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Modelling of artificial radioactivity migration in environment : a survey

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Introduction

The production of electrical energy in nuclear power plants results always in the release towards the environment of non-negligible quantities of radioactive effluents which are potentially noxious for mankind. However, also the use of fossil fuel in conventional power plants results in gaseous effluent releases containing trace quantities of some radioelements (uranium, radium).

In the case of nuclear fuel exploitation, the whole fuel cycle is concerned, through its different steps of mining and milling, fuel fabrication, thermal energy production, irradiated fuel reprocessing and radioactive waste conditioning, storage and disposal; during each one of these steps, controlled and possible accidental releases of radioactive effluents can occur, which contain some fission and activation products.
Once the pollutants have been released into the environment, they spread, migrate and evolve following laws which depend on:

- their chemical properties and physical state;
- the features of the receptor site and its environment;
- the time span available.

Finally, the pollutants can reach man through various pathways, i.e. inhalation, ingestion, skin adsorption, or can act by external irradiation.

It is very important to be able to establish a sufficiently precise relationship between the pollutant quantitites released into the environment (for instance, per unit of electrical power installed) and the dose which population undergoes, or could accidentally undergo.
To this goal, it is necessary to possess adequate models which should permit to assess a priori, for a given release mode and extent of a given pollutants set, their impact on the environment and population.

Finally, the capability to predict in quantitative terms the detritment to population associated with the exploitation of various types of power plants, should permit to compare them on the basis of their impact on population health and safety, and to identify pollutant critical pathways and their governing parameters, so that adequate measures could be taken.

The present models and computer codes catalogue represent a first step to provide a comprehensive survey of the material available in the current literature in the field of environmental migration modeling of those radioelements which are of particular concern in causing the consequences of nuclear energy exploitation; in fact, only through the availability of a sufficient set of models and environmental data, it will be possible to assess both immediate and future consequences of nuclear installations.

Particular attention was paid by most of the authors to some critical subject areas, such as aquatic and atmospheric dispersion of radioelements, aquatic and terrestrial food chains, doses to man's organs from internal and external exposure, while more specific and restricted areas, like soil deposition and resuspension or other particular topics were less extensively investigated.

A previous compilation of codes for nuclear accident analysis was performed by Winton[1] in 1969; again in 1971 and 1974 Winton published similar compilations of computer codes, grouped into different classes following their characteristics [2,3]. More recently, Hoffman, Miller et al.[4] presented a compilation of 83 environmental models, dealing with accidental and routine releases of radioactivity from nuclear power plants; initially, attention was largely concentrated on atmospheric dispersion phenomena, and inhalation pathways.

We have therefore thought that an up-to-date list of the models describing the behaviour of radioisotopes released from nuclear facilities, and their impact on environment and man, could be of some utility, mainly if the most relevant characterics and features of each model might bè summarized, in schematic form, in a set of cards; in fact, we think that scientists faced with similar problems could appreciate being helped in chosing, among the numerous existing models, those which contain either mathematical treatments or numnerical information or both, which can be assembled to form a new specific model, following the particular needs and personal preferences.

In Table 1, the properties of all the collected models are summarized, in order to facilitate the identification of the interesting ones.
The cards include information on the specific areas of environmental transport and dosimetry that each model takes into account, as well as information on whether accidental or routine releases are considered; a brief description of the model is then given.

Figure 1 shows the various topics of environmental transport and radiation dosimetry, according to the frequency with which they are treated in the models; from this analysis it appears that atmospheric transport has received a great attention, as well as ingestion and inhalation pathways to man; aquatic transport seems to be less extensively investigated. Obviously routine releases are more frequently described than accidental ones. Some models are applicable to a variety of cases, while others are very specific in their purposes.

