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ACCIDENTAL RELEASES OF RADIONUCLIDES IN WATERWAYS

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Abstract

Radionuclides released in waterways are not simply transported by the water. Other complex phenomena occur : adsorption/desorption to sediments, sedimentation and accumulation on river's bed, interaction with interstitial water, and eventually resuspension in the water column. These processes present various time and lenght scales.

The paper describes the major processes which govern the dynamic contamination of waterways in case of an accidental release, and presents a model which formulates the conservation of water, of sediments, and of radionuclides. This study is necessary to assess the dynamic transfer of radionuclides through aquatic ecosystems to man.

1. Introduction

Reactor risk and reactor safety analysis very seldom consider contamination of surface-water bodies. The main reason is that a few studies indicate that the contamination of surface-water bodies after reactor accident by erosion of atmospherically-deposited radionuclides is not a large contributor to the risk associated with reactor accident (HELTON, MULLER, BAYER, 1985).
However, the possibility of direct releases of contaminated water in reactor accident situation should not be neglected (a possible release mode could be the result of an outflow through a melting hole) : this situation can lead to a very intensive contamination of the surface water, which could require short-term operational counter measures, especially where surface waters are used for the production of drinking water. Contamination of surface waters can also induce contamination of suspended matter and sediments.

It is thus important to develop methods to assess the dynamics of water and sediment contamination in case of accidental release, as drinking water and sediment deposition on land are, in many european countries, one of the significant exposure pathways to man.

2. Modelling radionuclides transport in waterways

Radionuclides released in surface water bodies (lakes, rivers, ...) are not simply transported by the water. Other complex phenomena occur : adsorption/desorption to suspended matter, sedimentation of suspended matter, accumulation on river's bed, and eventually resuspension of sediments (and thus also of radionuclides) in the water column.

The behaviour of radionuclides in surface waters cannot thus be described without a preliminary knowledge of the water and sediment transport.

A deterministic, one-dimensionnal non-stationnay model, which formulates in a simple way the conservation of water, of sediments, and of radionuclides in rivers has been developped (SMITZ, EVERBECQ, FRERE, 1985). This model is organized in 3 steps.

Step 1 : the hydraulic and hydrodynamic submodel.
This submodel integrates the set of data describing the physical geometry of the river (width, slope of the bed, slope of the banks, location of docks and dams, ...), and eventually the constraints imposed to the river flow (water levels for navigation, ...); this hydrodynamic submodel calculates, at each point and each time, the hydrodynamic variables : river flow, depth, cross-section area, velocity, bottom stress, ... (cross-section averaged values).
The input data are the river flow measurements at one or several stations.

Step 2 : the sediment submodel.
The adsorption/desorption interaction of radionuclides between water and sediment particles is highly dependent on the physical characteristics of the sediment : radionuclides are strongly adsorbed to small particles (clay and silt), and very few to large particles (sand). Hydrodynamic processes of sedimentation/resuspension are also influenced by the grain size : small particles fall slowly, and easily remain in suspension.
It is thus necessary, for both hydrodynamic and radiologic arguments, to consider various grain size classes of particles.
To be able to describe the sedimentation/resuspension process, it is also necessary to consider 2 compartments (for each class of particles) : the suspended matter (g/m3), and the bottom sediment (g/m2).
In the sediment submodel developped, the sedimentation flux is considered to be proportionnal to the difference between the bed shear stress and a critical deposition shear stress (with one critical deposition shear stress per class of particles); the resuspension flux is considered to be proportionnal to the difference between the bed shear stress and a critical resuspension shear stress (with one critical shear stress per class of particles). Parameter values adopted for settling velocities, critical sedimentation shear stresses, critical erosion shear stresses, ... are typical values given in the litterature.
The source of sediments in the system is the supply of sediments by the tributaries, as the result of the global erosion process of the basin; this input of sediments is assessed by statistical relations based on fields maesurements.

Step 3 : the radionuclide submodel.
The radionuclides submodel developped describes the activity of radionuclides in water (Bq/m3), in suspended matter (Bq/g), and in the bottom sediments (Bq/g). As the radionuclides adsorb preferably to small particles, it is necessary to calculate the activity in each class of particles.
Radionuclides adsorbed to solid particles are considered to follow the particle motion : transport, sedimentation, or resuspension; the global interaction water/sediment is considered to be the sum of the adsortion/desorption processes between the water and each class of particles. The model developped is a multi-classes model (N classes, where N is variable), and can be considered as a development (non-stationnary, distributed, sediment-included) of the model used to assess the radiological exposure of the population in the Meuse basin (BAYER, 1982; CEE, 1986)

