VADOSCA: A SIMPLE CODE FOR THE EVALUATION OF POPULATION EXPOSURE DUE TO RADIOACTIVE DISCHARGES

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Abstract

The code consists of two parts, one for liquid discharges (VADOSCA-LI) and one for gaseous discharges (VADOSCA-GAS), and it incorporates the transfer parameters of twenty-four radioisotopes in the case of liquid discharges, and of twenty radioisotopes in the case of gaseous discharges. It allows the evaluation of the concentrations of the various isotopes in all the compartments of the critical paths outlined in the ICRP Publication No. 7, and the evaluation of the annual doses for five critical organs (whole body, G.I. tract, thyroid, bones, lung) for the various critical groups of population, on the basis of environmental parameters, such as the time of residence in a certain area, diet, type of activity, hydrological regimen, irrigation methods, and meteorological conditions.

Although extremely simple, the code allows rapid performance of all the evaluations required to define the amount of radioactivity that can be released and the associated exposures.

Introduction

As the peaceful uses of nuclear energy expanded, a great number of criteria had been voiced on environmental protection against radioactive discharges from nuclear plant; in 1965 they were collected in an orderly form in the ICRP Publication No. 7. In the light of the acquired knowledge of reconcentration of radionuclides in the environment as a result of chemical-physical (absorption, sedimentation) and biological processes, ICRP suggested assessing the doses due to the discharges following all the possible paths from the plant to man. This approach calls for a wide knowledge of the environment and transfer parameters of all nuclides present in the discharges, and sophisticated computer programs[1].

In the meanwhile the public opinion had risen against environmental degradation to the point of objecting even to the construction and operation of nuclear power stations, and especially to their effluents. The Regulatory Agencies were thus pressed to lower the limits of discharged radioactivity and to request of each station an analysis of its impact on the environment, more or less in harmony with the ICRP recommendations. This attitude is very well illustrated in a recent AEC document[2], which analyzes the merits of the various types of waste treatment plants in the light of the reduction of the population exposure to "as low as practicable" values.

Likewise, in Italy CNEN has long ago adopted the criterion of issuing operating licenses containing limitations on the radioactive discharges based on the actual station requirements and on an analysis of the receptivity of the environment. ENEL, the national producer and distributor of electricity in Italy, responsible for providing to CNEN such an impact analysis for its nuclear stations, developed a computer code in two parts that simplify the evaluation of of population exposure due to liquid and gaseous radioactive wastes (called VADOSCA-Li and VADOSCA-Gas).

VADOSCA-Li

In its present form, the code covers twenty-four radionuclides, of which some are fission products (^{89}Sr, ^{90}Sr, ^{91}Y, ^{95}Zr, ^{106}Ru, ^{131}I, ^{134}Cs, ^{137}Cs, ^{140}Ba, ^{144}Ce), others are activation products (^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{45}Ca, ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{65}Zn, ^{110m}Ag, ^{124}Sb), plus an alpha emitter, ^{239}Pu. The choice of these nuclides was dictated by the frequency of their presence in the station discharges and by their radiotoxicity. Nuclides having a half-life of less than a few days are not considered. However, the code can handle thirty isotopes to accommodate particular situations with isotopes that are not listed above.

When the wastes are discharged to a closed body of water (sea or lake) the main dilution considered is that due to the condenser coolant; moreover, dilution coefficients are fed to the computer for each critical path and for each single case on the basis of hydrological and thermal considerations. Introduction of the commonly used diffusion models[3,4] was avoided because they lack the required flexibility and they required a semi-empirical approach.

When the wastes are discharged into a river, they are considered diluted first by the condenser coolant and then by the average flow of the river itself. If the water table is involved, decontamination coefficients are fed to the computer to take into account the absorption due to the soils crossed by the liquid. Finally, additional dilution coefficients can be introduced for each pathway to take into account any other mechanisms, such as suitably large tributaries or sedimentation effects.

Fig. 1 provides a schematic illustration of the critical pathways considered for the liquid wastes. The code calculates the doses to four special groups, namely, fishermen, other workmen, local population, farmers. A separate calculation is made for the doses originated by drinking water. The doses are evaluated for five critical organs (whole body, gastro-intestinal tract, thyroid, bones, lungs) and they are expressed in mrem/year if the discharges are ex-