Atmospheric Transport

The basic equation used in most of the models to estimate atmospheric dispersion is Pasquill's equation as modified by Gifford[5]:

$$x = \frac{Q}{2\pi \sigma_y \sigma_z \mu} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \quad (1)$$

where

- χ concentration in air at the centerline of a plume X meters downwind from the point of release (curies/m^3),
- Q emission rate from the stack (curies/sec),
- μ mean wind speed (m/sec),
- σ_y horizontal dispersion coefficient (m),
- σ_z vertical dispersion coefficient (m),
- H effective stack height (physical stack height, h, plus the plume rise, Δ h) (m),
- y crosswind distance (m), and
- z vertical distance (m).

The downwind distance, x, comes into Eq.(1) through σ_y and σ_z which are functions of x as well as the atmospheric stability category applicable during emission from the stack. Pasquill described six atmospheric stability categories ranging from A (very unstable) to F (very stable).

Values for σ_y and σ_z as functions of x for each of the six original Pasquill categories are given in two diagrams widely described in literature (see for instance ref. 66).

The Gifford-Pasquill equation is based upon the assumption that atmospheric dispersion follows a gaussian law, both orizontally and vertically, with the maximum migrating along the x axis.

A different approach is that of Sutton[19], which gives the concentration D at ground level (z = 0) for a continuous discharge Q from a stack H meters high:

$$D(x, y, o) = \frac{2Q}{\pi C_y C_z \bar{\mu} x^{(2-n)}} \exp\left[- x^{(n-2)} \left(\frac{Y^2}{C_y^2} + \frac{H^2}{C_z^2} \right) \right] \qquad (2)$$

In this equation, n is an empirical coefficient which depends on the wind profile, as:

$$\frac{u_2}{u_1} = \left(\frac{Z_2}{Z_1} \right)^{\frac{n}{(2-n)}}$$

where u_1 and u_2 are the average wind velocities at altitudes Z_1 and Z_2, respectively.

The coefficients C_y and C_z, which express the diffusion along axis y and z, are given by an equation of the type:

$$C_z^2 = \frac{4 \mu^n}{(1-n)(2-n)} \left(\frac{W_z^2}{\bar{u}^2} \right)^{(1-n)}$$

where W is the turbulent velocity of air and μ is its viscosity. The measurement of W is rather hard, so that very often coefficients reported in literature are utilized, thus introducing the great uncertainty associated to their applicability to a specific situation.

The Gifford-Pasquill formula is certainly more convenient, all the required parameters being easily measured; many experiments have supported the validity of this approach. However, it is worth noting that in some very simple models a straight line one-dimensional air flow is assumed, no allowance being made for the effects of meteorological variations.

Aquatic and Terrestrial Distribution

Some models have been developed for the assessment of aquatic and terrestrial migration of radioactivity through food chains. The few aquatic models that have emerged in the present survey exhibit also different degrees of sophistication; Hermes and Vadosca[32,60] for instance calculate the radionuclide concentration in water by assuming a simple linear relationship between the effluent discharge rate and the pollutants concentration at various trophic levels; other models[27] use a more sophisticated approach, particularly when dealing with mechanisms of diffusion and sedimentation in aquatic bodies.

About all of these models use an approach in which experimentally measured transfer coefficients or concentration ratios are utilized to calculate radionuclide concentrations along various pathways.

As a rule, the transport in aquatic environment as well as in terrestrial bioma is assessed through the use of a set of transfer coefficients obtained either in laboratory or in field studies.

However, it is worth noting that very often the information gained for a given ecosystem is quite specific for that system and is not valid for other cases; thus, a realistic application of a given model can generate correct results only if the necessary specific chemical, biological and environmental data are available.

The radioactivity migration is treated, in general, by subdividing the overall system (pollution source + environment + man) in many compartments, the number of which depends on the degree of accuracy with which the various transfer steps are known.

Very elaborate models are justified only when accompanied by accurate transfer rates which have been carefully verified; the accuracy of model predictions may not necessarily increase when a model is made more complex: sometimes inclusion of additional parameters results in less accurate predicion, each parameter having an error associated with it.

