EUR 4897 e

COMMISSION OF THE EUROPEAN COMMUNITIES

APPLICATIONS OF A DERIVED FORMULA FOR THE DISCHARGE OF RADIOACTIVE LIQUID WASTES

by

G. BRANCA, F. BREUER, A.A. CIGNA
(CNEN)
and
R. AMAVIS
(CEC)

1973

Report prepared by CNEN
Comitato Nazionale per l'Energia Nucleare
Laboratorio di Ingegneria Sanitaria
Rome — Italy

EURATOM Contract No. 054-70-12 PST I

LEGAL NOTICE

This report is on sale at the addresses listed on cover page 4

at the price of B.Fr. 60.—

When ordering, please quote the EUR number and the title, which are indicated on the cover of each report.

Commission of the
European Communities
D.G. XIII - C.I.D.
29, rue Aldringen
Luxembourg

January 1973

EUR 4897 e

APPLICATIONS OF A DERIVED FORMULA FOR THE DISCHARGE OF RADIOACTIVE LIQUID WASTES by G. BRANCA, F. BREUER, A.A. CIGNA (CNEN) and R. AMAVIS (CEC)

Commission of the European Communities
Report prepared by CNEN
Comitato Nazionale per l'Energia Nucleare, Rome (Italy)
Euratom Contract No. 054-70-12 PST I
Luxembourg, January 1973 — 36 Pages — BF 60.—

The discharge of radioactive waste in the environment is a source of environmental pollution. For public health protection, it is essential to know the behaviour of each radionuclide in different media. This behaviour can be evaluated by a previsional mathematical model, such as has been developed in a former publication (EUR 4636e).

EUR 4897 e

APPLICATIONS OF A DERIVED FORMULA FOR THE DISCHARGE OF RADIOACTIVE LIQUID WASTES by G. BRANCA, F. BREUER, A.A. CIGNA (CNEN) and R. AMAVIS (CEC)

Commission of the European Communities
Report prepared by CNEN
Comitato Nazionale per l'Energia Nucleare, Rome (Italy)
Euratom Contract No. 054-70-12 PST I
Luxembourg, January 1973 — 36 Pages — BF 60.—

The discharge of radioactive waste in the environment is a source of environmental pollution. For public health protection, it is essential to know the behaviour of each radionuclide in different media. This behaviour can be evaluated by a previsional mathematical model, such as has been developed in a former publication (EUR 4636e).

In the present report, some examples of application of this developed model are given for the following practical problems:

- discharge into a watercourse used for drinking purposes;
- discharge into a watercourse used for irrigation;
- discharge into a lake used for fishing and the supply of drinking water;
- discharge from different nuclear installations into the same hydrological system;
- discharge of gaseous wastes into the atmosphere.

An application of this model is also proposed to non-radioactive pollution problems.

In the present report, some examples of application of this developed model are given for the following practical problems:

- discharge into a watercourse used for drinking purposes;
- discharge into a watercourse used for irrigation;
- discharge into a lake used for fishing and the supply of drinking water;
- discharge from different nuclear installations into the same hydrological system;
- discharge of gaseous wastes into the atmosphere.

An application of this model is also proposed to non-radioactive pollution problems.

EUR 4897 e

COMMISSION OF THE EUROPEAN COMMUNITIES

APPLICATIONS OF A DERIVED FORMULA FOR THE DISCHARGE OF RADIOACTIVE LIQUID WASTES

by

G. BRANCA, F. BREUER, A.A. CIGNA
(CNEN)

and

R. AMAVIS
(CEC)

1973

Report prepared by CNEN
Comitato Nazionale per l'Energia Nucleare
Laboratorio di Ingegneria Sanitaria
Rome — Italy

EURATOM Contract No. 054-70-12 PST I

ABSTRACT

The discharge of radioactive waste in the environment is a source of environmental pollution. For public health protection, it is essential to know the behaviour of each radionuclide in different media. This behaviour can be evaluated by a previsional mathematical model, such as has been developed in a former publication (EUR 4636e).

In the present report, some examples of application of this developed model are given for the following practical problems:

— discharge into a watercourse used for drinking purposes;
— discharge into a watercourse used for irrigation;
— discharge into a lake used for fishing and the supply of drinking water;
— discharge from different nuclear installations into the same hydrological system;
— discharge of gaseous wastes into the atmosphere.

An application of this model is also proposed to non-radioactive pollution problems.

KEYWORDS

RADIONUCLIDE MIGRATION
ECOSYSTEMS
RIVERS
MATHEMATICAL MODELS
RADIOACTIVE WASTE DISPOSAL
DRINKING WATER
FRESH WATER
TRITIUM
PLUTONIUM 239
CERIUM 144
CESIUM 137
STRONTIUM 90
RUTHENIUM 106
IRRIGATION
FORAGE
MILK
CATTLE
LAKES
FISHES
COBALT 60
WASTE DISPOSAL
ENVIRONMENT
AIR
RADIOACTIVE WASTES
GASES
PLANTS
ANIMALS
IODINE 131
RADIONUCLIDE MIGRATION

Toutes les bonnes maximes sont dans le monde;
on ne manque qu'à les appliquer.

B. PASCAL

PREFACE

The application of a compartment model, as defined in a previous study (EUR 4636e) to concrete instances of radioactive pollution improves the possibility of forecasting the consequences of such pollution for man and his environment. This is a proof of the importance of this method as a way of determining the quantities of radioactive substances which may be disposed of in the environment. Moreover this methodology can also be extended to the examination of problems raised by other types of pollution, notably chemical pollution.

Dr. P. RECHT

CONTENTS

1. — GENERAL INTRODUCTION

In a previous report [1] a mathematical model of a receiving environment was developed which is capable of giving a general picture of the distribution in time and space of the contamination which would result from the discharge of radioactive liquid wastes into surface waters.

In this report it is intended to show with certain examples how such a model can be applied to definite cases and how it can be of use in determining the discharge limits of the various radionuclides contained in the discharge from a particular installation within a given environmental context.

It was clearly stated in the report [1] that the rigorous application of the mathematical model involves an analysis of the numerous phenomena which influence the exchange of radioactive substances between the individual compartments of the environment and therefore presupposes a knowledge of the values of all the transfer constants between the compartments. Unfortunately the lack of detailed quantitative information about the processes which link the various compartments of the receiving environment does not allow a general application of the method at the present time. The examples which follow were chosen with this situation in mind in the sense that some of the cases are close to real ones, are actually possible and all the available information just allows the formulation and mathematical solution of the problem by having recourse to some artifice or simplification.

Obviously with the growth of experience and knowledge of radioecological applications not only will there be an increase in the number of cases to which the method can be applied but also the margin of error will be reduced in the results obtainable from the actual condition.

All this has been kept well in mind in this report, the contents and limits are those of an exercice exemplified by the general mathematical method, the reference values (M.P.C. intakes etc.) are not necessarily taken from the same source and sometimes have had to be assumed. In other words various laws and arrangements have been followed in order to cover all aspects of each particular case.

It will be necessary therefore not to care so much about the magnitude of the absolute values or any other parameters which come into the various examples but more about the type of reasoning and the way in which the model can be applied.

The following cases have been considered:

- the case of a watercourse used for drinking purposes;
- the case of a watercourse used for irrigation purposes;
- the case of a lake used for fishing and as a source of drinking water;
- the case of a hydrographic system onto which nuclear installations are imposed (this case is of particular interest because an extension of it lends itself to the formulation and solution of problems of an interregional and international character).

In addition to the above, which refers entirely to liquid discharges a case has been developed for gaseous discharge to demonstrate that the validity of the method is not limited to the strictly terrestrial hydrobiological environment but can be extended with slight variation even into different types of environment.

The model is open for application to conventional pollution as will be demonstrated in particular in the final observations and with suitable integrations applicable also to problems connected with pollution of the sea.

2. — DISCHARGE OF RADIOACTIVE LIQUID WASTES INTO A WATERCOURSE USED FOR DRINKING WATER

2.1 — Introduction

The case postulated is that of a processing plant where the delivery of low level active liquid waste (category 1 of I.A.E.A. classification [2]) is into a watercourse having an average annual flow rate of 100 m^3/sec and an average suspended material flow rate of 30 kg/sec.

The transported material consists of particles which are mainly of an argillaceous nature having an average diameter of less than 0.1 mm and therefore not capable of sedimentation in the watercourse under consideration.

The principle radionuclides contained in the discharge water are ^{3}H, ^{90}Sr, ^{106}Ru, ^{131}I, ^{134}Cs, ^{137}Cs, ^{144}Ce, and ^{239}Pu, all of which have a radioactive decay constant λ which is negligible compared with the renewal constants of the various compartments of the system.

Some of the radionuclides previously listed, in particular Cs, I and Sr, are nearly always present in an ionic form whilst others, in particular Ru, Ce, and Pu are present in a prevalently colloidal form. Consequently the phenomena which have an effect between the radionuclides and the body of water are substantially of two types. For the radionuclides in an ionic form it is possible to cause a sedimentation of the suspended material by the chemical-physical process of ion exchange. For the others mechanical adhesive phenomena have an effect between the radionuclides and the clay particles. For the radionuclides of the first type distribution coefficients (K_d) are referred to and it is presumed that measurements have been carried out on samples of the suspended material producing values between 940 and 125 respectively.

Downstream of the waste injection point the interaction between the ground water and the watercourse is taken as being negligible. There is no edible vegetation on the river-bed and fishing is irrelevant to the objectives of the present application.

River water is used as the supply water, downstream of the discharge a town aqueduct supplies drinking water previously treated by a process of rapid filtration (coagulation with $Al_2(SO_4)_3$ and passage through sandbeds under pressure).

Finally it is presumed that the radionuclides concerned are evenly dispersed throughout the entire flow of the river in a mountainous area and the work is located near the aqueduct*.

2.2 — Application of the method

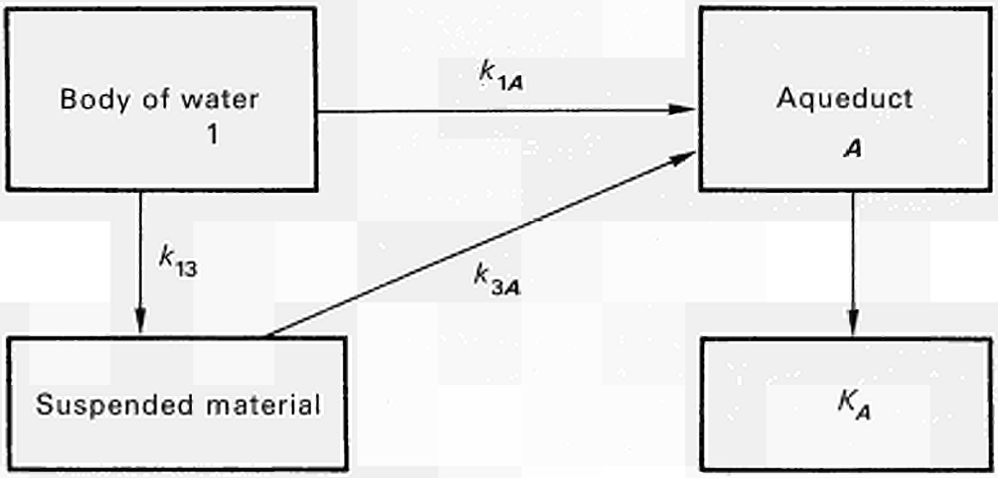
In the case specified the model of the receiving environment is reduced to a partial system W(2) ultimately a simplified system which lacks the compartments relating to ground water and the biotic community.

