods defined in the law. The Prefect sends the results of his consultations and the public inquiry to the Ministries of Industry and the Environment, with his own opinion.

At the same time, the DSIN asks the IPSN to analyze the release authorization request and the impact study. The competent departments of the IPSN express their opinion on the file, formalized in a summary letter from the IPSN Manager to the DSIN.

3 Analysis of the impact study by the IPSN

The file received by the IPSN is examined considering safety (process aspects; optimization, exhaustiveness and release pathways) and considering radiation protection aspects (impact on health and environment). The following is restricted to radiation protection aspects.

3.1 The file contents

It is essential that effluents to be released should be characterized : indication of the quantity (mass, activity), composition, and the physicochemical forms (gas, aerosol, size grading, chemical form, etc.). In the same way for release conditions: flow, speed, emission period, release height, temperature, pressure.

If the releases occur for determined weather conditions, those should be precised. If this is not the case, a description of representative average annual conditions must be given and particularly: the occurrence of different stable atmospheric states and of wind directions and intensities (including calm winds), and the occurrence of precipitation (form and intensity).

The characterization of the environment must also be included: local soils with their agricultural use, the biotope and vegetation type, agriculture and breeding (nature and importance of production and herds, land occupancy, agricultural practice (open field, greenhouse, spreading, etc.), and economic activities in relation with the food processing production system (transformation and distribution of local production).
Finally, the impact on the public needs the identification of the reference group(s) (population). Information about the demography (age, sex, social-professional category, geographic location) and dose-relevant habit (fraction of the time spent outdoors, place of work, activity type, dwelling type, dietary habits, source of consumed products and local food practices), are necessary.

3.2 The IPSN expertise

An examination of the previous points provides information necessary to evaluate significant transfer pathways, research work done by the operator to achieve the best possible dispersion, whether or not the selected reference groups are relevant and the quality of data (representativeness and traceability).

The IPSN expert examines the calculations carried out by the operator, then make his own calculations (either using the data supplied by the operator, or using his own data if he considers that these data are more relevant or if they were not supplied in the file). The comparison between his results and the results obtained by the operator and with regulatory requirements (public exposure level, possibly product marketing thresholds) manages an opinion about the acceptability of the requested releases. In this context, the IPSN expert calculations are realized with the

FOCON96 program to calculate the dosimetric consequences of gaseous radioactive releases from nuclear installations in normal operation, described below.

4 The FOCON96 program

FOCON96 uses simple models applicable to a large number of cases and with an excellent user interface. These characteristics are necessary to supply reasonable orders of magnitude and enable intensive use.

The dosimetric impact is estimated by chaining three calculation modules to calculate atmospheric dispersion of radioactive elements, transfer of these elements through the biosphere, and the impact on the public.

At the end of the 1980s, the IPSN used the FOCON90 program, which its user interface was not good and the documentation was not complete.

The model was updated in 1996 and a modern and user friendly program, FOCON96, was developed to incorporate methodological innovations related to transfer models through the biosphere, the large number of files subsequent to decree 95-540, and to take account of the European Directive and new ergonomic and Quality Assurance requirements.

Several successive updates about functional or technical modifications were made to take account of operating experience from users and the changeover to the year 2000 (for example to update library data, add new parameters, for the management of data libraries).

4.1 Description of the model

The model is based largely on [1], which one of the main characteristics is the equilibrium. This assumption leads to simplified calculations based on annual averages.