As a rule, in environmental models the assumption is done that each compartment is homogeneous, and no concentration gradients exist inside. Although in general natural transfer processes show a time dependent behaviour, it is often convenient to describe them by linear transfer functions with constant coefficients, of the type:

$$C_A = R\, C_B$$

C_A and C_B being concentrations in compartment A and B respectively, and R the concentration ratio, which is assumed to be independent on time. Otherwise, linear differential equations are required, thus taking into account the overall dynamics of the system, of the type:

$$\frac{d\,Q\,i}{d_t} = A - \lambda_E\, Q_i\,(t) \qquad (3)$$

where Q_i is the quantity of radioisotope i in the considered compartment; λ_E is its effective decay constant, which comprises both the radioactive decay and the chemical transfer out of the compartment, and A is the input rate.

Upon integration, eq. (3) becomes

$$Q_t = \frac{A}{\lambda_E}\,[\,1 - \exp(-\lambda_E{}^t)\,] \qquad (4)$$

at equilibrium, we have

$$Q_t = \frac{A}{\lambda_E} \qquad (5)$$

Equation (4) can be used to calculate the burden of radionuclides in living organisms[66].

Dosimetry

Approximately one half of the models listed in the present report take into account external and internal irradiation of man's body, resulting from different modes of exposure. Only about 11% of the models and codes listed in Table 1 are concerned with external dose received from ground, shoreline, or water contamination; for internal dosimetry, most of the models utilize recommendations and data given in ICRP publications[6, 7].

Internal and external irradiation of other living organisms is treated in BIORAD by S.V. Kaye[15].

The mathematical approach used to calculate the behaviour of radionuclides in man's organs is very similar to that used to treat the migration among different environmental compartments; equations of the type (3) and (4) are in fact of common use.

There are however cases in which equations must be used with time-dependent coefficients, for instance when changes in metabolic parameters with the aging of the organism are to be considered; in such a case, eq. (3) can be rewritten as:

$$\frac{dQ_i}{dt} = A(\tau) - K(\tau)\,Q_i \qquad (6)$$

τ being the age of the living organism.
In this case, the handling of such kind of mathematical systems may become particularly difficult.

Conclusions

A great variety of models do exist, to describe environmental and physiological distribution of radionuclides; their degree of sophistication varies over a wide range.

However, it is necessary to bear in mind that a model is of little practical value if measurements of the parameters required for its use are not available with the necessary accuracy. This situation can easily arise in environmental modeling, where the components of ecosystems are often well described qualitatively but not so well quantitatively; thus, a practical environmental model must often be oversimplified to fit the available data. For instance, in the milk pathway, it is customary to consider the activity to be transferred from a grass compartment to the milk compartment without passing through a gut or a blood compartment; these two intermediate compartments may be deleted because their deletion does not seriously affect the dynamics of the system, and accurate transfer coeefficients are not available for radionuclides.

In principle, more elaborate models are justified only when accompanied by accurate transfer rates which have been verified through comparison with environmental measurements; but, as a rule the accuracy of model predictions may not necessarily increase when a model is made more complex; sometimes, inclusion of additional parameters results in less accurate predictions.

It is therefore very unlikely to find out, among the many existing models, the one which satisfies completely our particular needs, with the desired degree of sophistication; however, it is quite possible to construct a personal and specific model by assembling pieces from different models; our opinion is that the present review may help with this work.