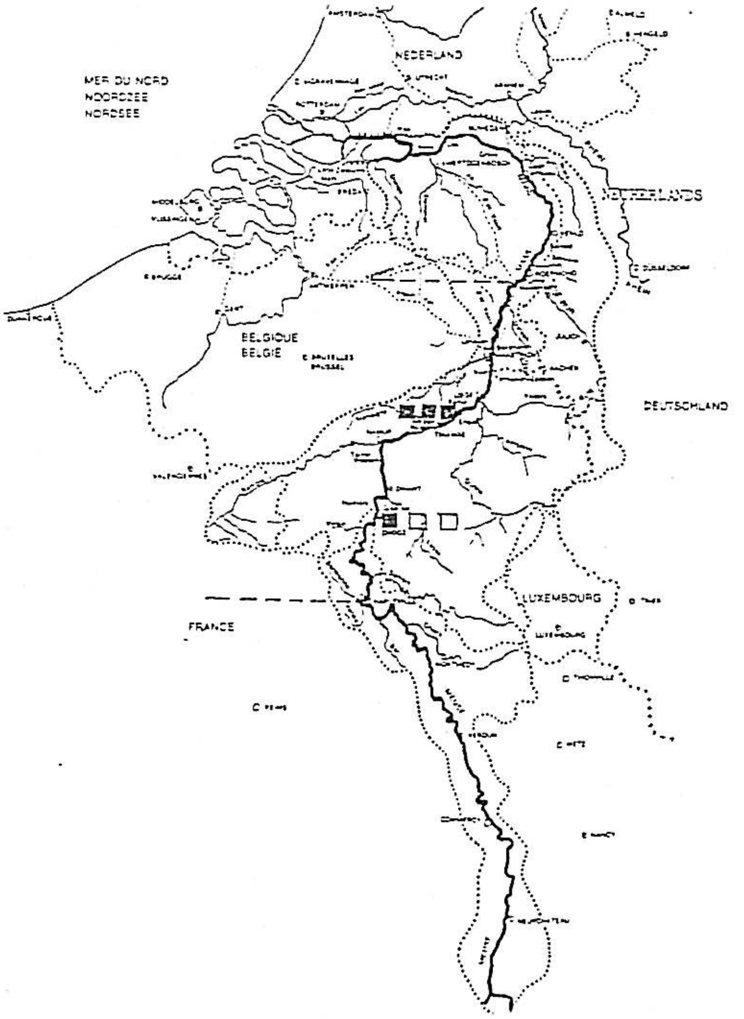

Fig.1. River Meuse basin

3. Application of the model : routine releases

The model has been applied to the river MEUSE. The geographical extension of the model covers the french and belgian sections, from the source (km 0) to km 600. In this particular application, 2 particle size classes are routed :
class 1 : clay + fine silt (diameter < 16 µm);
class 2 : coarse silt + sand (diameter > 16 µm).

Computations have been made to asses the transport of radionuclides released to the river MEUSE by routine discharges from the nuclear power plants. During the year 1975, the nuclear power plant SENA located at CHOOZ (km 473, see fig. 1) has released significant quantities of Cs-137 : 12 monthly-averaged values of Cs-137 discharges are available (see fig. 2). Field data are also available (12 maesurements of Cs-137 activity in bottom sediments at HASTIERE, km 488) from routine surveys (IHE/CEN, 1965-1983).
A non-stationnary simulation of the year 1975 has been realized : one of the results is presented at the fig. 3 (activity in bottom sediments at HASTIERE). Good agreement is obtained between observed and computed values (please note that the model is data-independant : the field data's are not used to a calibration or fitting process, but only for comparison with computed values).