4.1.1 Atmospheric dispersion

Dispersion of a passive pollutant into the atmosphere can be modelised by the changes with time to a puff swept along by wind and turbulent diffusion and expresses by the so-called advection-diffusion equation. Assuming homogeneous wind and diffusion, this equation takes a Gaussian solution expressing the concentration C of contaminant, to the exclusion of any depletion (1):

$$C(rn,x,y,z,t,u,CM) = \frac{Q(rn)}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} . e^{-\frac{1}{2}\left(\frac{(x-ut)^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}+\frac{(z-h)^2}{\sigma_z^2}\right)} \quad (1)$$

Q = release of contaminant at t=0; x = downwind distance from the emission point to the calculation point; y = distance from the centerline of the plume to the calculation point; z = height of the calculation point ; σ_x, σ_y, σ_z = standard deviations of Gaussian distribution; u = wind speed; h = release height; CM = stable atmospheric state, occurrence or not of rain

Under stationary conditions (constant releases), the concentration at a downwind point is calculated by integrating the contribution of the concentrations of each element with an infinitesimal duration producing a quantity of contaminant q(rn,t')dt' (q is then the release flow) at this point. The concentration is then in the following form (2):

$$C(rn,x,y,z,u,CM) = \int_{-\infty}^{+\infty} \frac{q(rn,t')dt'}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} . e^{-\frac{1}{2}\left(\frac{(x-u(t-t'))^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}+\frac{(z-h)^2}{\sigma_z^2}\right)} \quad (2)$$

Therefore, the concentration is proportional to a continuous release flow, with a coefficient named the atmospheric transfer coefficient (CTA), expressed by (3):

$$\mathbf{CTA}(x,y,z,u,CM) = \int_{-\infty}^{+\infty} \frac{dt'}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z}.e^{-\frac{1}{2}\left(\frac{(x-u(t-t'))^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}+\frac{(z-h)^2}{\sigma_z^2}\right)} \quad (3)$$

This gives the following relation (4):

$$C(rn,x,y,z,u,CM) = q(rn)\cdot CTA(x,y,z,u,CM) \quad (4)$$

The Doury model hold by IPSN considers that standard deviations depend on the only transfer time t (t=x/u) of the element between the emission point and the calculation point as follows (5):

$$\sigma_i(t) = (A_i t)^{k_i} \quad (5)$$

A_i and k_i depend on diffusion conditions and the interval of transfer time.

The Doury model considers two atmospheric conditions: normal and low, essentially function of thermal gradient.

During the transfer, the concentration is modified by gravity and impaction (dry deposition), by washing by rain (wet deposition), by reflection on the ground, by reflection on the line of temperature inversion (mixing layer) and radioactive decay.

In the low layers of the atmosphere, gravity and turbulent air-ground and vegetation exchanges cause the dry deposition. The dry deposition rate is modelised with a deposition speed V_{ds}, defined as the ratio of the corresponding flow on the ground to the concentration in air at ground level, and depending on the physicochemical form of the radionuclides and on the characteristics of the ground surface. The depletion by dry deposition App_s (fraction remaining in the plume) is given by the expression (6):

$$App_s(x,u,CM,rn) = e^{\left(-\sqrt{\frac{2}{\pi}}\cdot\frac{V_{ds}(rn)}{\sigma_z}\cdot\int_0^{\frac{x}{u}} e^{\left(-\frac{h^2}{2\sigma_z^2}\right)}dt\right)} \quad (6)$$

Loss of material due to washing by rain is expressed with a washing rate, depending on the rain intensity I as follows: $\Lambda = \mathbf{I.C}$ (C is a constant). This washing rate gives a deposition rate by rain, modelised with a deposition speed V_{dp}. For a constant rain intensity during the transfer, the depletion by wet deposition App_p (fraction remaining in the plume) is as follows (7):

$$App_p(x,u,CM) = e^{-\Lambda(CM)\cdot\frac{x}{u}} \quad (7)$$

By an other way, FOCON96 considers the reflection of the plume on the ground using a multiplicative coefficient of 2, but considers neither the reflection on the line of temperature inversion nor the radioactive decay.