The quantity of sediment deposited on the river-bed is negligible compared with the amount transported in the water, given that the characteristics of the suspended material are as previously alluded to.

---

* It is noteworthy that complete mixing of the discharged substances with the watercourse depends on many factors such as temperature and density of the liquid wastes and of the diluting body of water, it depends also on the form and position of the discharge outlet, also on the relationship between the flow rate of the current and the flow rate of the discharged wastes, hence it can require a mixing time which can be anything up to many hours. It is possible to reduce this time notably by means of suitable measures (predilution of the wastes, discharge through an injector and so on).

The scheme is as follows:



Applying equation 9 (page 34 of [1]),

$$\frac{dC_1}{dt} = \frac{R + C_2 k_{21} + C_3 k_{31}}{V_1} - (K_1 + \lambda) C_1$$

for the equilibrium condition $C_1 =$ a constant and ignoring $\lambda \ll K_{1i}$

$$C_{1i} = \frac{R_i}{V_1 K_{1i}}$$

where R_i is the quantity of the element i introduced into the river in unit time, V_1 (m^3) is the volume of the stretch of the river concerned with the phenomena of contamination distribution and K_{1i} (days $^{-1}$) is the renewal constant of compartment 1 dependent on hydrodynamic transport, and turbulent diffusion of the river and all the phenomena on which the transfer constant k_{13i} is dependent. The latter can be defined as that volume of water (theoretically) which contains the amount of a radionuclide in the suspended material which passes daily and the dimensions of which (in m^3/day) are in turn dependent on the phenomena of adsorption, ion exchange, etc. which occur between the radionuclides and the suspended material after the discharge into the river. On the basis of such a definition V_1 K_1 is nothing other than the flowrate of the river augmented by the theoretical flowrate k_{13} (from the passage of a certain amount of the radionuclide into the suspended material and the diminution of its concentration in the water it follows that this is equivalent to an increase in the dilution and therefore an increase in the effective flowrate of the river).

Starting with equation 17

$$C_3 = \frac{C_1 k_{13}}{S_3 (K_3 + \lambda)}$$

referred to on page 35 of [1] and modifying it to take account of the fact that the suspended material does not settle but remains suspended and λ is always negligible compared with K_3 one obtains:

$$C_{3i} = \frac{C_{1i} k_{13i}}{M_3 K_3}$$

where C_{3i} is the concentration in the solid phase (expressed in µCi/kg) and M_3 the mass of the solid phase (expressed in kg) and K_3 the removal constant (expressed in seconds $^{-1}$)

From the above it follows that the product $M_3 K_3$ represents the solid flowrate in kg/sec.

Hence

$$Kd_i = \frac{C_{3i}}{C_{1i}}$$

one then obtains

$$k_{13i} = K_{di}\, M_3 K_3$$

Then proceeding by substituting the numerical values:

	Cs	Sr
k_{13}	28 200	3 750

The values of k_{13} are given in l/sec and represents as stated before the assumed flowrate which contributes to the dilution of the discharge.

The equivalent flowrate $V_1 K_{1i}$ takes into account the passing of certain amounts of radionuclides from the free state into suspension*

	Cs	Sr	T, Ru, I, Ce, Pu
$V_1 K_1$ (m^3/sec)	128	104	100

For a discharge of 1 Ci spread continuously over the year (1 Ci/year) for each radionuclide one should have the following concentrations* calculated on the basis previously stated:

	Cs	Sr	T, Ru, I, Ce, Pu
C_1 (μCi/cm^3)	2.48×10^{-10}	3.05×10^{-10}	3.17×10^{-10}

As previously stated the treatment plant provides a flocculation with aluminium hydroxide followed by a sand filtration. From the literature it is known that such treatment allows the following percentage removals for the radionuclides in question:

Cs, I	Sr	Ru	Ce	Pu
negligible	10%	70%	80%	90%

Consequently the concentration of discharged radionuclides in the plant effluent are:

	$^{134,137}Cs$	^{90}Sr	^{106}Ru	^{144}Ce
C_{effl} (μCi/cm^3)	2.48×10^{-10}	2.75×10^{-10}	9.51×10^{-11}	6.34×10^{-11}

	^{239}Pu	^{3}H, ^{131}I
C_{effl} (μCi/cm^3)	3.17×10^{-11}	3.17×10^{-10}

For the radionuclides in question the M.P.C. in drinking water are respectively**

	^{134}Cs	^{137}Cs	^{90}Sr	^{106}Ru	^{144}Ce
M.P.C. pop	3.00×10^{-6}	6.67×10^{-6}	1.33×10^{-7}	3.33×10^{-6}	3.33×10^{-6}

	^{239}Pu	^{3}H	^{131}I
M.P.C. pop	1.67×10^{-6}	1.00×10^{-3}	3.33×10^{-7}

---

* In order to simplify the calculation for radionuclides in a prevalently colloidal form no account is taken of the fact that in reality a fraction of it adheres to the clay particles and therefore is not really present in the water in colloidal form. The values of the concentrations in water then obtained can be understood to be the upper limits.

** These values have been fixed by Italian legislation for particular population groups and take babies into account, these values correspond to 1/30th of the amount indicated by Euratom for the exposure of professional workers.

It is now possible to calculate by simple proportioning the maximum dischargeable quantity $Q_{\max}$ for each radionuclide because the resultant dose to the population is equal to the maximum accepted as a norm for protection against ionizing radiation.

For the quantity mentioned above (Ci/year) the results prove to be as follows:

	^{134}Cs	^{137}Cs	^{90}Sr	^{106}Ru	^{144}Ce	^{239}Pu	^{3}H	^{131}I
$Q_{\max}$	12 100	26 900	484	35 200	52 500	52 700	3 170 000	1 060

These values represent the discharge limits for each radionuclide. The condition which must be complied with for their simultaneous discharge will be therefore:

$$\frac{q_{^{134}\mathrm{Cs}}}{12\,100}+\frac{q_{^{137}\mathrm{Cs}}}{26\,900}+\frac{q_{^{90}\mathrm{Sr}}}{484}+\frac{q_{^{106}\mathrm{Ru}}}{35\,200}+\frac{q_{^{144}\mathrm{Ce}}}{52\,500}+\frac{q_{^{239}\mathrm{Pu}}}{52\,700}+\frac{q_{^{3}\mathrm{H}}}{3\,170\,000}+\frac{q_{^{131}\mathrm{I}}}{1\,060}\leqslant 1$$

where q_i is the amount of the radionuclide i discharged in one year.

This statement therefore represents the discharge formula in the hypothetical case postulated. It is necessary however to add the following considerations:

(a) It is intended that all the quantities q_i must be continuously introduced into the river. However, on the basis of what was said in paragraph 6.3.4. of [1] it is possible to effect an instantaneous discharge, concentrating in a single monthly operation not more than 1/12th of

$$\sum_{i=1}^{n} q_i .$$

(b) The preceeding evaluation is valid on the assumption that there is no other way of exposure other than that represented by the use of drinking water from the river. If such an assumption is not valid (for example if a gaseous discharge from a nuclear installation is present) then it is necessary to take this into account.

(c) The accumulation of radionuclides in the sludge produced in the purification plant can give rise to radiation, even after the sludge has been carried away it can be an inhalation hazard following the release of powder when it has been dried. These phenomena obviously mostly concern the purification plant employees.

3 — DISCHARGE OF RADIOACTIVE LIQUID WASTES INTO A WATERCOURSE USED FOR IRRIGATION PURPOSES

3.1 — Introduction

The case assumed is that of a nuclear centre where low level radioactive waste liquid is discharged into a watercourse which has an average flow rate of 7.3×10^3 m^3/day and which has a negligible flowrate of transported solid material.

The principal radionuclides contained in the discharge of water are ^{90}Sr, ^{106}Ru and ^{137}Cs.

The ^{90}Sr is present partly in ionic form and partly in the form of a complex, the ^{106}Ru is present in an ionic form and is also partly in a colloidal form whilst the ^{137}Cs is completely in an ionic form.

The characteristics of the water are such that the phenomena of insolubility, ion exchange, adsorption etc. can be treated as negligible.

Downstream of the injection point of the waste the interaction between the watercourse and the ground water can be ignored as far as the present application is concerned. It is assumed that there is no edible vegetation on the river bed and that the fish are not for human consumption.

The water from the river is used to irrigate (by spraying) horticultural crops and forage fields; such forage being used to feed milking cows whose drinking water is drawn from wells.

3.2 — Application of the method

3.2.1 — THE RECEIVING AQUATIC ENVIRONMENT

In the case being considered, taking into account the absence of the ground water compartment [2] the aquatic flora [4] the aquatic fauna [5] and ignoring the interaction between the radionuclides and the sediment the average concentration C_{1i} of the individual radionuclides is calculable directly with the simple formula

$$C_{1i} = \frac{R_i}{Q}$$

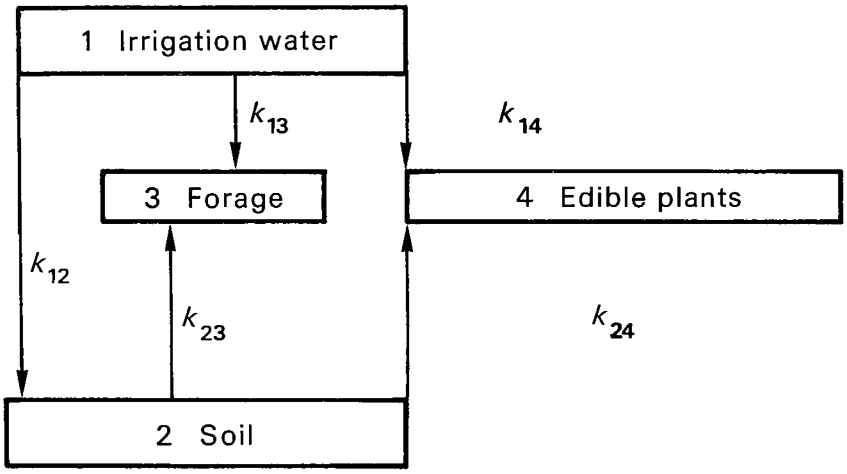
where R_i is the quantity of the element introduced into the river in unit of time (one year) and Q the average annual flowrate of the watercourse (2.66×10^6 m^3/year).