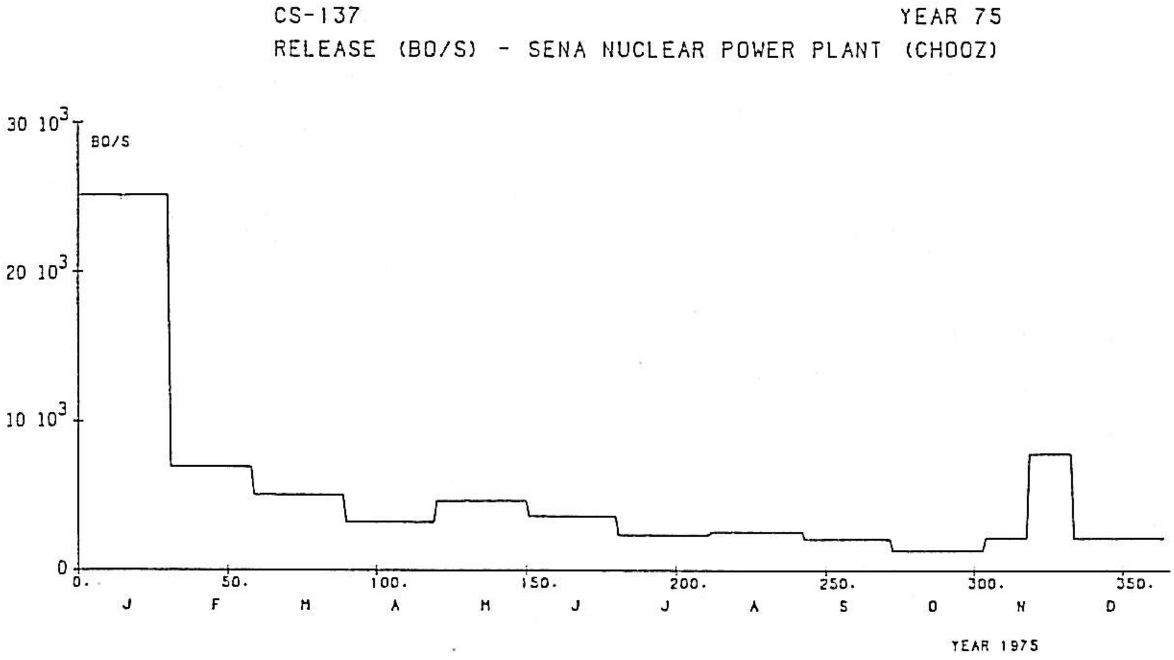

Fig.2. Cs-137 discharges at the nuclear power plant CHOOZ (km 473) (year 1975, 12 monthly-averaged values)

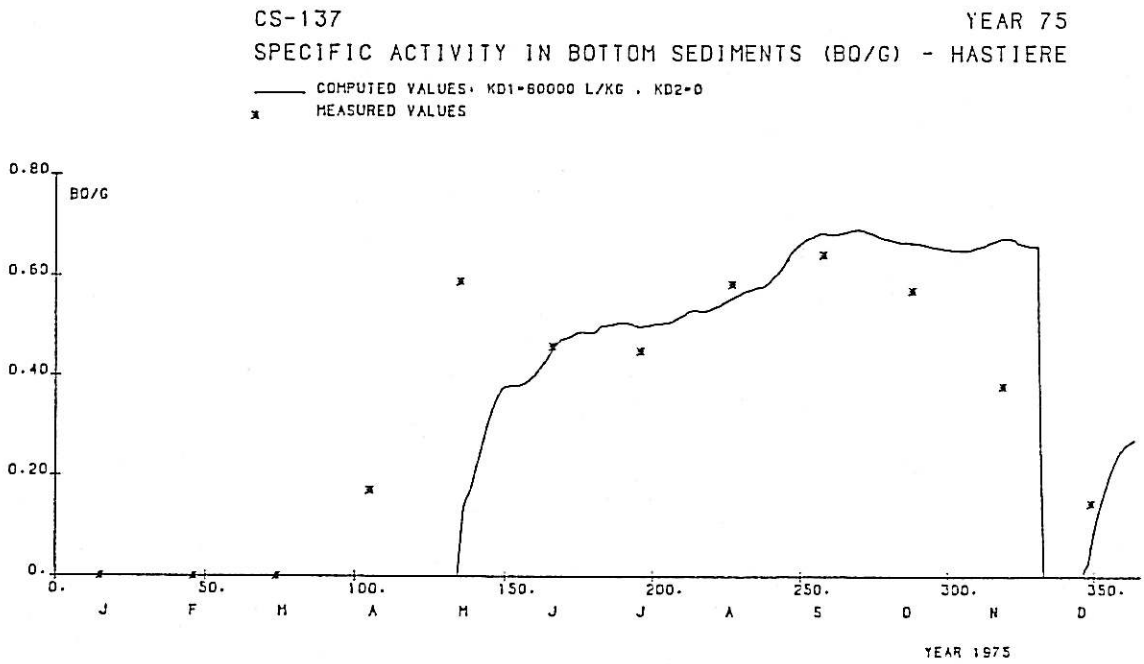

Fig.4. Activity in bottom sediments at HASTIERE (km 488)
(year 1975, computed and measured values)

4. Application of the model : accidental release

The model can be used to asses the contamination of a surface-water body due to an accidental release of radionuclides. The scenario considered is an accidental release (1000 Ci Cs-137 = 37 10E12 Bq) to the river MEUSE from the nuclear power plant TIHANGE (km 565), released at a constant rate during 48 hours.

As the contamination concentration, transport, dispersion, sedimentation, ... are highly dependant on the river flow, two cases are considered (see fig. 4 : MEUSE river flow during the year 1986) :

- case 1 : release during high flow conditions : the release is assumed to occur on may 10th and may 11th, 1986 (river flow : 300 m3/s);
- case 2 : release during low flow conditions : the release is assumed to occur on august 1st and August 2d, 1986 (river flow : 50 m3/s).