TABLE 1 : LIST OF MODELS AND THEIR CHARACTERISTICS

MODELS AND CODES	ENVIRONMENTAL TRANSPORT										Human dietary and behavioral factors*	External dosimetry				Int. dos.		Computerization			REFERENCES
	Atmospheric	Wet deposition	Dry deposition	Resuspension	Surface water	Ground water	Sedimentation	Irrigation	Terrest. foods	Aquat. foods		Air exposure	Ground exposure	Shoreline exposure	Water exposure	Inhalation	Ingestion	Language (+)	Computer (++)	Documentation	
AERIN																A	A	F IV		E	8
AIRDOS	R	R	R						R		R	R	R	R	R	R	R	F IV	360/91	E	9
AISITE II	A R											A R				A R		F II	7094	P	10
Aoyama et al.										R	R						R			P	11
Armstrong et al.					A R													F 63	1604	P	12
AQUAMOD					A R		A R			A R								F IV	360/91	S	13
Blanchard et al.	R				R				R	R	R	R				R	R			P	14
BIORAD					R		R								R		R	B		P	15
Bittel et al.					R				R		R						R			E	16
BITTEL					A R					A R	A R						A R			P	17
Bloom et al.	R				R					R	R						R			P	18
Charack	A	A																F	1604	P	19
Cigna et al.					R		R	R	R	R	R						R			E	20
COMRADEX	A											A				A		F		E	21
CONDOS									R	R	R	R				R	R	F IV		P	22
Cowser et al.	R		R									R				R				P	23
CUEX	A R	A R	A R						A R		A R	A R	A R		A R	A R	A R	F IV	360/91	P	24
CURIEDOSE	A											A				A		F		P	25
DOSE-B												A R				A R			6600	S	26
Eberhardt et al.									R		R						R			P	27
EXREM III												A R	A R	A R	A R			F IV	360/91	E	28
FOOD		R	R					R	R		R						R	B	1108	P	29
Garnier	A	A							A		A	A					A			E	30
Grifford	A R																			E	31
HERMES	R	R	R		R	R	R	R	R	R	R	R	R	R	R	R	R	F IV	1108	E	32
INDOS																A R	A R	F IV	10	S	33
INREM																A R	A R	F IV	360/91	E	34
ISOLA II	R											R						F IV		P	35

cont.