The general formula for the atmospheric concentration is then given by expression (8):

$$C(rn,x,y,z,u,CM) = 2.q(rn)\cdot CTA(x,y,z,u,CM)\cdot App_s(x,u,CM,rn)\cdot App_p(x,u,CM) \quad (8)$$

The dry and wet deposition rates, DD_s and DD_p, are expressed by (9) and (10):

$$DD_s(rn,x,y,u,CM) = V_{ds}(rn)\cdot C(rn,x,y,0,u,CM) \quad (9)$$

$$DD_p(rn,x,y,u,CM) = V_{dp}\left(\frac{x}{u},CM\right)\cdot C(rn,x,y,0,u,CM) \quad (10)$$

where

$$V_{dp}\left(\frac{x}{u},CM\right)=\sqrt{\frac{\pi}{2}}\cdot\Lambda(CM)\cdot\sigma_z\left(\frac{x}{u}\right) \qquad (11)$$

The total deposition rate is the sum of the dry deposition rate and the wet deposition rate.

The release authorization requested by an operator are annual and the population leave on the ground. So, FOCON96 calculates annual average responses on the ground by balancing the associated response to a weather condition and a calculating point by the probability f of the weather condition for the calculating point sector and by holding a constant annual average release rate. The responses are as follows :

- the annual average Atmospheric Transfer Coefficient CTA_m (12) :

$$CTA_m(rn,x,y)=\sum_{u,CM} f(u,CM,x,y)\cdot CTA(x,y,0,u,CM)\cdot App_s(x,u,CM,rn)\cdot App_p(x,u,CM) \quad (12)$$

- the annual average atmospheric concentration c_m (13) :

$$C_m(rn,x,y)=q(rn)\cdot CTA_m(rn,x,y) \qquad (13)$$

- the annual average dry deposition rate DD_{sm} (14) :

$$DD_{sm}(rn,x,y)=V_{ds}(rn)\cdot C_m(rn,x,y) \qquad (14)$$

- the annual average wet deposition rate DD_{pm} (15) :

$$DD_{pm}(rn,x,y)=q(rn).\sum_{u,CM} V_{dp}\left(\frac{x}{u},CM\right)\cdot f(u,CM,x,y)\cdot CTA(x,y,0,u,CM)\cdot App_s(x,u,CM,rn)\cdot App_p(x,u,CM) \quad (15)$$

FOCON96 considers calculating points on a polar grid and weather conditions frequencies for each sector, and takes account of the contribution of adjacent sectors.

The deposition on the ground is calculated during the last year of operation considered for the installation (maximum deposition). It is obtained by integrating deposition rates in dry weather and in rainy weather, with losses by radioactive decay and migration to the ground, over the operating time of the installation.

4.1.2 transfer to the biosphere

FOCON96 evaluates concentrations of radionuclides in the different compartments of the environment: ground, air, plants and animals.

Transfer to plants

Depositions on parts of plants above or on the ground cause transfers to leaves and to roots.

Transfer to leaves: the dry and wet capture ratios represent the fractions of the dry and wet depositions intercepted by parts of the plant above the ground. These fractions decrease by radioactive decay and biomechanical elimination (washing due to rain, action of wind, plant growth). The translocation factor is used to obtain the activity per unit mass of edible parts.

Transfer to roots: deposition on the ground are caused by what was not intercepted by parts of the plant above the ground, washing of parts of the plant above the ground and contaminated crop residues left in the field after the harvest. It is difficult to quantify this deposition since it depends on crop practice and the crop type. The model uses the total deposition calculated for the last year of operation considered, in order to produce a conservative estimate of transfer to roots.

Radionuclides deposited on the ground surface are then considered to be uniform throughout the thickness of the worked ground.
In stationary conditions, the activity per unit mass (taken by roots) is proportional to the activity present in the soil (root transfer factor)
The total activity present in edible parts of plants is the result of contamination by leaf and root pathways.

Transfer to food originating from animals
In stationary conditions, activity per unit mass in food originating from animals (meat, milk) is deduced from the activity incorporated by animals due to the ingestion of plants and contaminated soil, with appropriate transfer factors. The model assumes a fraction of plants ingested by the animal originating from uncontaminated areas and the possibility to store plants before consumption by animals.