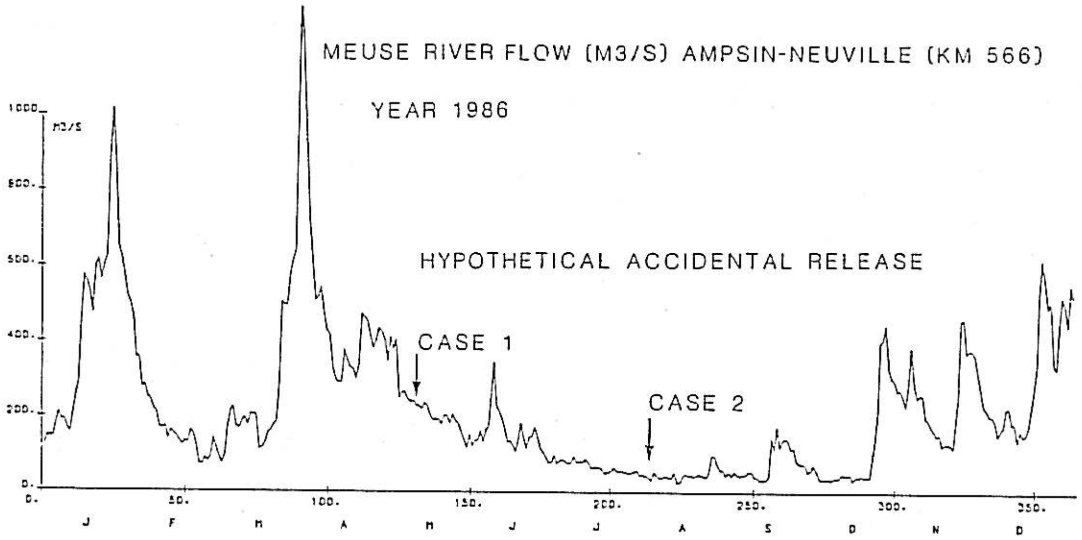

Fig.4. Meuse river flow (m3/s), year 1986

CASE 1 : The fig. 5 presents the time evolution of the total contamination of the water (liquid + solid phase) at a point which is located 50 km downstream; detailed results show that, due to high flow conditions, no sedimentation occur (no storage of sediments and of radionuclides on the river's bed). The transport of Cs-137 by the solid phase (suspended matter) is more important (66 %) that the transfer of Cs-137 by the liquid phase (water) (34 %).

CASE 2 : The fig. 6 presents the time evolution of the total contamination of the water body (liquid + solid phase) at a point which is located 50 km downstream. The residence time is high (9 to 12 days to cover a distance of 50 km), the velocity and turbulence are low, so that sedimentation can occur. The time evolution of the bottom sediment concentration (g/m2) is presented at the fig. 7 : the sedimentation rate is positive during july, august and september, so that a large amount of sediments can be stored on the bed of the river; the flood (on the 22th october, 1986) induces a complete resuspension and washout process.

The computed time evolution of the bottom sediments activity is presented at the fig. 8. The total quantity of radionuclides stored in the bottom sediments over a distance of 50 km, in the particular scenario considered, is about 3 % of the total activity released. A significant fraction of the total activity released can thus be stored in the bottom sediments over the course of the river from the release point (TIHANGE, km 565) to the sea (DONGE, km 860).

The computed time evolution of the radionuclide transport by the liquid phase is presented at the fig. 9; the computed time evolution of the radionuclide transport by the solid phase (suspended sediments) is presented at the fig. 10. These results show clearly that sediments in surface water bodies can act as a sink (effectively removing a significant fraction of the contamination from the water column), can act as a storage capacity, and also can act as a postponed source (which generates a second contamination peak a few weeks or a few months after the accidental release).