TABLE 1 : LIST OF MODELS AND THEIR CHARACTERISTICS *(cont.)*

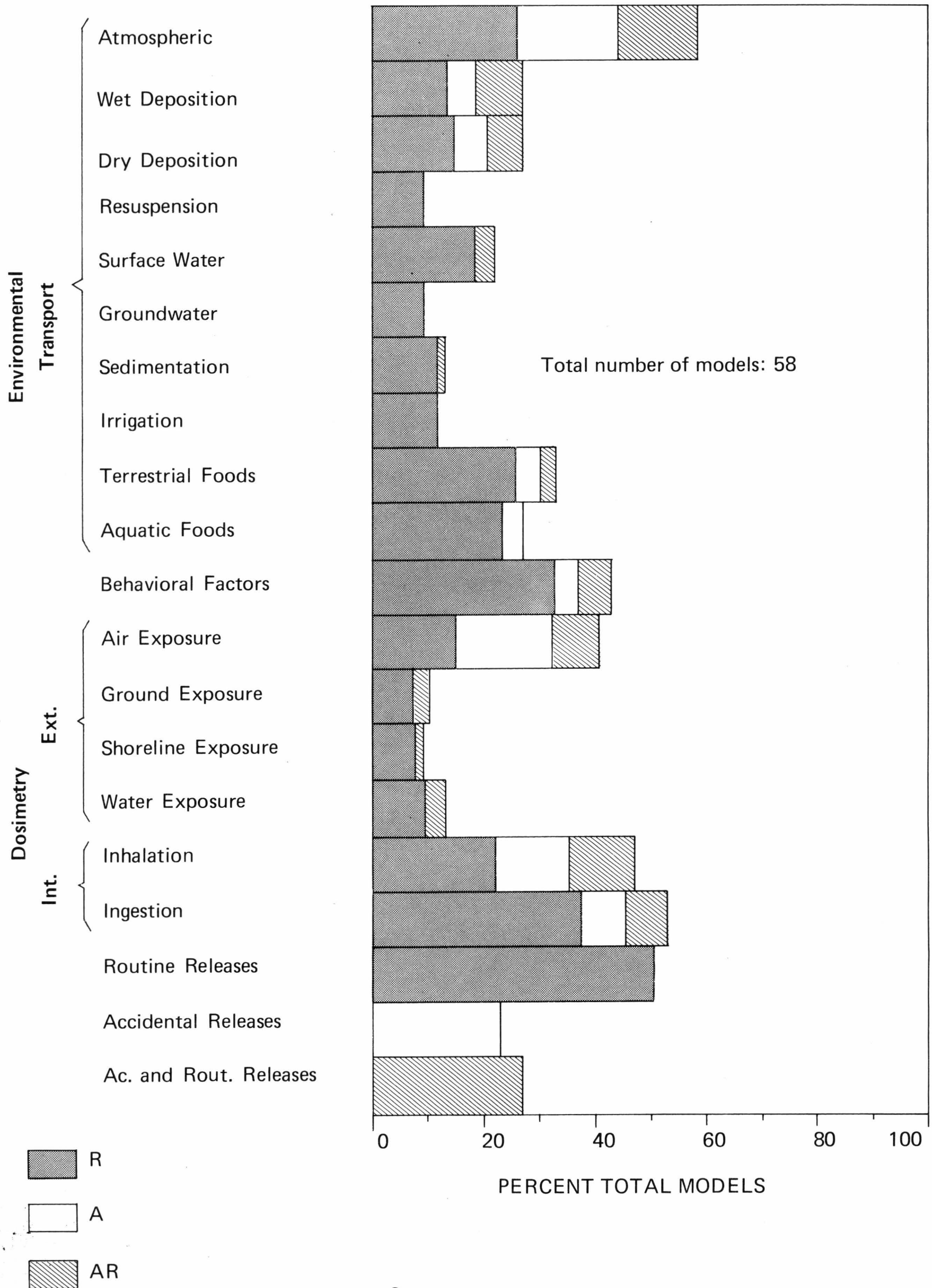
MODELS AND CODES	ENVIRONMENTAL TRANSPORT											External dosimetry				Int. dos.		Computerization			REFERENCES
	Atmospheric	Wet deposition	Dry deposition	Resuspension	Surface water	Ground water	Sedimentation	Irrigation	Terrest. foods	Aquat. foods	Human dietary and behavioral factors*	Air exposure	Ground exposure	Shoreline exposure	Water exposure	Inhalation	Ingestion	Language(+)	Computer(++)	Documentation	
Jakubick	R	R	R			R														P	36
Kaye and Ball	R								R	R						R	R			E	37
LÍDIA	A		A									A				A		F IV	370/165	P	38
Likhtarev																	R			P	39
Lu						R														P	40
Martin et al.				R					R		R					R	R			E	41
METEO 1	A R	A R	A R																	P	42
MIRD																	A R	F IV		P	43
MUNDO	A		A								A	A				A		F		P	44
Murray & Avogadro					R		R			R	R						R			E	45
NAEG				R					R		R					R	R			E	46
Palms et al.	R								R							R	R			S	47
RADS-ARADS	A R																	F IV	1401/ 7040	P	48
RADOS	A											A						F IV	360/65	E	49
RAMM						R				R	R						R			P	50
Reeves et al.	R		R									R				R				P	51
RISC	A	A	A													A			7090	S	52
RISØ model	A	A	A									A				A				E	53
Smith et al.	R	R		R					R											P	54
Soldat	R	R							R	R	R	R				R	R			P	55
Soldat et al.	R				R						R	R		R	R	R	R	B		P	56
Snyder et al.																A R				S	57
TERMOD									A R		A R							F IV	360/91	P	58
Travis	A		A	A														F IV		E	59
VADOSCA	R		R		R		R	R	R	R	R	R	R	R	R	R	R	F	635	E	60
Zuccaro	R	R			R		R	R	R	R	R						R	F	360/30	P	61
																					cont.