Special cases of tritium and carbon 14
Specific transfer of hydrogen and carbon in biological systems enjoin the use of a special model. The activity of tritium and carbon 14 in different compartments of the environment is calculated using the ratio of the concentration of the element in plants and food originating from animals, to the concentration of the element in air.

4.1.3 Dosimetric impact on populations

Dosimetric consequences are effective doses and doses to certain organs (internal), received by an adult.

External exposure to the plume: the corresponding dose is equal to the product of the average activity per unit volume of air and an external plume dose factor, and the annual fraction of the time during which the person is present at the calculation point.

External exposure to the deposition: the corresponding dose is equal to the product of the activity per unit area of the soil and an external deposition dose factor, and the annual fraction of the time during which the person is present at the calculation point.

Internal exposure by inhalation: the corresponding dose is equal to the product of the activity per unit volume of air and a dose factor (effective or to organs) and the adult's breathing rate, and the annual fraction of the time during which the person is present at the calculation point.

Internal exposure by ingestion: the corresponding dose is equal to the product of the different food activity of the diet, the dietary habits, the exogenic fraction and a dose factor (effective or to organs). The model takes account the food ingested by man, which can be fresh ingested during a part of the year and after storage during the other part; more, the variation in contamination due to food processing practices is considered.
The dosimetric impact due to release of all radionuclides on a person is calculated by summing doses associated with all exposure pathways and all radionuclides.

4.2 Functions of the FOCON96 program

The main functions of the program are presented below.

Environment: FOCON96 runs under Windows 95 and NT with a graphic man-machine interface in the form of screens to be filled in, or filled in by the program depending on the case.

Interactivity: FOCON96 is an interactive program; calculations are executed on line.

Forced result: at the end of dispersion and transfer modules, the user has the option of forcing values of calculating responses (measurements results for concentration in air, plants or animal products for example).

Ergonomics: FOCON96 has a modular architecture in which three theoretical modules can be represented. The user can input data to each of the modules. Each module is subdivided in screens which deal with a specific theme (release data, transfer to plants through leaves, internal exposure by inhalation, etc.). Each data, parameter or result is presented with a title and a unit.

Default data libraries and integrity checks: all fields (data, parameters) are filled in with a default value that the user can modify. Default values are stored in libraries and an allowable range is kept for each of them. When a default value is modified, integrity checks are carried out to see if the value is within the allowable range or if incorrect characters are entered (negative sign, letter, etc.), to decide whether or not the calculations can continue.

Data security: the FOCON96 program requires an administrator who is the only person able to access libraries and sources. The administrator can add, delete or modify elements in reference tables (list of elements manipulated by the program, namely radionuclides, plants, animals, food, etc.).

4.3 Software limitations

The software presents implicitly the limitations of the developed dispersion model : homogeneity of the weather conditions on the studied area (rate and direction of wind, weather conditions), and absence of relief. The constant weather conditions is a important approximation too. More, no wake building effect is considered.

FOCON96 only calculates effective doses and for three organs, and only takes account of the adult of the public. In the same way, the habitat protection factor is not a parameter in the models.

Finally, releases are independent of the year, so, FOCON96 doesn't allow easily to realize realistic impact calculation of a site.

Operating experience shows that many comments formulated by users are related to updating values of parameters or factors consecutively to methodological innovations.

4.4 Using the software

FOCON96 has a number of functions that make it a frequently used, user-friendly program that is easy and fast to use. About a hundred calculations are carried out every year using FOCON96, both for Release Authorization Request files and for impact studies. FOCON96 has thus become the main tool used by experts of IPSN.

Considering the present use of the software, its functional limitations and the radiation protection concerns of IPSN, it could be envisaged to build an option to realize impact studies, collective dose calculations and to consider age categories and more organs.

5 Reference

[1] *Methodology for assessing the radiological consequences of routine releases of radionuclides to the environment*, European Commission, Report EUR 15760 EN, 1995