For a discharge of 1 Ci effected continuously throughout the year (1 Ci/year) for each radionuclide therefore the concentration would be:

$$C_1 = 3.76 \times 10^{-7} \text{ Ci/m}^3$$

3.2.2 — THE RECEIVING ENVIRONMENT OF TERRESTRIAL PLANTS

The watercourse considered supplies the irrigation water for spraying plants which are being cultivated for forage and horticulture. The model of the terrestrial (vegetable) receiving environment can be reduced to the following scheme:



From the literature it is possible to obtain information about how much of certain radionuclides are transferred for some kinds of edible plant.

There is available for example precise quantitative data on the transfer of ^{137}Cs and ^{90}Sr to forage, for other radionuclides and other edible plants the information is lacking. Consequently in the treatment which follows it is possible to assign specific numerical values in some cases whereas in others it is necessary to have recourse to ad hoc assumptions based for example on analogous behaviour.

3.2.2.1 — ^{137}Cs *in forage and edible plants*

In the absence of detailed information about the transfer of ^{137}Cs to edible plants it is assumed that the same data as that for forage is valid.

From equation 23 (page 37 of [1]),

$$C_2(t) = C_1 t^* k_{12}\, e^{-(K_2+\lambda)t}$$

if C_1 is constant with time i.e. in a condition of equilibrium with the body of water:

$$C_2(t) = C_1 \frac{k_{12}}{K_2+\lambda} [1 - e^{-(K_2+\lambda)t}]$$

Since on average about 1 m^3 of irrigation water is distributed per year per m^2 of surface area and given that 7% of the contamination contained in the water remains on the plants and is removed by absorption* hence K_{12} can be calculated as follows:

$$K_{12} = 0.93 \text{ m}^3/\text{year}\cdot\text{m}^2$$

The ^{137}Cs contamination available for absorption by edible plants through the soil in the cultivation of forage* and by analogy of edible plants is reduced by 60% each year, thus the contamination is halved every 1.36 years, hence:

$$K_2 = 0.51 \text{ years}^{-1}.$$

Ignoring λ as usual, putting $C_1 = 3.76 \times 10^{-7}$ Ci/m^3 (in the manner given in section 3.2.1) and considering a time $t = 1$ year, it is possible to substitute numerical values into the equation given earlier, thus obtaining:

$$C_2 = 2.7 \times 10^{-7} \text{ Ci/m}^2$$

By calculating this way it should be noted that C_2 is not the total concentration of ^{137}Cs in the soil but only that fraction of Cs which can be absorbed by the plants.

In the equilibrium condition where $t = \infty$ one obtains:

$$C_2 = 6.86 \times 10^{-7} \text{ Ci/m}^2$$

Considering equation 24 (page 37 of [1])

$$C_i(t) = C_1(t)^* k_{1i}\, e^{-(K_i+\lambda)t} + C_2(t)^* k_{2i}\, e^{-(K_i+\lambda)t}$$

as applied to edible plants $C_3(t) = C_1(t)^* k_{13}\, e^{-(K_3+\lambda)t} + C_2(t)^* k_{23}\, e^{-(K_3+\lambda)t}$

Assuming that the forage (or the edible plants for reasons given earlier) is soon in equilibrium with the water and the soil and ignoring λ as usual, gives:

$$C_3(t) = C_1 \frac{k_{13}}{K_3} + C_2(t) \frac{k_{23}}{K_3}$$

In this equation the first term refers to the contamination which is absorbed directly by the plant through the leaves and to that fraction of the contamination which reaches the soil and is absorbed quickly by the plants and some of which can also be leached out by the soil.

To obtain the values of the various coefficients which figure in the equation it is possible to use the following relationship obtained by Van der Stricht *et al.* [3] which was a study of the contamination in forage due to the caesium and strontium in fall-out.

---

* 93% of the contamination effectively reaches the soil and the relative halving time has been inferred from [3].

$$C = F_r p_r + F_d p_d$$

where

C = concentration of ^{137}Cs in the forage in Ci/kg dry weight;

F_r = quantity of Cs deposited on the soil in the last 6 months in Ci/m^2;

p_r = $0.0843 \frac{\text{Ci}}{\text{kg}} \frac{\text{m}^2}{\text{Ci}}$ (for caesium);

F_d = quantity of caesium present in the soil before the last six months in Ci/m^2 (it is to be remembered that 93% of the irrigation water reaches the soil because 7% is directly absorbed by the edible plants and each year 60% of the contamination remains from the previous year);

P_d = $0.0166 \frac{\text{Ci}}{\text{kg}} \frac{2}{\text{Ci}}$ (for caesium).

Comparing this last equation with the previous one and putting $C = C_3(t)$ it is possible to calculate the values of the ratios k_{13}/K_3 and k_{23}/K_3. The value of F_r is obtained by multiplying C_1 by the intensity of the irrigation for the time to which F_r refers (0.5 year)

$$F_r(\text{Ci/m}^2) = C_1(\text{Ci/m}^3) \cdot 1 \left(\frac{\text{m}^2}{\text{m}^2\ \text{year}}\right) \cdot 0.5\ (\text{year})$$

and analogously for F_d:

$$F_d(\text{Ci/m}^2) = C_2(\text{Ci/m}^2)$$

from which can be derived:

$$\frac{k_{13}}{K_3} = \frac{F_r . p_r}{C_1} \text{ and } \frac{k_{23}}{K_3} = \frac{F_d\, p_d}{C_2}$$

and F_r being equal to the product of the concentration C_1 and the annual volume of irrigation water per unit area (in this case 1 m^3/year × m^2) then in the last 6 months one has:

$$F_r = C_1 \cdot 1 \cdot 0.5$$

and therefore

$$\frac{k_{13}}{K_3} = P_r.\ 0.5 = 0.0422$$

In the calculation of the value of k_{23}/K_3 it is necessary to note that $F_d = C_2$ also that in the present case a continuous integration is being used whereas in the work quoted in [3] a summary of discrete quantities was used, hence:

$$\frac{k_{23}}{K_3} = P_d \cdot \mathrm{e}\, K_2 \cdot 0.5 = 0.0166 \cdot 1.29 = 0.0214$$

Substituting the values obtained from equation 24 (page 37, [1])

$$C_i(t) = C_1(t)^*\, k_{1i}\, \mathrm{e}^{-(K_i+\lambda)t} + C_2(t)^*\, k_{2i}\, \mathrm{e}^{-(K_i+\lambda)t}$$

and integrating over one year:

$$C_3 = 3.76 \times 10^{-7} \cdot 0.0422 + 2.7 \times 10^{-7} \cdot 0.0214 = 15.8 \times 10^{-9} + 5.8 \times 10^{-9}$$
$$= \text{about } 2.2 \times 10^{-8} \text{ Ci/dry kg.}$$

Where the discharge is continued indefinitely it is possible to calculate the value of C_3 for the resulting equilibrium condition:

$$C_3 = 3.76 \times 10^{-7} \cdot 0.0422 + 6.86 \times 10^{-7} \cdot 0.0214 = 15.8 \times 10^{-9} + 14.7 \times 10^{-9}$$
$$= \text{about } 3.0 \times 10^{-8} \text{ Ci/dry kg.}$$

3.2.2.2 — ^{90}Sr *in forage and edible plants*

For ^{90}Sr all the considerations which applied in section 2.2.1 to ^{137}Cs can be applied again having regard however to different numerical values which must be assigned to certain parameters.

In this case 10% of the contamination contained in the irrigation water remains on the plants [4] it can be put that:

$$k_{12} = 0.90 \text{ m}^3/\text{year}\cdot\text{m}^2$$

Given that in the case of ^{90}Sr the soil contamination (available for absorption by edible plants) in the cultivation of forage is reduced by 85% from the previous years then there is a halving of such contamination in 4.27 years giving:

$$K_2 = 0.162 \text{ years}^{-1}$$

Substituting these values in equation 23 (page 37, [1])

$$C_2(t) = C_1(t)^* \, k_{12} \, \mathrm{e}^{-(K_2-\lambda)t}$$

then with the usual assumptions we have:

$$C_2 = 3.12 \times 10^{-7} \text{ Ci/m}^2$$

and in the equilibrium condition:

$$C_2 = 2.09 \times 10^{-6} \text{ Ci/m}^2$$

Considering again the equation quoted in [3] which related to the concentration in forage:

$$C = F_r p_r + F_d p_d$$

in this case the numerical values are:

$$p_r = 0.130 \ \frac{\text{Ci}}{\text{kg}} . \frac{\text{m}^2}{\text{Ci}}$$

$$p_d = 0.0322 \, \frac{\text{Ci}}{\text{kg}} . \frac{\text{m}^2}{\text{Ci}}$$

Once again comparing the previous equation with equation 24 (page 37, [1])

$$C_i(t) = C_1(t)^* \, k_{1i} \, \mathrm{e}^{-(K_i+\lambda)t} + C_2(t)^* \, k_{2i} \, \mathrm{e}^{-(K_i+\lambda)t}$$

and working in an analogous manner to the case of ^{137}Cs one obtains:

$$\frac{k_{13}}{K_3} = 0.0650 \qquad \frac{k_{23}}{K_3} = 0.0349$$

and integrating over one year the concentration C_3 is given by:

$$C_3 = 3.76 \times 10^{-7} \cdot 0.0650 + 3.12 \times 10^{-7} \cdot 0.0349 = 2.44 \times 10^{-8} \cdot 1.09 \times 10^{-8}$$
$$= \text{about } 3.5 \times 10^{-8} \text{ Ci/dry kg.}$$

In the case of a discharge for an indefinite time in the equilibrium condition C_3 becomes:

$$C_3 = 3.76 \times 10^{-7} \cdot 0.0650 + 2.09 \times 10^{-6} \cdot 0.0349 = 2.44 \times 10^{-8} + 7.29 \times 10^{-8}$$
$$= \text{about } 9.7 \times 10^{-8} \text{ Ci/dry kg.}$$

3.2.2.3 — ^{106}Ru *in edible plants*

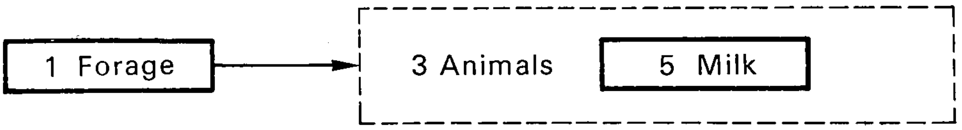
For ruthenium it is only necessary to consider the transfer through edible plants because it is well known that there is a discrimination against this nuclide in the production of cow's milk therefore there is no sense in being concerned with propagation through forage.