TABLE 1 : LIST OF MODELS AND THEIR CHARACTERISTICS *(cont.)*

MODELS AND CODES	ENVIRONMENTAL TRANSPORT											External dosimetry				Int. dos.		Computerization			
	Atmospheric	Wet deposition	Dry deposition	Resuspension	Surface water	Ground water	Sedimentation	Irrigation	Terrest. foods	Aquat. foods	Human dietary and behavioral factors*	Air exposure	Ground exposure	Shoreline exposure	Water exposure	Inhalation	Ingestion	Language(+)	Computer(++)	Documentation	REFERENCES
Webb et al.						R				R	R						R			E	62
WEERIE	A R		A R									A R				A R		F IV	370/165	P	63
WRED	A											A							360/65	P	64
Bertozzi et al.				C	C	C		C	C		C					C	C			P	65

A = Accidental release,
R = Routine release,
C = Continuous unintentional release,
E = Extensive,
P = Partial,
S = Sparse
(*) Includes such factors as breathing rate, rate of food intake, occupancy rate, etc.
(+) B = BASIC
F = FORTRAN
(++) Refers to the model numbers of the following computers: IBM 360/91, 7090, 360/30, 1401/7040, 370/165; PDP 10; UNIVAC 1108; CDC 1604; GE 635.

Fig. 1 : The frequency of occurrence in Table 1. of the Environmental Transport and Dosimetry



References

1. M L Winton «A compilation of computer codes for nuclear accident analysis», Nuclear Safety 10, (2), 131-147, 1969
2. M L Winton «Computer codes for analyzing nuclear accidents», Nuclear Safety, 12, (5), 464-482, 1971
3. M L Winton «Computer codes for analyzing nuclear accidents», Nuclear Safety, 15, (5), 535-553, 1974
4. F O Hoffman, C W Miller et al «Computer codes for the assessment of radionuclides released to the environment», Nuclear Safety, 18, (3), 343-354, 1977
5. D H Slade (ed) «Meteorology and atomic energy», USAEC Report TID-24190, 1968
6. «Recommendations of the International Commission on Radiological Protection, Report of Committee 2, on permissible dose for internal radiation», ICRP Pub 2, Pergamon Press Inc , London, 1959
7. Recommendation of the International Commission on Radiological Protection, Report of Committee IV on evaluation of radiation doses » ICRP Publ 10, Pergamon Press Inc , London, 1968
8. P Voilleque «AERIN - A code for acute aerosol inhalation exposure calculations», Health Phys , 19, 427-432, 1970
9. R E Moore «AIRDOS A computer code for estimating populations and individual doses resulting from nuclear facilities», ORNL-TM-4687, 1975
10. R Blaine, E Bramblett «AISITE II - A digital computer program for investigation of reactor siting», NAA-SR-9982, 1964
11. I Aoyama et al «Evaluation of the radioactive waste disposal into the deep ocean», Health Phys , 33, 227-240, 1977
12. N Armstrong, E Gloyna «Mathematical models for the dispersion of radionuclides in aquatic systems», CONF-670503, 1967
13. R Booth «A systems analysis model for calculating radionuclide transport between receiving waters and bottom sediments», ORNL-TM-4751, 1975
14. R Blanchard, B. Khan «Pathways for the transfer of radionuclides from nuclear power reactors through the environment to man», EUR 4800e, 1971
15. S V Kaye «Assessing potential radiological impacts to aquatic biota in response to the National Environmental Policy Act (NEPA) of 1969», Proc Symp Environm Behaviour of Radionuclides released in the Nuclear Industry, Aix-en-Provence, France, 1973
16. R Bittel et al «Etude du transfer à l'homme, par ses aliments, des radioisotopes du ruthénium, du cobalt et du zinc rejetés dans les eaux continentales», EUR 4800, 1971
17. R Bittel «Contribution d'un model prévisionnel à l'établissement de formules de rejet d'éffluents radioactifs dans les eaux», EUR 4800, 1971
18. G Bloom, et al «A preliminary mathematical model for predicting the transport of radionuclides in the marine environment», BMI-171-123, 1969
19. I Charak· «Atmospheric dispersion of fission products including the effects of building dilution and radioactive decay», Nucl Appl , 3, 283-286, 1967
20. A Cigna et al «Applicazione di un modello matematico per la determinazione su scala comunitaria delle norme di scarico per gli affluenti radioattivi», EUR 4800, 1971
21. C Willis, A Spangler, A. Rhoades «A new technique for reactor siting dose calculations», Health Phys , 19, 47-54 1969
22. R O'Donnell, L McKay et al «CONDOS - A model and computer code to estimate population and individual radiation doses to man from the distribution use and disposal of consumer products that contain radioactive materials», ORNL-TM-4663, 1975, ORNL-TM-5190, 1976
23. K Cowser et al «Evolution of the potential radiological impact of gaseous effluents on local environments», EUR 4800, 1971.
24. S Kaye et al· «A cumulative exposure index (CUEX) for assessing environmental releases of radioactivity», EUR 4800, 1971
25. G Kenfield et al· «Program for external and internal radiation dose calculations», NAA-SR-884, 1965
26. W. Ellison, A Dunham «Dose B - A CDC 6600 program for calculation of inhalation and external dose for establishing reactor siting distance requirements», KAPL-M-6592, 1967
27. L, Eberhardt, R Nakatani: «Modeling the behaviour of radionuclides in some natural sytems», CONF-670503, 1976
28. D Trubey, V Kaye: «The EXREM III for estimating external radiation doses to populations from environmental releases», ORNL-TM-4322, 1973
29. D Baker, R Hoenes, K Soldat· «FOOD - an interactive code to calculate internal radiation doses from contaminated food products», BNWL-SA-5523, 1976
30. A Garnier «Méthodòlogie d'évaluation des doses à la population résultant des réjets radioactifs dans l'atmosphère», CEA-R 4781, 1976
31. A Gifford «The rise of strongly radioactive plumes», Appl Meteorol., 6, 44-49, 1967
32. J Fletcher, W Dotson «HERMES - a digital computer code for estimating regional radiological effects from nuclear power industry», HEDL-TME-168, 1971