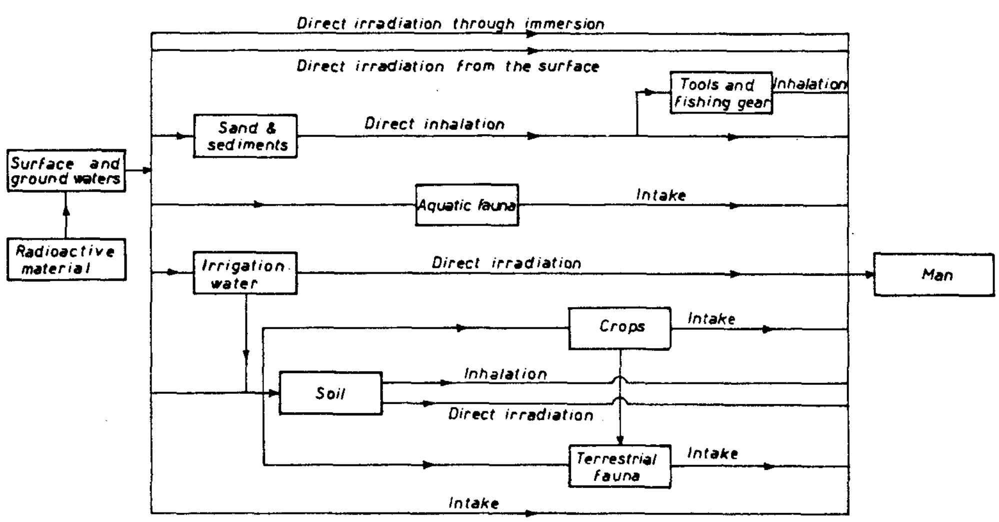

Fig. 1 - Critical pathways for liquid discharge

pressed in Ci/year.

The concentrations in each compartment in Fig. 1 are obtained by means of a linear relation from the preceding compartment and with the transfer coefficients taken from the literature or from the concentrations of stable isotopes in the respective compartments or evaluated on the basis of other considerations, as illustrated below.

Marine biota and fresh water fish. Frecke's[5] concentration factors were used for the former, whereas reference was made to the concentration factors found in the literature[6,7,8] for the latter.

Irrigated crops. Six types of crops were considered, namely, rice, other cereals, leafy vegetables (including forage), radishes, other vegetables and fruit. The literature provides very scanty information on the relative concentration factors, so reference was often made to the method of specific activity; a standard concentration was assumed for fresh water and the concentrations for the vegetables were taken from the literature. When this method was not applicable, the concentration factors of chemically similar elements were used.

Terrestrial animals and products. The following critical pathways were considered: meat of herbivors (beef, rabbit, lamb, pork) and milk, poultry and eggs. The radionuclide transfer is considered from the forage for herbivors and from cereals for poultry. The transfer factors for C, P, S, Ca, Fe, Mn, I, Zn, Co, Sr were obtained by the specific activity method, the factor for Cs from the literature[9], Cr, Co, Y, Zr, Ru, Ag, Sb, Ba, Ce and Pu were considered little assimilated by the GI tract, (i.e. 1% in respect of Cs).

Sediments. Lacking specific data that would any way strongly depend on local factors (meteorology, hydrology, type of river banks and soils), we assumed standard transfer factors that varied by a factor of 10 depending on the half life and type of sediment (sandy or silty). The tailrace was taken as the preceding compartment before complete mixing with the receiving body.

Irrigated tillage. The irrigating water was assumed to deposit its radioactivity in the first ten centimeters of soil and equilibrium concentration was assumed to be reached with a 15% leaching yearly.

Once the concentration in each compartment is known, the doses to the critical groups are calculated taking into account critical parameters, such as time of residence in water, on water, on sediments, on irrigated land, dietary habits, and working time. The doses due to irradiation from water and land were calculated with the formula[10]:

$$D_i = 1.06 \times 10^3 \times Ci \times Si \times T$$

where D is expressed in mrem/yr, C_i is the concentration of isotope i (Ci/m^3), S_i is the energy of beta and gamma rays emitted by the isotope i (Mev), T is the irradiation time (hours). The formula is based on the assumption of a plane infinite source and it overestimates the actual dose. When applied to sediments, the formula gave an excessive dose because of their high concentration factors; therefore, a more sophistical mathematical treatment[11] was used, whereby allowance is made for the actual thickness of the sediments, for the overlying water layer and for the geometry effect of the source (semi-plane in the case of irradiation of a critical group residing on river banks or sea coast).

For the intake doses the CMAs given in the ICRP Publication No. 2 for the various organs, following the method proposed by Essig[12], and the yearly food consumption of the various population groups were used.

The doses due to inhalation of resuspended material (sediments and agricultural soil) are factored in by assuming a standard breathing rate of 0.83 m^3/hr and a content of airborne particulates of 10 mg/m^3. The latter value is a maximum obtained from samples of air taken in different conditions, such as open country, construction sites, residential areas.

The code is written in FORTRAN; it needs 20 K memories and it takes approximately 15 seconds in a GE 635 computer.