Through the literature [5, 6] it is now known that for soil irrigation the concentration factor for ruthenium through edible plants is small or equal to 1. Consequently the concentration of ^{106}Ru in edible plants is equal to that in the irrigation water.
Therefore: $C_4 = C_1 = 3.76 \times 10^{-10}$ Ci/fresh kg.

3.2.3 — THE RECEIVING ENVIRONMENT OF TERRESTRIAL ANIMALS

3.2.3.1 — ^{137}Cs *in milk*

As stated in the introduction we are dealing with the rearing of milking cows fed on contaminated forage but drinking uncontaminated water. The scheme can be reduced to the following terms:



From equation 25 (page 38, [1])

$$C_4 = \frac{C_1 k_{13} + C_2 k_{23}}{M_4 (K_4 + \lambda)}$$

by substituting for M_4 with V_5 and for K_4 with K_5 and as usual ignoring λ by application of the simplified partial system we have:

$$C_5 = \frac{C_1 k_{13}}{V_5 \cdot K_5}$$

Then substituting the numerical values:

$C_1 = 3 \times 10^{-8}$ Ci/dry kg (in the equilibrium state).

$k_{13} = 10$ kg/day of forage (dry weight) per animal [7].

$V_5 = 250$ litres. This distribution volume has been calculated by extrapolation to zero of the percentage milk secretion following an instantaneous ingestion ([8], page 341).

$K_5 = 0.35$ days^{-1}. The elimination constant calculated on the basis of a halving time of 2 days for milk contamination ([8], page 341).

Hence

$C_5 = 3.4 \times 10^{-9}$ Ci/litre is obtained.

3.2.3.2 — ^{90}Sr *in milk*

By proceeding in an analogous manner to that for ^{137}Cs and substituting suitable numerical values it follows that:

$C_1 = 9.7 \times 10^{-8}$ Ci/dry kg (in the equilibrium state).

$K_{13} = 10$ kg/day of forage (dry weight) per animal [7].

$V_5 = 2500$ litres. This volume has been calculated by extrapolation to zero of the percentage milk secretion following an instantaneous ingestion ([8], page 263).

$K_5 = 0.35$ days $^{-1}$. The elimination constant calculated on the basis of a halving time of 2 days for milk contamination ([8], page 263).

Hence

$C_5 = 1.1 \times 10^{-9}$ Ci/litre*.

3.2.4 — THE CALCULATION OF THE DISCHARGE LIMIT AND FORMULA

The social-economic enquiry into the feeding habits of the population gravitated around the receiving environment and brought about the specification of two potentially critical groups:

(a) The adult community which consumes the greater part of the edible plants i.e. 0.34 kg/day per capita as an average. For members of this community the milk consumption is 0.1 litre/day per capita as an average.

(b) The infant community which consumes the greater part of the milk consumed by the whole community i.e. 0.9 litre/day per capita as an average. It is noted that these babies of less than 1 year old do not consume edible plants. On the basis of the elemental aspects so far gathered together and taking into account the fresh to dry weight ratio as being equal to 10 in the case of edible plants, it is possible to proceed to calculate, for each potentially critical group using the derivations previously mentioned, the unit injection (1 Ci/year) for each radionuclide in the environment. The results of this calculation are reported in the following table.

Daily ingestion (10^{-9} Ci/day) per unit discharge (1 Ci/year)

	^{137}Cs	^{90}Sr	^{106}Ru
Adults	1.36	3.41	0.128
Infants	3.06	0.99	0.00

From the values of maximum permissable ingestion per radionuclide under scrutiny [9] and reduced for infants [10, 11] by a factor of 2/3 for ^{137}Cs and a factor of 1/4 for ^{90}Sr the following results are obtained:

Daily permissible ingestion (10^{-9} Ci/day)

	^{137}Cs	^{90}Sr	^{106}Ru
Adults	33	0.88	26
Infants	22	0.22	—

From a comparison of the values of the two preceeding tables it follows that the critical groups for the three radionuclides considered are:

(a) For ^{137}Cs the infant community.

(b) For ^{90}Sr both of the communities.

(c) For ^{106}Ru the adult community.

It is possible to calculate now the maximum quantity of each radionuclide continuously dischargeable in 1 year (discharge limit).

By simple proportion ([1], page 42):

For ^{137}Cs	7.2 Ci/year.
For ^{90}Sr	0.22 Ci/year.
For ^{106}Ru	203 Ci/year.

---

* It is observed that by applying the criterion of specific activity and taking account of the isometabolic element Ca one can proceed to calculate C_5 on the basis of the following assumptions:

(a) That the daily ingestion by cows of Ca is 90 g.

(b) That the mean concentration of Ca in milk is 1.2 g/litre.

(c) That the observed ratio between milk and forage is 0.1.

Thus in equilibrium conditions the following value is obtained:

$C_5 = 1.3 \times 10^{-9}$ Ci/litre which accords well with the value previously found.

Hence the condition which must be respected for simultaneous discharge will be therefore:

$$\frac{q_{^{137}\mathrm{Cs}}}{7.2}+\frac{q_{^{90}\mathrm{Sr}}}{0.22}+\frac{q_{^{106}\mathrm{Ru}}}{203}\leqslant 1,$$

where q_i are the amounts of radionuclides effectively discharged in one year. This statement therefore represents the discharge formula for the case stated.

The considerations under sub-headings (a) and (b) are valid at point 1.2.

4 — THE DISCHARGE OF RADIOACTIVE LIQUID WASTES INTO A LAKE USED FOR FISHING AND THE SUPPLY OF DRINKING WATER

4.1 — Introduction

The case put hypothetically is that of a nuclear research centre which is represented as having a natural outlet for its low level radioactive liquid waste into a lake which has only the characteristics required for the present purposes, and which are:

Volume: 3.7×10^{10} m^3.

Area: 212 km^2.

Average outlet flowrate: 300 m^3/sec*.

The principle radionuclides foreseen are those contained in the discharge water i.e. ^{60}Co, ^{90}Sr, ^{106}Ru and ^{137}Cs.

The discharge is effected through a small tributary of the lake, the waters of this tributary not being used by other people and which would have a flowrate of 0.3 m^3/sec as an average over the year. Such a water course would assume the role of an outlet for the waste from the centre. The lake water would be used as a water-supply for certain places on its shore after filtration through sand-beds and chlorination. Additionally commercial fishing would take place.

4.2 — Application of the method

From a general point of view the application of the method presupposes a knowledge of all the values of the parameters which appear in the related formulae.

As has already been stated, a knowledge of these values depends in its turn upon a complete and detailed understanding of the complex chemical, physical, chemical-physical and biological phenomena which affect the movements of the radionuclides within the receiving environment. As a rule these phenomena are not well known in quantitative terms, in some cases the information is totally lacking.

There is no other possibility of making a start except by releasing certain discharges of an experimental type and making a series of measurements and studies in order to arrive at the knowledge necessary for an experimental evaluation of the effective receiving capacity of the environment in question.

At this point it is necessary to point out the existence of a certain amount of information concerning fall out and however much fall out may be deprecated it is presented paradoxically enough as a valid help in this situation.

---

* The theoretical renewal time is therefore 4 years.

In particular from amongst the data obtained and suitably processed, the results of the measurements relating to fall out show that the fractions of the radionuclides present in the water which are settling to the bottom in a year are as follows [12]:

^{90}Sr	^{106}Ru	^{137}Cs
0.19	0.50	0.36

According to the nomenclature adopted in [4] these values correspond to the ratio between the transfer constant k_{13} and the volume V_1 of the body of water considered and are therefore expressed in (years)$^{-1}$.

In regard to ^{60}Co which is a radionuclide not contained in any appreciable quantity in fall out the relative fraction which settles out is not known but in the calculations which follow its value is taken as zero*.

Again from the measurements effected in connection with fall out the following values of fish to water concentration factors** have been determined:

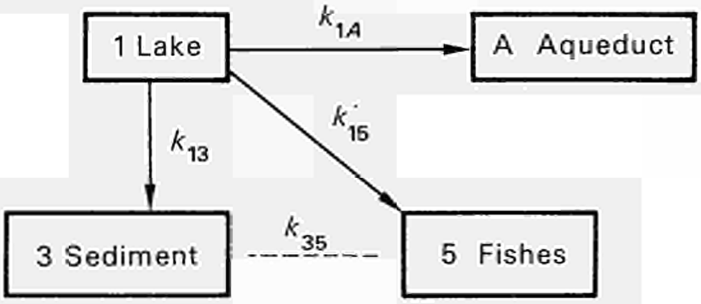
	^{90}Sr	^{137}Cs
FC	320	2 900

For the other two radionuclides present in the discharges with the absence of direct experimental data values (of orders of magnitude) are obtained from the literature [13] as follows:

	^{60}Co	^{106}Ru
FC	100	100

The model of the receiving environment under examination is reduced to the partial system W but in slightly more simplified form considering that it lacks a ground water compartment and that the role of the aquatic flora is implicit in the concentration factors.

The scheme is consequently as follows:



It is to be remembered that the transfer from compartment 3 to compartment 5 is already taken into account in the fish to water concentration factors.

Once all the direct and indirect experimental information available has been acquired it only remains to have resort to assumptions, to be able to proceed with the application of the method.

In order that the assumptions are treated safely but reasonably it is convenient to treat the cases of fish and drinking water separately as both are possible ways of exposure.

---

* From the first results obtained in [12] experimental discharges a value of about 0.03 was found for ^{60}Co.

** The higher values have been selected from among all the determined mean values for various edible species [12].

4.2.1 — THE CASE OF FISH

The species of edible fish can be represented by Perca fluviatilis, Scandinius erithrophtalmus, Lepomis gibbosus. Such species live close to the surface of the water and only descend with difficulty below 5 metres. For this reason it is postulated that the radioactive substances are only present in this stratum and in that zone of the lake from the discharge point down through the tributary.

The resultant volume considered then is as follows:

$$V_1 = \text{km}^2\ 30 \text{x}\ \text{m}\ 5 = 1.5 \times 10^8\ \text{m}^3$$

It is presumed that the radioactive substances are evenly distributed throughout this volume.

With this premise it is possible to apply equation 9 (page 57, [2]) for the equilibrium condition C_1 = a constant and one obtains:

$$C_{1i} = \frac{R_i}{V_1(K_{1i}+\lambda_i)}$$

in which R_i is the quantity of the radionuclide introduced into the lake in 1 year, V_1 is the volume as indicated above in m^3, K_{1i} is the renewal constant of the lake expressed $(\text{years})^{-1}$ and λ_i is the radioactive decay constant. The value of the renewal constant K_{1i} depends as stated in [2] on all the transfer phenomena linked with compartment 1 also on the hydraulic phenomena such as turbulent or molecular diffusion and hydrodynamic transport by the tributary.