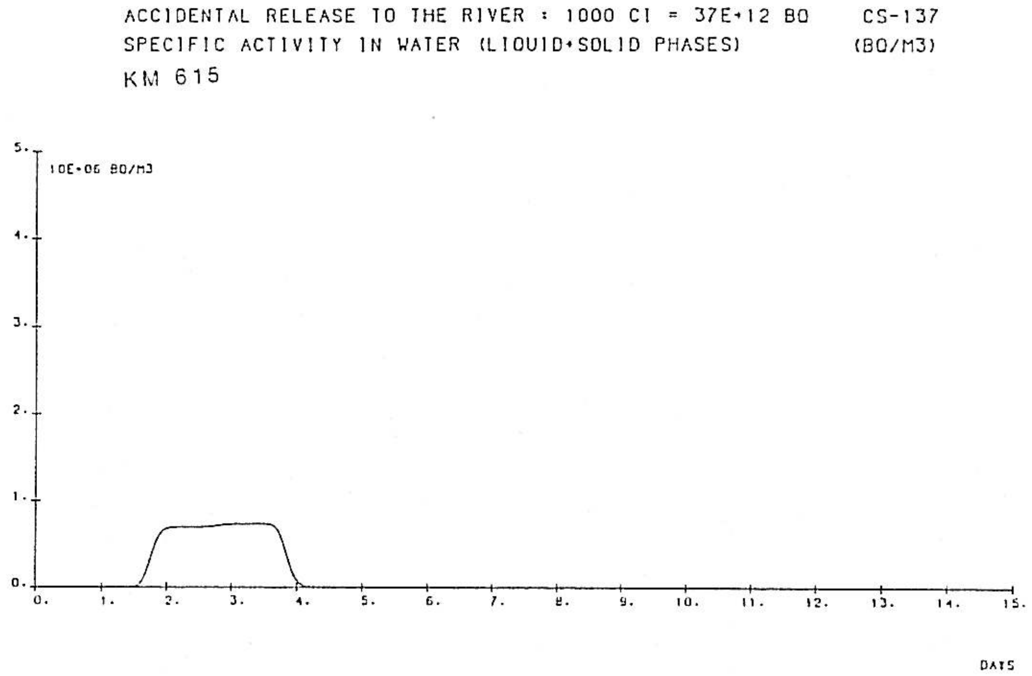

Fig. 5. CASE 1 : time evolution of the total contamination (Bq/m3)

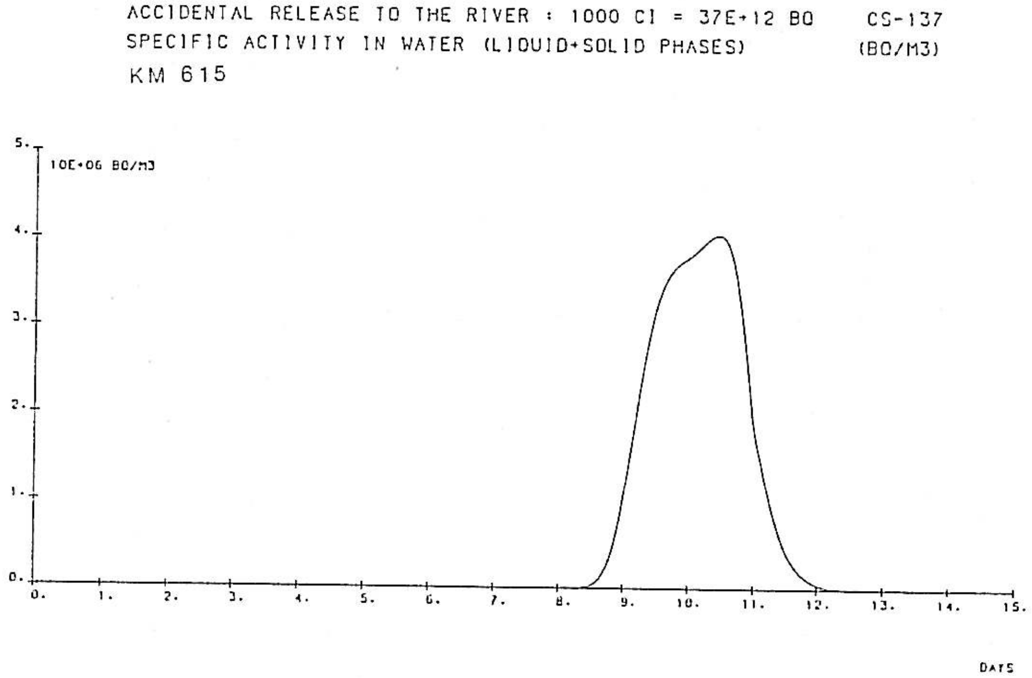

Fig. 6. CASE 2 : time evolution of the total contamination (Bq/m3)