33 G Killough, P Rohwer «INDOS - conversational computer codes to implement ICRP-10-10 A models for estimation of internal radiation dose to man», ORNL-4916, 1974

34 INREM - a FORTRAN code which impliments ICRP 2 models of internal radiation doses to man», ORNL-5003, 1975

35 W Hubschmann, D Nagel «ISOLA II - ein Fortran IV-Programm zur Berechnung der langfristigen Dosisverteilung in der Umgebung kerntechnischer Anlagen», KFK-2210, 1975

36 A T Jakubick «Migration of plutonium in natural soils», IAEA-SM-199/3, 47, 1976

37 S Kaye, S Ball «Systems analysis of a coupled compartment model for radionuclide transfer in a tropical environment», CONF-67050 3, 1967

38 D Dini, L Pucciarelli «LIDIA un programma di calcolo per la valutazione delle conseguenze radiologiche di rilasci accidentali», RT/DISP (78) 1, 1978

39 J Likhtarev, et al «Use of a specialized analog computer for the model of the metabolism of some radionuclides», CONF-73090 7, pt 2, 1974

40 A H Lu «Modeling of radionuclide migration from a low-level radioactive waste burial site», Health Phys , 34, 39-44, 1978

41 W Martin, S Bloom «Plutonium transport and dose estimation model», IAEA-SM-199/78, 1976

42 O Veverka et al «METEO-1 a program for calculations of atmospheric dispersion of activities from nuclear power reactors», ZJE-166, 1975

43 Butler, P et al «Determination of internal radiation absorbed dose a computer method», Health Phys , 33, 459-463, 1977

44 F Heller et al «MUNDO - a digital code for computing accident dose rates in reactor environs», EURFNR-461, 1967

45 N Murray, A Avogadro «Effect of a long-term release of Pu and Am into a estuarine-coastal sea ecosystem», submitted to Journal of Health Physics, 1977

46 W Martin, S Blom et al «NAEG plutonium study modeling program Pu transport and dose estimation model», NVO-142, 1974

47 J Palms et al «The envirommental impact of I-129 released by a nuclear fuel reprocessing plant», Nucl Safety, 16, Nr 5, 1975