However, given the lack of direct quantitative data on such phenomena and the low reliability of the application in actual cases of theoretical evaluation, one must with caution assume that the hydraulic phenomena are negligible. Consequently the renewal constant K_{1i} is reduced, apart of V_1, to the transfer constant k_{13i}.

Hence substituting numerical values, for $R_i = 1$ Ci/year, one obtains:

	^{90}Sr	^{137}Cs	^{106}Ru	^{60}Co
C_1 (μCi/cm^3)	3.5×10^{-8}	1.9×10^{-8}	5.6×10^{-9}	5.0×10^{-8}

The corresponding values for fishes, taking into account the concentration factors previously mentioned are as follows for the concentration C_{5i}:

	^{90}Sr	^{137}Cs	^{106}Ru	^{60}Co
C_5 (μCi/fresh gm)	$1{,}1 \times 10^{-5}$	5.5×10^{-5}	5.6×10^{-7}	5.0×10^{-6}

A social-economic enquiry has identified certain coastal fishermen as a separate critical group. The average daily individual consumption of the adults was seen to be 120 gms/day. Consequently for an injection of 1 Ci/year in the lake the additions due to each of the components of the above mentioned group for each radionuclide are reported in the following table:

Daily ingestion ($\times 10^{-9}$ Ci/day) per unit discharge (1 Ci/year)

^{90}Sr	^{137}Cs	^{106}Ru	^{60}Co
1.3	6.6	0.07	0.6

For the radionuclides under examination the values of the maximum permissible ingestion [9] are as follows:

Maximum permissible daily ingestion ($\times 10^{-9}$ Ci/day)

^{90}Sr	^{137}Cs	^{106}Ru	^{60}Co
0.88	33	26	77

By simple proportion it is possible now to proceed to calculate the maximum amount continuously dischargeable for each radionuclide over one year (the discharge limit) and the following results are given:

Fo ^{90}Sr	0.68 Ci/year
For ^{137}Cs	5.00 Ci/year
For ^{106}Ru	370 Ci/year
For ^{60}Co	128 Ci/year

The preceeding considerations have full validity in the hypothesis that the way of exposure is through the ingestion of contaminated fish. It is now necessary to take into consideration another possible way, that is, the ingestion of water from an aqueduct supplied by the waters of the lake.

4.2.2 — THE CASE OF THE AQUEDUCT

The waters of the lake are used to supply some municipal aqueducts which serve small coastal towns.

After being headed off the waters are filtered through sand-beds then chlorinated. The rigorous application of the method for the determination of the concentration of each radionuclide in the water, requires as has been repeatedly stated, a quantitative knowledge of the parameters which enter the formulae to be resolved.

Since this information is lacking we will be limited to the calculation of the concentration values of the individual radionuclides in the watercourse which functions from the tributary in which the radioactive discharge takes place, taking into account the flowrate of the latter.

Next the compatibility of these values is checked against the M.P.C. for drinking water taking into account the decontamination factors achievable by the processes adopted for the improvement of the quality of the water for drinking purposes.

In other words one takes account of the only certain data available at the moment, ignoring the other phenomena (diffusion etc.) which nevertheless exist but which contribute to a further dilution of the radioactive contamination.

Since the integrated annual flowrate of the tributary canal is 9.5×10^6 m^3 then for those four radionuclides which have been specified with regard to discharge limits for fish the following mean values will be obtained for the same tributary:

	^{90}Sr	^{137}Cs	^{106}Ru	^{60}Co
C_1 max(μCi/cm^3)	7.2×10^{-8}	5.3×10^{-7}	3.9×10^{-5}	1.4×10^{-5}

These values, as has been said, are presumed to be equal to the maxima that they can have in the water of the lake. Comparing such values with 1/10 of the M.P.C. for occupationally exposed persons it is seen that the concentrations of ^{90}Sr, ^{137}Cs and ^{60}Co are lower than such values because, albeit modestly, some removal of the radioactivity must take place in the sand filters. For ruthenium however the concentration is higher than the M.P.C. and one cannot rely on the removal of this radionuclide by the work of the filters. It is therefore necessary to reduce the amount discharged in one year and this turns out to be about 90 Ci.

4.2.3 — DISCHARGE FORMULA

The term which must be respected for the simultaneous discharge of the four radionuclides in question will be:

$$\frac{q_{^{90}Sr}}{0.68} + \frac{q_{^{137}Cs}}{5.0} + \frac{q_{^{106}Ru}}{90} + \frac{q_{^{60}Co}}{128} \leqslant 1$$

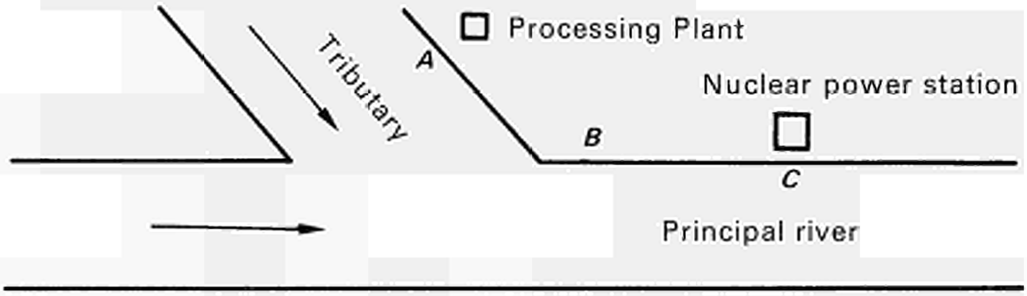
where q_i is the maximum amount of the radionuclide which is dischargeable in 1 year.

The considerations under sub-headings (a) and (b) at the point 1.2. are also valid here.

5 — THE DISCHARGE OF RADIOACTIVE LIQUID WASTE FROM MORE NUCLEAR INSTALLATIONS INTO THE SAME HYDROGRAPHIC SYSTEM

5.1 — Introduction

The case postulated is represented schematically below:



A = Discharge point for the liquid waste of the processing plant;

B = Point of confluence;

C = Discharge point for the liquid waste of the nuclear power station.

It can be seen that at A there is a processing plant which discharges low-level radioactive liquid waste into a tributary of the principal watercourse. At C there is a nuclear power station.

The mean flowrates of the two watercourses measured in the sections where the two plants introduce their discharges are respectively as follows:

A. 65 m^3/sec;
C. 125 m^3/sec.

The flowrate of suspended solids is taken as being negligible.

The bodies of water in question are used exclusively for fishing along their entire length.

It is worthwhile to note that edible aquatic flora does not exist along the stretches concerned.

The principal radionuclides contained in the discharge from the processing plant are ^{3}H, ^{90}Sr, ^{106}Ru, $^{134,137}Cs$, ^{144}Ce and ^{239}Pu whilst the radionuclides discharged from the nuclear power-station are ^{3}H, ^{54}Mn, ^{59}Fe, ^{60}Co, $^{134,137}Cs$ in the main.

5.2 — Application of the method

The model of the primary (aquatic) receiving environment is modified in the present case in the manner illustrated in the following pages.

The body of water I corresponds to the stretch of the tributary along *AB* and II corresponds to the stretch of the river along *BC* and III to the stretch downstream of the point *C*.

5.2.1 — THE AQUATIC RECEIVING ENVIRONMENT I

The aquatic receiving environment I consists of:

(a) The tributary of the principal watercourse, i.e. the stretch from the injection point of the waste to the point of confluence.

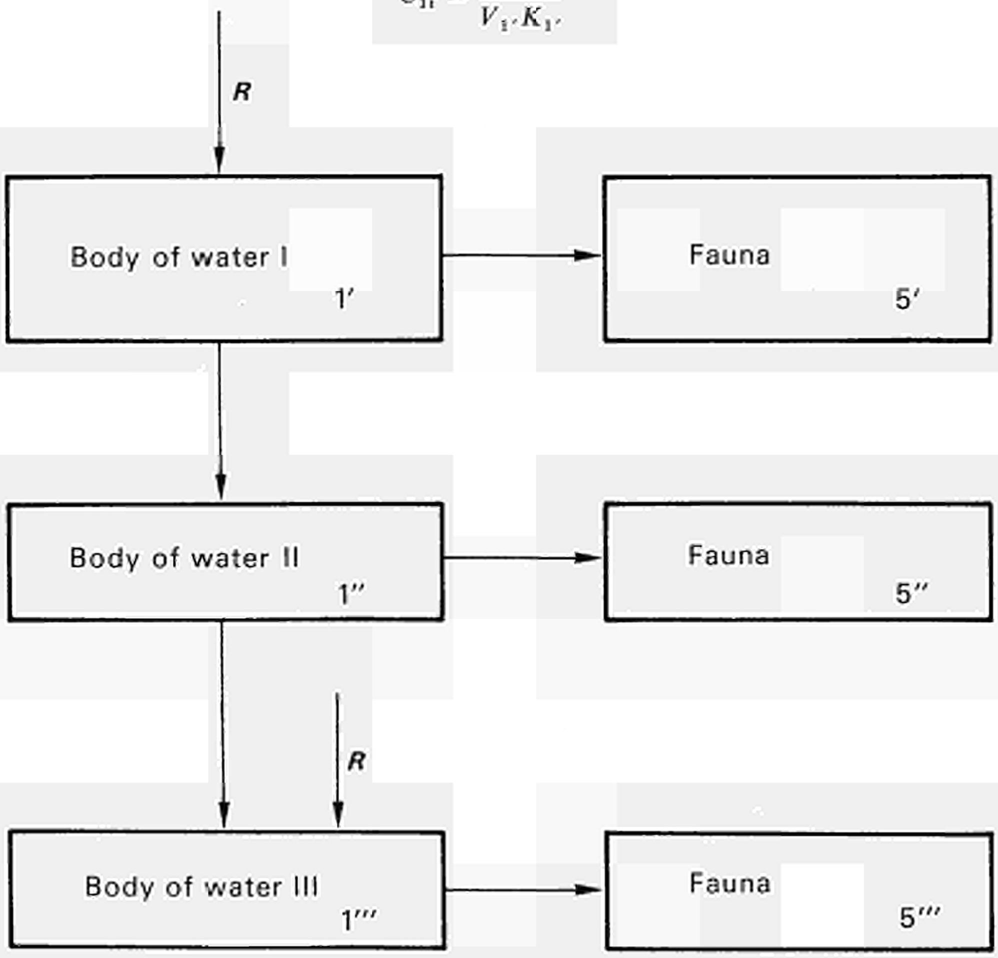
(b) The aquatic fauna existing within that stretch.