ACCIDENTAL RELEASE TO THE RIVER : 1000 CI = 37E+12 BQ CS-137
BOTTOM SEDIMENTS (G/M2)
KM 615

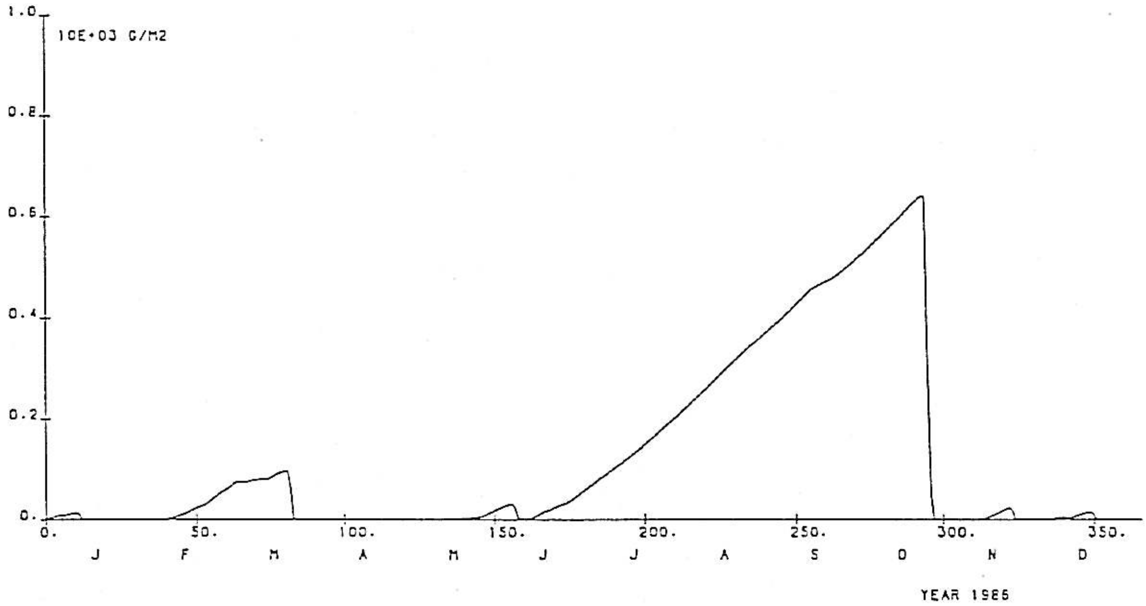

Fig. 7. Bottom sediment concentration (g/m2), year 1986

ACCIDENTAL RELEASE TO THE RIVER : 1000 CI = 37E+12 BQ CS-137
SPECIFIC ACTIVITY IN BOTTOM SEDIMENTS (BQ/G)
KM 615

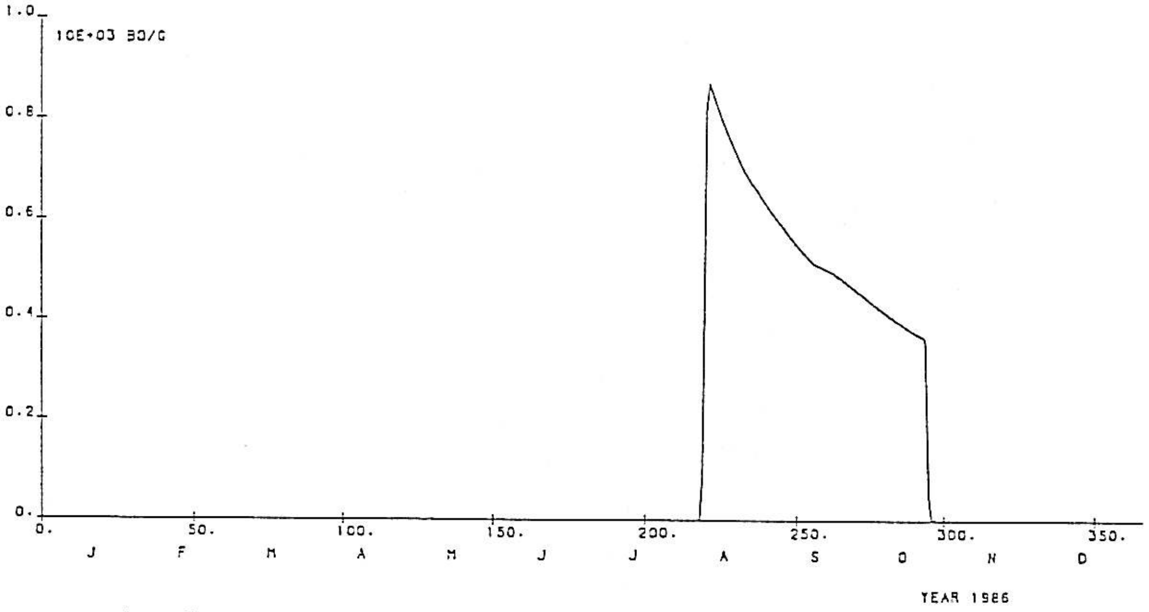

Fig. 8. CASE 2 : time evolution of the bottom sediment activity (Bq/g)