VADOSCA-Gas

Twenty nuclides are considered, of which eight noble gases (fission and activation products: ^{41}A, ^{85m}Kr, ^{85}Kr, ^{87}Kr, ^{88}Kr, ^{133}Xe, ^{135}Xe, ^{138}Xe), various isotopes as particulates (^{60}Co, ^{88}Rb, ^{89}Sr, ^{90}Sr, ^{131}I, ^{134}Cs, ^{137}Cs, ^{138}Cs, ^{239}Pu), and ^{3}H, ^{13}N, ^{14}C in the form of vapor. Short-lived isotopes were taken into account only when experience indicated that they might be present in the discharges. At any rate, the code can accommodate other five nuclides. For each nuclide it is necessary to supply the average yearly discharge.

Atmospheric diffusion is evaluated with Pasquill's theory[13] adapted to the meteorological data available. In fact, two sets of information are handled by the code, namely,

Set A: Only a wind rose and an average distribution of the six stability categories are available. This is the general case described by P. Bryant[13].

Set B: In this case, in addition to the wind rose, one must have the frequency distribution of the stability categories for each wind direction, subdivided by wind speed ranges. This is the sort of information used by May and Stuart for their diffusion analysis at Brookhaven[14].

For simplicity, in its present form the code does not take into account particular effects such as the cloud depletion due to deposition, down draft and building effect; the particulate deposition rate is assumed constant at 3×10^{-2} m/s.

Fig. 2 shows the critical pathways for gaseous discharges. Two sets of doses are considered: (1) doses due to irradiation and inhalation as a function of the distance from the stack and direction of plume travel; (2) doses due to intake of agricultural (vegetal and animal) produce. The former are calculated

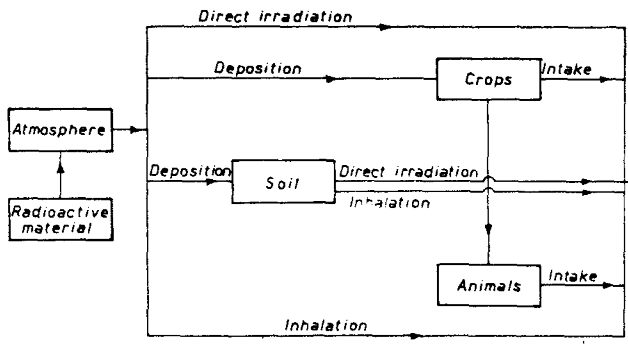

Fig 2 Critical pathways for discharges to the atmosphere

over a discrete number of distances between 0.3 and 50 km and for a maximum of sixteen sectors; the latter are calculated only at the point of maximum fall-out and for two population groups (farmers and local population) and for the usual five organs.

The exposure due to the cloud is calculated with a method developed by Gamertsfelder[15]. This method takes into account the contribution made by a cloud of finite dimentions with a gaussian vertical concentration distribution and an average horizontal concentration.

The exposure due to inhalation is calculated from the ground concentrations, evaluated with Pasquill's formula[13]. The same formula is used to calculate the deposition on the crops, excluding the short-lived ^{88}Rb and ^{138}Cs.

The transfer factors for crops were calculated taking into account the growth time of the crops, the concentrations of the stable isotopes, the decontamination due to decay and processing. The related doses were calculated like those resulting from the liquid discharges.

The code is written in Fortran; it needs 60 K memories and it takes about 60 seconds in a GE 635 computer.

General Comments

Applied to the analysis of environmental impact, VADOSCA has proved to be a useful tool for the health physicist. While relieving him of painstaking calculations, it has compelled him to single out from the host of ecological data those that were most significant for radioprotection. In practical application, it was necessary to modify the standard transfer factors to adapt the code to the results of the surveys at the nuclear station sites. For instance, for the nuclear station on the Garigliano river at 11 km from the coast, the Cs transfer factor for fish was found to be much lower (200) than the standard value (1000). Instead, at Trino Vercellese on the upper course of the Po river the same factor was 1400 and for certain species of fish that feed on periphyton it was as high as 2500. This example is typical to illustrate the limitations of this type of code, which starts from standard values selected conservatively and then must be adapted through successive approximations.

In the negotiations with the safety authorities for the discharge permits, the availability of an agreed standard code facilitates mutual understanding and saves considerable time.

It is recognized that further improvements of the code are necessary in order to factor in all the information on radioactivity concentration and dispersion mechanisms in the environment that is building up. Moreover, the next step should be the use of dynamic models of the type already widely used in other branches of ecology[1,16], but this will be warranted only when a better understanding of the aforesaid mechanisms has been acquired and more complex problems are to be dealt with.

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