Applying equation 9 (reported in [1] page 34)

$$\frac{\mathrm{d}C_1}{\mathrm{d}t} = \frac{R + C_2 k_{21} + C_3 k_{31}}{V_1} - (K_1 + \lambda)\, C_1$$

for the condition of equilibrium $C_1 =$ a constant and since $\lambda \ll K_1$ one obtains:

$$C_{1i} = \frac{R_i}{V_{1'} \cdot K_{1'}}$$



The symbols ′, ″ and ‴ refer to the stretch of the tributary *AB*, the stretch *BC* of the principal watercourse, and to the stretch of the latter but downstream of the section *C* respectively.

where as usual R_i is the amount i of the radionuclide measured in curies which has been discharged from the processing plant in unit time, V_1, (m^3) is the volume of the stretch of the river concerned with the contamination distribution phenomena and $K_{1'}$ (days $^{-1}$) is the renewal constant of compartment 1′. The product $V_{1'}K_{1'}$ represents the flowrate of the watercourse (m^3/day).

With regard to the aquatic fauna compartment, equation (16) of reference [1]

$$C_5 = \frac{C_1 k_{15} + C_3 k_{35} + C_4 k_{45}}{K_5 + \lambda}$$

can be used by putting in $k_{35} = k_{45} = 0$ and by using suitably chosen numerical values for the parameters of the transfer of radionuclides from the body of water to the aquatic flora and hence to the fauna by means of conveniently selected values for k_{15} and K_5. Thus obtaining

$$C_{5'i} = \frac{C_{1'i} k_{1'5i}}{K_{5'i} + \lambda_i}$$

hence

$$\frac{C_{5'i}}{C_{1'i}} = \frac{k_{1'5i}}{K_{5'i} + \lambda_i}$$

The ratio $k_{1'5i}/(K_{5'i}+\lambda_i)$ represents the concentration factor from fish to water and coincides with expression (19) of the report [1]

$$\frac{C_5}{C_1} = \frac{k_{15}}{K_5+\lambda} + \frac{k_{13}k_{35}}{S_3(K_3+\lambda)\,(K_4+\lambda)} + \frac{k_{14}k_{45}}{(K_4+\lambda)\,(K_5+\lambda)} + \frac{k_{13}k_{34}k_{45}}{S_3(K_3+\lambda)\,(K_4+\lambda)\,(K_5+\lambda)}$$

in which the 2nd and 4th terms of the second part of the expression (corresponding to, waterways–sediment–fauna and watersediment–flora–fauna respectively) should be equal to zero (given that sediments and suspended materials are absent from the body of water) and that the contribution from the radionuclide transfer from the water via the flora to the fauna should be considered as a whole with the direct transfer from water to fauna as stated before.

In the absence of direct determinations of the fish to water concentration factors $C_{5'i}$ for use in the present case, values were obtained from the literature, for each radionuclide the highest value was selected for each of the various edible species and after rounding off these were

	^{3}H	^{90}Sr	^{106}Ru	^{134,137}Cs	^{144}Ce	^{239}Pu
C.F.	1	300	100	3000	1000	100

It is now possible to proceed to the calculation of the concentration of the various radionuclides in water and fish for unit discharge $R = 1$ Ci/year of each nuclide obtaining

Radionuclides	Equilibrium concentrations	
	In water	In fish
^{3}H	4.88×10^{-10} µCi/cm^3	4.88×10^{-10} µCi/g
^{90}Sr	4.88×10^{-10} µCi/cm^3	1.464×10^{-7} µCi/g
^{106}Ru	4.88×10^{-10} µCi/cm^3	4.88×10^{-8} µCi/g
^{134,137}Cs	4.88×10^{-10} µCi/cm^3	1.464×10^{-6} µCi/g
^{144}Ce	4.88×10^{-10} µCi/cm^3	4.88×10^{-7} µCi/g
^{293}Pu	4.88×10^{-10} µCi/cm^3	4.88×10^{-8} µCi/g

5.2.2 — THE AQUATIC RECEIVING ENVIRONMENT II

The aquatic receiving environment II is morphologically identical to environment I.

From a quantitative point of view the only variation is the flowrate of the watercourse which was previously stated to be 125 m^3/sec.

As a protective approximation the quantity of radioactive substance which enters the principal river through the tributary is taken as R Ci/year (that is 1 Ci/year as postulated in section 5.2.1) for each of the radionuclides the concentrations in water and fish become

Radionuclides	Equilibrium concentrations	
	In water (μCi/cm^3)	In fish
^{3}H	2.54×10^{-10}	2.54×10^{-10} μCi/g
^{90}Sr	2.54×10^{-10}	7.62×10^{-8} μCi/g
^{106}Ru	2.54×10^{-10}	2.54×10^{-8} μCi/g
^{134,137}Cs	2.54×10^{-10}	7.62×10^{-7} μCi/g
^{144}Ce	2.54×10^{-10}	2.54×10^{-7} μCi/g
^{239}Pu	2.54×10^{-10}	2.54×10^{-8} μCi/g

5.2.3 — THE AQUATIC RECEIVING ENVIRONMENT III

This aquatic receiving environment has the same morphology as the other two. The contaminant radionuclides are those proceeding from upstream (i.e. those discharged from the processing plant which join the radionuclides discharged from the nuclear power station).

The radionuclide concentrations in the river water and fish downstream of section A discharged by the processing plant are the same as those calculated in the proceeding paragraph. The discharge from the nuclear power station is now considered separately assuming as usual that $R = 1$ Ci/year. The resulting radionuclide concentrations from the nuclear power station discharge into the water and fish are given, assuming the higher values available from the literature for the fish to water concentration factors for the new radionuclides.

	^{54}Mn	^{59}Fe	^{60}Co
C.F.	10	10^4	10^2

these are reported in the following table:

Radionuclides	Equilibrium concentrations	
	In water (in μCi/cm^3)	In fish (in μCi/g)
^{3}H	2.54×10^{-10}	2.54×10^{-10}
^{54}Mn	2.54×10^{-10}	2.54×10^{-9}
^{59}Fe	2.54×10^{-10}	2.54×10^{-6}
^{60}Co	2.54×10^{-10}	2.54×10^{-8}
^{134,137}Cs	2.54×10^{-10}	7.62×10^{-7}

5.2.4 — CALCULATION OF THE DISCHARGE LIMIT AND DISCHARGE FORMULA

The social-economic enquiry into the feeding habits of the population encompassed by the receiving environment now allows a specification of the potentially critical groups. These are:

(1) The adult community which consumes fish caught in the stretch *AB* (daily consumption 35 g per capita).

(2) The adult community which consumes fish caught in the stretch *BC* (35 g/day per capita).

(3) The adult community which consumes fish caught downstream of the point *C* (20 g/day per capita).

Given that the amount of fish taken from the stretch *B-C* is less than that taken from the stretch *A-B* it is evident that the daily ingestion of radioactive substances by members of group 2 will be less in each case that due to group 1 and therefore will not be considered further as potentially critical.

It is now possible to proceed with the calculation of the maximum amount of each radionuclide dischargeable into the environment. To this purpose the daily ingestions through fish consumption corresponding to unit discharge are calculated and then compared with the maximum permissible ingestions for each of the same radionuclides these are obtained from [9] in an analogous manner to that in 4.2.1.

The daily ingestion through fish of the radionuclides discharged by the processing plant alone assuming unit discharge (1 Ci/year) results in the following table for groups 1 and 3.

Nuclides	Daily ingestion (μCi) for R = 1 Ci/year	
	Group 1	Group 3
^{3}H	1.7×10^{-8}	5.08×10^{-9}
^{90}Sr	5.1×10^{-6}	1.52×10^{-6}
^{106}Ru	1.7×10^{-6}	5.08×10^{-7}
$^{134,137}Cs$	5.1×10^{-5}	1.52×10^{-5}
^{144}Ce	1.7×10^{-5}	5.08×10^{-6}
^{239}Pu	1.7×10^{-6}	5.08×10^{-7}

The daily ingestion of radionuclides discharged by the nuclear power station alone, still keeping $R = 1$, for group 3 which is the only group concerned in such a discharge results in the following table

Nuclides	Daily ingestion (μCi) for R = 1 Ci/year
^{3}H	5.08×10^{-9}
^{54}Mn	5.08×10^{-8}
^{59}Fe	5.08×10^{-5}
^{60}Co	5.08×10^{-7}
$^{134,137}Cs$	1.52×10^{-5}

For all the various radionuclides ingested through fish from [9] the maximum daily permissible ingestions are:

Nuclides	Maximum daily permissible ingestion (μCi)
^{3}H	7.1
^{54}Mn	2.62×10^{-1}
^{59}Fe	1.15×10^{-1}
^{60}Co	7.7×10^{-2}
^{90}Sr	8.8×10^{-4}
^{106}Ru	2.6×10^{-2}
^{134}Cs	1.9×10^{-2}
^{137}Cs	3.3×10^{-2}
^{144}Ce	2.6×10^{-2}
^{289}Pu	1.0×10^{-2}

By simple proportion it is now possible to calculate the maximum dischargeable amount of the various radionuclides from both installations considered separately for each of the potentially critical groups.

The following values in curies are obtained

Nuclides	Processing plant		Nuclear power station
	Group 1	Group 3	Group 3
^{3}H	4.2×10^{8}	1.4×10^{9}	1.4×10^{9}
^{54}Mn	—	—	5.2×10^{6}
^{59}Fe	—	—	2.3×10^{3}
^{60}Co	—	—	1.5×10^{5}
^{90}Sr	1.7×10^{2}	5.8×10^{2}	—
^{106}Ru	1.5×10^{4}	5.1×10^{4}	—
^{134}Cs	3.7×10^{2}	1.2×10^{3}	1.2×10^{3}
^{137}Cs	6.5×10^{2}	2.2×10^{3}	2.2×10^{3}
^{144}Ce	1.5×10^{3}	5.1×10^{3}	—
^{239}Pu	5.9×10^{3}	2.0×10^{4}	—

The preceeding table allows immediate identification of the critical group for each radionuclide concerned. From the previously determined discharge limits it is possible to pass finally to the three discharge formulae which are:

(a) discharges from the processing plant alone;

(b) discharges from the nuclear power plant alone;

(c) discharges from both installations combined.

(a) *Discharge formula for the processing plant*

The term which must be complied with for the discharge of the various radionuclides originating from the installation in question will be

$$\frac{q_{^{3}H}}{4.2 \times 10^{8}} + \frac{q_{^{90}Sr}}{1.7 \times 10^{2}} + \frac{q_{^{106}Ru}}{1.5 \times 10^{4}} + \frac{q_{^{134}Cs}}{3.7 \times 10^{2}} + \frac{q_{^{137}Cs}}{6.5 \times 10^{2}} + \frac{q_{^{144}Ce}}{1.5 \times 10^{3}} + \frac{q_{^{239}Pu}}{5.9 \times 10^{3}} \leqslant 1$$

where q_i is expressed in Ci/year.