ACCIDENTAL RELEASE TO THE RIVER : 1000 CI = 37E+12 BQ CS-137
TRANSPORT IN LIQUID PHASE (WATER) (BQ/S)
KM 615

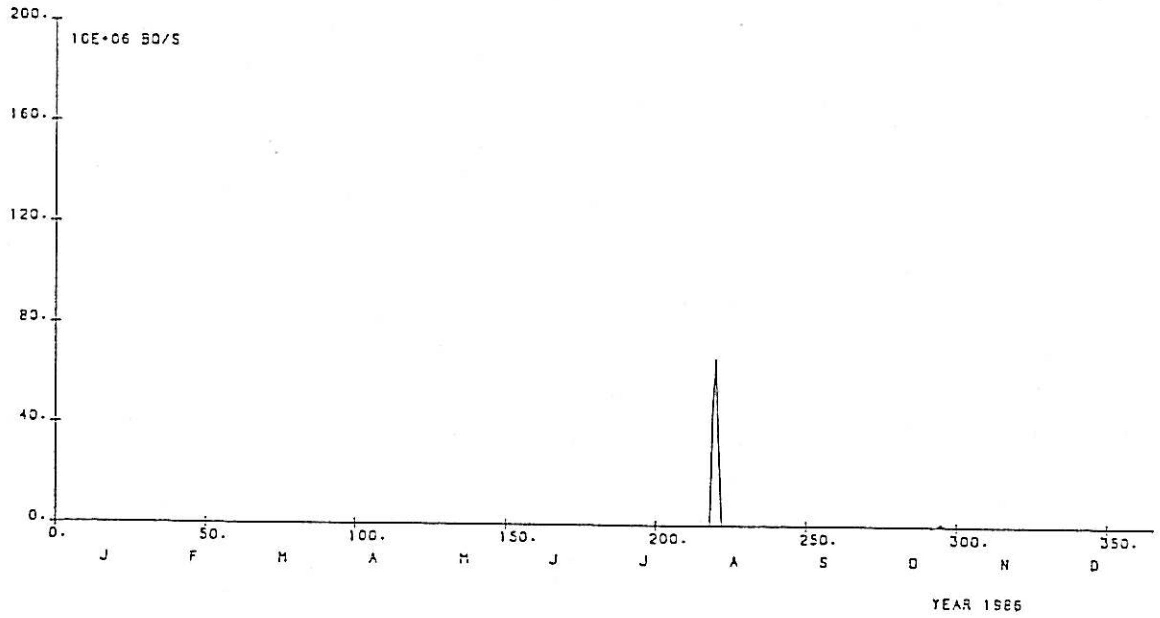

Fig. 9. CASE 2 : radionuclides transport by the liquid phase

ACCIDENTAL RELEASE TO THE RIVER : 1000 CI = 37E+12 BQ CS-137
TRANSPORT IN SOLID PHASE (SUSPENDED SEDIMENTS) (BQ/S)
KM 615

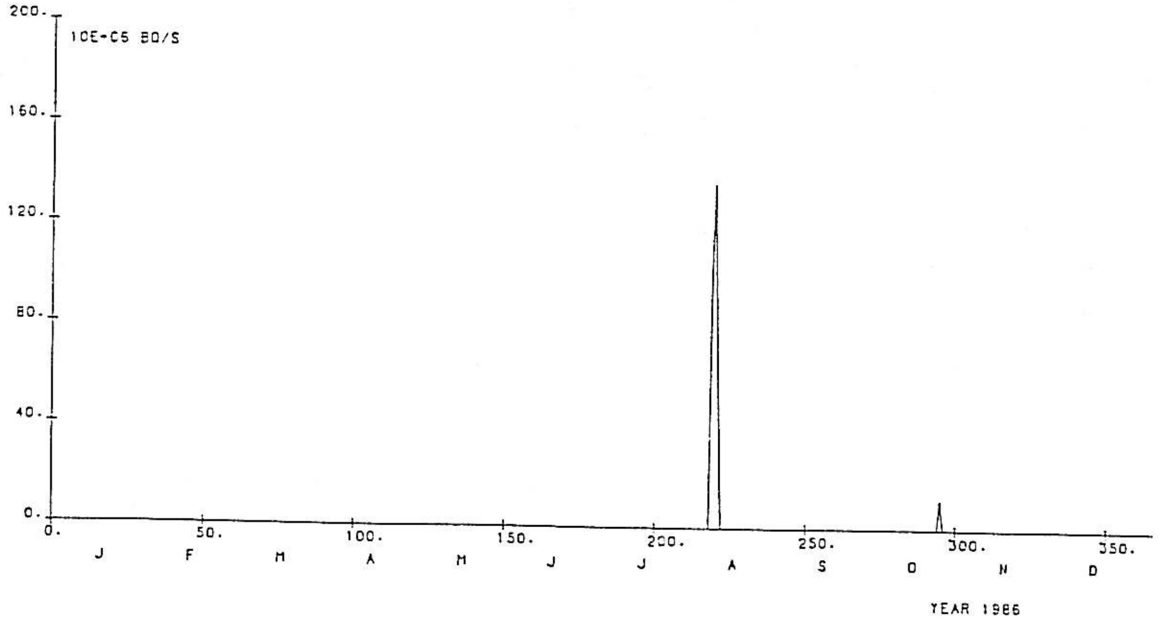

Fig. 10. CASE 2 : radionuclides transport by the solid phase

REFERENCES

BAYER, A., 1982, The radiological exposure of the population in the Rhine-Meuse region, CCE; Luxemburg.

CAILLOT, A., 1982, Rôle des sédiments sur le transport et l'accumulation des radionuisances dans les fleuves et estuaires. Ag. Internationale de l'En. atom., Programme de recherches coordonnées, Rapport ORIS/SAB/S/82-17-C 269

CCE, 1986, The radiological exposure of the population in the Meuse basin. Radiation Protection series, Report EUR 10670 RN, 166 pp.

COUGHTREY,P.J., JACKSON, D.J. THORNE, M.C.,1984, Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems. A critical review of Data, vol. 1 à 6, AA. Balkema, Rotterdam, 1983-1985

DEBAUCHE, A., DESCY, J.P., 1985, Radioecological monitoring in the river Meuse (Belgium) : results in the aquatic mosses. 8th annual congress of UIR, Bruxelles, 23-27 sept. 1985, 4 p. + 1 tabl. (in preparation).