(b) *Discharge formula for the nuclear power station*

The expression which must be complied with for the discharge of the various radionuclides originating from the nuclear power station will be

$$\frac{q_{^{3}\mathrm{H}}}{1.4\times10^{9}}+\frac{q_{^{54}\mathrm{Mn}}}{5.2\times10^{6}}+\frac{q_{^{59}\mathrm{Fe}}}{2.3\times10^{3}}+\frac{q_{^{60}\mathrm{Co}}}{1.5\times10^{5}}+\frac{q_{^{134}\mathrm{Cs}}}{1.2\times10^{3}}+\frac{q_{^{137}\mathrm{Cs}}}{2.2\times10^{3}}\leqslant 1$$

(c) *Formula for the combined discharge*

In addition to the two preceeding expressions the following expression must also be complied with for the simultaneous discharge from both installations and for which the common critical group is group 3.

$$\frac{q'_{^{3}\mathrm{H}}}{1.4\times10^{9}}+\frac{q''_{^{3}\mathrm{H}}}{1.4\times10^{9}}+\frac{q''_{^{54}\mathrm{Mn}}}{5.2\times10^{6}}+\frac{q''_{^{59}\mathrm{Fe}}}{2.3\times10^{3}}+\frac{q''_{^{60}\mathrm{Co}}}{1.5\times10^{5}}+\frac{q'_{^{90}\mathrm{Sr}}}{5.8\times10^{2}}+\frac{q'_{^{106}\mathrm{Ru}}}{5.1\times10^{4}}+\frac{q'_{^{134}\mathrm{Cs}}}{1.2\times10^{3}}$$

$$+\frac{q''_{^{134}\mathrm{Cs}}}{1.2\times10^{3}}+\frac{q'_{^{137}\mathrm{Cs}}}{2.2\times10^{3}}+\frac{q''_{^{137}\mathrm{Cs}}}{2.2\times10^{3}}+\frac{q'_{^{144}\mathrm{Ce}}}{5.1\times10^{3}}+\frac{q'_{^{239}\mathrm{Pu}}}{2.0\times10^{4}}\leqslant 1$$

in which q'_i and q''_i represent the dischargeable amounts from the processing plant and the nuclear power station respectively. These amounts will be fixed in proportion to the various discharge limits on the basis of the requirements of the installations or of other criteria.

6 — DISCHARGE OF GASEOUS WASTE INTO THE ATMOSPHERE

6.1 — Introduction

By the use of some examples in the preceeding pages an illustration was given of the way in which the mathematical model could be developed to determine the receptive capacity of a hydrobiological environment and how it could actually be applied in the derivation of a formula for the discharge of radioactive liquid waste.

It is proposed to demonstrate with further examples that the validity of the method is not limited only to the case of liquid waste but with some variation it can be extended to the case of gaseous waste. The case considered is that of the regular discharge of ^{131}I from a nuclear power station.

In the area surrounding the installation there are pastures used to feed milking cows whose drinking water is supplied by an aqueduct which is not open to contamination from the installation.

6.2 — Application of the method

6.2.1 — PRIMARY RECEIVING ENVIRONMENT

In this, the atmosphere is the primary receiving environment. For the application of the method it is necessary to point out that the principal difference between this case and the preceding one is the fact that the atmosphere which is concerned with this discharge is not an environment confined within definite limits as were the watercourses in the other examples.

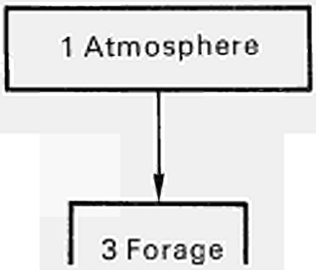
A good description of the relationships between the mean concentration in the air and the intensity of the discharge is given by an elaboration of Pasquill's formula as applied to a continuous discharge which takes into account the mean annual meteorological conditions of the zone concerned.

The application of such a formula to the case in question allows an evaluation of the mean annual concentration in the air immediately above the soil of the forage fields.

The value of this concentration turns out to be $C = 10^{-14}\ \mu\text{Ci/cm}^3$ for an annual unit release ($R = 1$ Ci/year) from the running of the installation.

6.2.2 — Receiving environment of terrestrial plants

Considering that the mean life of ^{131}I is rather short compared with the time taken for the radionuclide to pass from the air through the forage to the soil, it is possible for the receiving environment of terrestrial plants to be reduced in an actual case to the following scheme



The amount of ^{131}I deposited onto the soil, expressed in units of Ci/m^2/year, can be calculated, provided the velocity of deposition in the absence of precipitation (e.g. 0.50 cm/sec). the wash-out factor* (e.g. 500) and the rainfall (e.g. 1000 mm/year) are known. The numerical value referring to the example under consideration is:

$$^{131}\text{I deposition} = 10^{-14}(\text{Ci/m}^3)\cdot 5\times 10^{-3}(\text{m/sec})\cdot 3.15\cdot 10^7(\text{sec/year})$$

$$+\,10^{-14}(\text{Ci/m}^3)\cdot 500(\text{wash-out factor})\cdot \frac{1}{1{,}293}\,(\text{m}^3/\text{kg of air})\cdot 1000\ (\text{mm/year})$$

$$= 6.5\times 10^{-9}\ (\text{Ci/m}^2/\text{year}).$$

This amount multiplied by the interception factor (the fraction of ^{131}I which has fallen and has been retained by the grass) and divided by the productivity of the soil (kg of forage per m^2 of soil), gives the amount which becomes absorbed by the plants in a year and corresponds to the value $C_1 k_{13}$ according to the notation used in equation 24 given in [1]

$$C_i(t) = C_1(t)^* \, k_{1i}\, e^{-(K_i+\lambda)t} + C_2(t)^* \, k_{2i}\, e^{-(K_i+\lambda)t}$$

In the case considered having an interception factor of 0.5 and a productivity of 2 kg/m^2 one obtains

$$C_1 k_{13} = 1.6\times 10^{-9}\ \text{Ci/fresh kg/year}$$

Since the removal of the iodine from the grass is either due to radioactive decay or to other phenomena typical of the natural environment (transfer to the roots, washing away by rain, death and decomposition of the leaves etc.) all taken to happen with a half life of 5 days [8], [15] the mean concentration in the forage will be

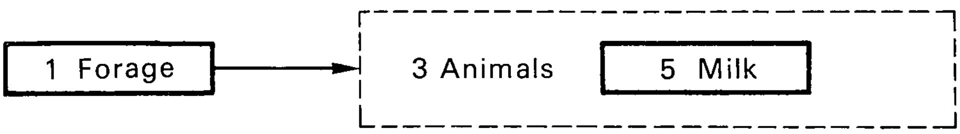
$$C_3 = \frac{C_1 k_{13}}{K_3+\lambda} = 3.2\times 10^{-11}\ \text{Ci/fresh kg}$$

---

* The wash-out factor $= \dfrac{\text{concentration in rain (Ci/kg)}}{\text{concentration in air (Ci/kg)}}$.

6.2.3 — RECEIVING ENVIRONMENT OF TERRESTRIAL ANIMALS

As previously emphasized, in the vicinity of the installation the rearing of milking cows takes place, they are fed all the year round on fresh forage and they drink uncontaminated water. Consequently the scheme can be reduced to the following term.



Substituting V_5 for M_4 and K_5 for K_4 in equation 25 on page 38 [1]

$$C_4 = \frac{C_1 k_{13} + C_2 k_{23}}{M_4 (K_4 + \lambda)}$$

and applying the simplified partial system gives

$$C_5 = \frac{C_1 k_{13}}{V_5 (K_5 + \lambda)}$$

The substituting numerical values

C_1 = 3.2×10^{-11} Ci/fresh kg (in equilibrium);

k_{13} = 60 kg/days foraging (fresh weight) per animal [15];

V_5 = 200 litres. This distribution volume has been calculated by extrapolating to zero the milk secretion following an instantaneous ingestion (page 303 [8]).

K_5 = 0.91 days^{-1}. Elimination constant calculated on the basis of a halving time of 0.76 days in the milk (page 303 [8]).

λ = 0.087 days $^{-1}$.

then $C_5 = 10^{-11}$ Ci/litre.

6.2.4 — CALCULATION OF THE DISCHARGE LIMIT AND DISCHARGE FORMULA

The ecological enquiry into the zone surrounding the installation also the social-economic study of the feeding habits of the population within the receiving environment have both indicated the absence of other ways of propagation of the contamination outside the forage-cow-milkman chain.

In particular the critical group is that of infants fed on cows milk. These infants consume 0.9 litres/day per capita of milk. From results shown previously a daily ingestion of 9×10^{-12} Ci/day is obtained for a unit discharge (1 Ci/year) of ^{131}I.

Assuming a dose limit of 1.5 rem/year to the thyroid [16, 17], for the infants of the population, the resulting daily ingestion will be 2.75×10^{-10} Ci/day [15] and therefore the discharge limit of ^{131}I is 30 Ci/year for the environment under consideration.

Hence the discharge formula in this case takes the form of the following expression

$$\frac{q_{^{131}\mathrm{I}}}{30} \leqslant 1$$

where $q_{^{131}\mathrm{I}}$ is the effective amount (in Ci) continuously dischargeable in one year.

7 — EXTENSION OF THE MODEL TO COVER NON RADIOACTIVE POLLUTION PROBLEMS

Analogies exist between radioactive pollution and certain types of other types of pollution as will be better explained shortly, these analogies lead to the extension of the methods already given and along essentially similar lines to those of the strictly nuclear field.

The other types of pollution which are particularly well suited to simulation by some types of radioactive pollution are of the micro-chemical types which have little or no quality of degradation and which retain their characteristics and possibly their toxicity for a long time. The comparison with the non radioactive field must be limited to micro-pollution, this is easily understood when it is remembered that the model elaborated for radioactive pollution is based on the assumption that the effect of mass can be disregarded when considering the phenomena which occur after the discharge and which influence the distribution of the contamination within the environment*.

Comparing radioactive pollution with chemical pollution there appears to be a distinct analogy between

(a) radionuclides with a medium or short half-life on the one hand and unstable chemical contaminants on the other;

(b) radionuclides with a long or very long half-life on the one hand and chemical contaminants which are more or less stable on the other hand.

It is well to remember however that whilst the radioactive disintegrations obey an unchanging physical law, the chemical contaminants do not have a degradation constant but instead are bound to various phenomena and processes which are variable in time and space.