DEBAUCHE, A., 1986, Accident de Tchernobyl. Résultats des mesures effectuées durant la période allant du 1 mai au 31 juillet 1986, 104 pp. Institut national des radioéléments,Belgium.

FOULQUIER L., PALLY M., 1984, Données radioécologiques sur les sédiments du Bas-Rhône. Revue française des Sciences de l'Eau, 3 (1984), 259-277

GOMEZ, H., MAGGIO, G.E. & HOPWOOD, H.J., 1985, Transfer of radioactive pollutants from water to sediments in the Rio Parana de Las Palmas and Rio de la Plata, 3d Meeting CRP, Transport and Accumulation of Radionuclides in waterways, IAEA, Casaccia, Rome, 1985

HELTON ,J.C., MULLER ,A.B.& BAYER ,A., 1985.Contamination of surface-water bodies after reactor accidents by the erosion of atmospherically deposited radionuclides. Health Phys. 48,757-771.

HERRMANN, H., RUF, M., HUBEL, K. & LUNSMANN, W., 1975, Impacts of nuclear Releases into the Aquatic Environment, IAEA-SM-198/14, 461-470, Vienna

IHE/CEN, (KIRCHMANN R., BONNIJS-VANGELDER E., CANTILLON G., eds.), Surveillance radiologique des sites d'implantation des centrales nucléaires. Groupe mixte IHE-CEN. 17 volumes (1965-1983)

IHE/CEN, Etude de l'impact des rejets provenant des centrales nucléaires de type PWR sur la biocènose dulciole, 8 volumes (1976-1983)

INTERNATIONAL ATOMIC ENERGY AGENCY, 1983, Guidebook of Nuclear Techniques in Hydrology : 1983 Edition, Technical Reports Series N°91, IAEA, Vienna (1983)

INTERNATIONAL ATOMIC ENERGY AGENCY, 1985, Hydrological Dispersion of Radioactive Materiel in Relation to Nuclear Power Plant Siting, Safety Guides, n° 50-SG-S6

INTERNATIONAL ATOMIC ENERGY AGENCY, 1985, Behaviour of radionuclides released into coastal waters, IAEA-TECDOC-329, Vienna (1985).

INTERNATIONAL ATOMIC ENERGY AGENCY, 1987, Role of sediments in the accumulation and transport of radionuclides in the waterways, in press.

LAMBRECHTS, A. & FOULQUIER, L. 1985, Experimental study of the transfers of a radionuclide mixture between water, sediment and fish. Scientific seminar on the application of distribution coefficients to radiological assessment models. 7-11 october 1985, Louvain-la-Neuve, Belgium

MIGNIOT C., 1982, A.I.E.A., Rôle des sédiments sur le transport et l'accumulation des radionuisances dans les fleuves et les estuaires, journées du 10 au 15 octobre 1982 - MOL (Belgique), Hydrodynamique des sédiments

ONISHI, Y., YABUSAKI, S.B., KINCAID, T.B., SKAGGS, R.L., WALTERS, W.H., 1982, Sediment and radionuclide transport in rivers. (Radionuclide transport modeling for Cattaraugus and Buttermilk Creeks, New York). U.S. Nuclear Regulatory Comission. NUREG/CR-2425; PNL-4111

PICAT, P., BOVARD, P., GRAUBY, A., IJUIN, M., REVEILLAULT, J., FAVRE, J., ANDRES, J., 1971. Bilan de la dispersion des radionuclides dans un bassin hydrologique. Perspectives en fonction des activités nucléaires : usines de traitement et réacteurs de puissance. La radioécologie appliquée à la protection de l'homme et son environnement, Rome, 9-10 sept 1971, CCE ed. 1972, 139-174

PICAT, P., GRAUBY, A. & DEBEUNS, G., 1977, Etude radiosédimentologique de la Meuse, Annales de l'Association Belge de Radioprotection, vol. 2, n° 3, 183-199

SIBLEY T.H., MYTTENAERE C. eds., 1986, Application of distribution coefficients to radiological assessment models, Elsevier, 1986.

SMITZ, J.S., EVERBECQ, E., FRERE, E., 1985, Modelling of radionuclide transport by sediments in waterways, 3d Meeting CRP Transport and Accumulation of radionuclides in waterways, IAEA, Casaccia, Rome, 1985

SMITZ, J.S. & EVERBECQ, E., 1986, Modelling the behaviour of radionuclides in the aquatic ecosystem. CEE Seminar on the "Cycling of long-lived radionuclides in the biosphere : observations and models", Madrid, September 15-19, 1986, in press.

SMITZ, J.S., EVERBECQ, E., 1986, Estimation du flux de sediments en Meuse et leur role dans le transport de radioélements .Rapport CCE 113 p, 85E1004.