Another analogy between the two pollutants rests with the fact that both radionuclides and chemical contamination are subject to concentration effects which produce a progressive accumulation in certain links of the alimentary chain. It is true also that the higher sensitivity of physical methods of measurement of radioactivity allow the identification and assessment of much smaller amounts than those determinable by chemical methods. The concept of an alimentary chain currently adopted in radiological studies of the propagation of radioactive wastes from discharge to man has still not been fully explored in the non radioactive field. An incidental difficulty only, is being dealt with here because nothing can invalidate the parallelism which is now established.

Two further observations arise from the comparison between the two types of pollution. Firstly the radioactive contamination is different in that it can produce both internal and external irradiation of man whereas chemical pollution is only looked upon as a source of internal poisoning of the individual which in that case reduces the number of paths of propagation to be considered and thus simplifies the problem.

The second observation concerns the fact that whilst in the field of radioactivity the protection of the human species, which is among the most radiosensitive, assumes the protection of the environment itself, in the non radioactive field this is not so because the two aspects must be evaluated independently according to criteria and methods not necessarily the same.

In regard to the application of the method discussed to the resolution of problems connected with non radioactive toxic pollution it should be remembered that in the field of radioactivity one is not limited to the consideration of the immediate effects of acute irradiation, that is to phenomena which are relevant but of short duration but also the longer term genetic effects by chronic

---

* Nevertheless, in those cases in which the effect of mass is not negligible and the theory of linear compartments is no longer applicable, appropriate models with a different but more suitable mathematical approach can be used.

irradiation from low doses have to be considered. This does not apply to the non radioactive field in which what is known (at best) is the lethal concentration or the so called L. D.$_{50}$ (i.e. the dose which carries a 50% probability of death within a fixed time for a group of organisms), while for even the most common pollutants the amount which can be absorbed by an organism for the duration of a normal lifetime without suffering appreciable damage is unknown.

It is significant that for many if not all of the chemical contaminants reference values still do not exist which are comparable to those in the field of radioactivity i.e. maximum permissible doses for the population or derived operational values (maximum permissible intakes, maximum permissible concentration and so on). Indeed the mechanism by which organisms are damaged through chemical pollutants is extremely varied and complex and also the lack of a common unit (like the rem for radioactive pollutants) makes it impossible to sum up arithmetically the harm done by chemical pollutants. Synergistic and antagonistic phenomena exist also which are however a long way from being understood.

In the case of chemical pollution it is certainly more difficult to fix the reference levels than it was for radioactive pollution particularly for chronic pollution at low concentrations. Another difficulty in applying the same model is the lack of detailed quantitative information on all the processes which link the various compartments of the receiving environment. The lack of this information cannot be ignored in the radioactive field where the most up to date knowledge of applied ecology is required to apply the method explained and it was seen to be necessary to resort to certain artifices even in that case. In the non radioactive field however the situation is much worse and much more research is required still.

Of the two deficiencies, lack of reference levels and lack of quantitative data on the transfer processes the first is by far the most grave and prejudicial to the maintenance of the good health of the population. It is most necessary that scientists specify such levels because no serious discussion can take place on the protection of man and his environment without this knowledge.

In regard to the second deficiency it is not the intention of the authors to under-value a full and precise knowledge of all the phenomena which influence the exchange of chemical pollutants between the individual components of the environment. With the object of applying the model, it is well to note that the number of parameters of any importance which it is necessary to know is not unduly great. For example it is not strictly indispensable to have all the data on the transfer processes of the micropollutants between all the trophic levels of the aquatic fauna compartment but it is sufficient to know to a good approximation the behaviour of the last link in the alimentary chain, considering that the model is directed towards the protection of man.

A mathematical model of the type proposed has the advantage of contributing to the orientation of future applied ecological research, indicating which are the transfers of chemical contaminants which concern practical ends and which characteristics, phenomena and processes of the receiving environment should engage the interest of the research worker.

BIBLIOGRAPHY

1. BRANCA, G., BREUER, F., CIGNA, A. A., and AMAVIS, R., Principles and Methods for the Derivation of a Formula for the Discharge of Radioactive Liquid Wastes in Surface Waters, EUR 4636e (1971).
2. Standardisation of Radioactive Waste Categories. Technical Reports Series No. 101, IAEA (1970).
3. VAN DER STRICHT, E., GAGLIONE, P., and DE BORTOLI, M., Valutazione della contaminazione dell'erba e del latte dovuta al ^{137}Cs presente nelle ricadute radioattive. *Giornale di Fisica Sanitaria e Radioprotezione*, **14**, 53-60, 1970.
4. VAN DER STRICHT, E., GAGLIONE, P., and DE BORTOLI, M., Predictions of ^{90}Sr levels in milk on the basis of deposition values. *Congresso dell'IRPA*, *Brighton*, maggio 1970.
5. BARBIER, G., *La rétention et la migration des ions radio-actifs dans les sols*, 145-150, Presses Universitaires de France, Paris (1963).
6. BARBIER, G., Étude expérimentale de la contamination radio-active des cultures notamment par l'eau d'irrigation. *C. R. Acad. Agriculture France*, 611/620 (1963).
7. CARNER, R. J., Environmental contamination and grazing animals. *Health Phys.*, **9** 597/605 (1963).
8. SCOTT RUSSELL, R. (Ed.), *Radioactivity and Human Diet*. Pergamon Press (1966).
9. I. A. E. A., Basic safety standards for Radiation Protection. Safety Series No. 9, (1967).
10. BREUER, F., Rapporti tra le " concentrazioni limite " di sostanze radioattive per bambini e per adulti nelle sostanze alimentari. *Giorn. Fis. San. Radioprotezione*. **12**, 233/238 (1968); CNEN RT/PROT (69) 40.
11. BREUER, F., BROFFERIO, C., and NARDI, A., Considerazioni sui parametri da utilizzare nel calcolo dei "Livelli di riferimento derivati " per emergenze nucleari. *Memoria presentata al XV Congr. Nazionale AIFSPR*, Cagliari 1969 (in press).
12. DE BORTOLI, M. and GAGLIONE, P., EUR/C-IS/880/70i.
13. CIGNA ROSSI, L. and CIGNA, A. A., *Giornale di Fisica Sanitaria Radioprotezione*, **12** (4) 261/271 (1968); CNEN RT/PROT (69) 30.
14. CAGNETTI, P., Determination of the equal-concentration curves in the air around a continuous release of a radioactive effluent, on the basis of the meteorological information collected on site. *Giorn. Fis. San. Radioprotezione*, **12** (4) 239/251 (1968); CNEN RT/PROT (69) 37.
15. BREUER, F. and DE BORTOLI, M., Comportamento del radioiodio nell'ambiente e nell'uomo. *XVII Congresso nazionale dell'Associazione Italiana di Fisica Sanitaria e Protezione contro le Radiazioni*. Monteporzio Catone (Roma), 5-7 ottobre 1971 (in press).
16. Recommendations of the International Commission on Radiological Protection. ICRP Publication 9.
17. Dirretive della C. E. E. A. che fissano le norme fondamentali relative alla protezione sanitaria della popolazione e dei lavoratori contro i pericoli derivanti dalle radiazioni ionizzanti adottate il 2.2.1959 (G.U. delle Comunità Europee n° 11 del 20.2.1959), modificate con direttive del 5.3.1962 (G.U. delle Comunità Europee n° 57 del 9.7.1962) e direttive del 27.10.1966 (G.U. n° 216 dell 26.11.1966).

NOTICE TO THE READER

All scientific and technical reports published by the Commission of the European Communities are announced in the monthly periodical **"euro-abstracts"**. For subscription (1 year: B.Fr. 1 025,—) or free specimen copies please write to:

Office for Official Publications
of the European Communities
Case postale 1003
Luxembourg 1
(Grand-Duchy of Luxembourg)

> To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.
>
> Alfred Nobel

SALES OFFICES

The Office for Official Publications sells all documents published by the Commission of the European Communities at the addresses listed below, at the price given on cover. When ordering, specify clearly the exact reference and the title of the document.

GREAT BRITAIN AND THE COMMONWEALTH

H.M. Stationery Office
P.O. Box 569
London S.E. 1

UNITED STATES OF AMERICA

European Community Information Service
2100 M Street, N.W.
Suite 707
Washington, D.C. 20 037

BELGIUM

Moniteur belge *Belgisch Staatsblad*
Rue de Louvain 40-42 Leuvenseweg 40-42
1000 Bruxelles 1000 Brussel 12 00 26
CCP 50-80 Postgiro 50-80

Agency:
Librairie européenne Europese Boekhandel
Rue de la Loi 244 Wetstraat 244
1040 Bruxelles 1040 Brussel

GRAND DUCHY OF LUXEMBOURG

Office for Official Publications
of the European Communities
Case postale 1003 Luxembourg 1
and 29, rue Aldringen, Library
Tel. 4 79 41 CCP 191-90
Compte courant bancaire: BIL 8-109/6003/200

FRANCE

Service de vente en France des publications
des Communautés européennes
26, rue Desaix
75 Paris-15ᵉ Tel. (1) 306.5100
CCP Paris 23-96

GERMANY (FR)

Verlag Bundesanzeiger
5 Köln 1 Postfach 108 006
Tel. (0221) 21 03 48
Telex: Anzeiger Bonn 08 882 595
Postscheckkonto 834 00 Köln

ITALY

Libreria dello Stato
Piazza G. Verdi 10
00198 Roma Tel. (6) 85 09
CCP 1/2640

Agencies:
00187 Roma Via del Tritone 61/A e 61/B
00187 Roma Via XX Settembre (Palazzo Ministero delle finanze)
20121 Milano Galleria Vittorio Emanuele 3
80121 Napoli Via Chiaia 5
50129 Firenze Via Cavour 46/R
16121 Genova Via XII Ottobre 172
40125 Bologna Strada Maggiore 23/A

NETHERLANDS

Staatsdrukkerij- en uitgeverijbedrijf
Christoffel Plantijnstraat
's-Gravenhage Tel. (070) 81 45 11
Giro 425 300

IRELAND

Stationery Office
Beggar's Bush
Dublin 4

SWITZERLAND

Librairie Payot
6, rue Grenus
1211 Genève
CCP 12-236 Genève

SWEDEN

Librairie C.E. Fritze
2, Fredsgatan
Stockholm 16
Post Giro 193, Bank Giro 73/4015

SPAIN

Libreria Mundi-Prensa
Castello, 37
Madrid 1

OTHER COUNTRIES

Office for Official Publications
of the European Communities
Case postale 1003 Luxembourg 1
Tel. 4 79 41 CCP 191-90
Compte courant bancaire: BIL 8-109/6003/200

OFFICE FOR OFFICIAL PUBLICATIONS OF THE EUROPEAN COMMUNITIES
Case postale 1003 — Luxembourg 1 5928

CDNA04897ENC