48 P Plato et al «Computer code for the prediction of the dispersion of airborne radioactive pollutants», Health Phys , 13, 1105, 1967

49 R Cooper «RADOS, a code to estimate gamma dose from a cloud of radioactive gases», DP-1098, 1967

50 R Lyon « RAMM - a system of computer programs for radionuclide pathways analysis calculations», AECL-5527, 1976

51 Reeves et al « A computer code for analyzing routine atmospheric releases of short-lived radioactive nuclides», ORNL-TM-3616, 1972

52 G Anno et al « RISC radiological inhalation safety code for IBM 7090», Trans Amer Nucl Soc , 6, 106-107, 1963

53 P Hedermann et al « Calculation of the individual and population doses on Danish territory resulting from hypothetical core-melt accidents at the Barseback reactor», Riso Report No 356, 1977

54 W Smith, L, Wheeler, et al « A preliminary evolution of the potential for plutonium release from burial ground at Los Alamos Scientific Laboratory» LA-6100-PR, 1975 — LA-6694-M, 1977 — LA-UR-77-1020, 1977

55 J K Soldat «Modeling of environmental pathways and radiation doses from nuclear facilities», BNWL-SA-3939, 1971

56 J Soldat, N Robinson, A Baker «Models and computer codes for evaluating environmental radiation doses», BNWL-1754, 1974

57 W Snyder et al «A computer program for estimating microcurie days of a radionuclide in the organs of the human body», ORNL-546, 1975

58 R Booth, S Kaye et al «A system analysis methodology for predicting dose to man from a radioactively contaminated terrestrial environment», CONF-710501-P1, 1971

59 J Travis «A model for predicting the redistribution of particulate contaminant from soil surfaces», LA-6035-MS, 1975

60 L Bramati et al «VADOSCA - codice di calcolo per la valutazione delle dosi alla popolazione, dovute agli scarichi radioattivi», ENEL, Italia

61 G Zuccardo Labellarte «A distribution model for radioactive and other persistent pollutants in the environment and in the food-chain», IAEA-SM-175/29

62 G Webb, F Morley «A model for the evaluation of the deep ocean disposal of radioactive waste», NRPB-R14, 1973

63 R Clarke «The WEERIE program for assessing the radiological consequences of airborne effluents from nuclear installation», Health Phys , 25, 267-280, 1973

64 R Cooper «WRED - a siting code to estimate dose probability distribution from measured meteorology data», Health Phys , 16, 735-738, 1969

65 F Girardi, G Bertozzi, M D'Alessandro «Long-term risk assessment of radioactive waste disposal in geological formations», EUR-5902e, 1978

66 M Eisenbud «Environmental radioactivity», Academic Press, 1973

APPENDIX

MODEL CARDS AND DESCRIPTION

MODEL 1	REFERENCE N° 8
MODEL NAME	: AERIN
AUTHORS	: P. Voilleque´
ESTABLISHMENT	: Health Serv. Lab., Idaho Falls (USA)
DATE OF PUBLICATION	: 1969
AIM OF THE MODEL	: evaluation of internal doses due to inhalation of radioactive aerosols
CONTAMINATION SOURCE	: accidental atmospheric release
NUCLIDES CONSIDERED	:
RADIOISOTOPE PATHWAYS	: inhalation
DATA GIVEN IN THE REPORT	:
FORMULAS	: activity dose in the NP-TB-LYM-P regions; gastro-intestinal physiological transfer
MODELING AND MATHEMATICAL APPROACH	: physiological, dynamic compartmental model written in FORTRAN IV

Description of the Model

AERIN is a FORTRAN IV program written to simplify the application of equations for computing the organ and tissue burdens and doses resulting from an acute inhalation exposure to a radioactive aerosol. The models which form the basis for the calculations are (1) the deposition and clearance models of the ICRP Task Group on Lung Dynamics, (2) the gastrointestinal (GI) tract model of EVE, and (3) a single exponential model for the «critical» organs and tissues. The output consists of a complete listing of the assumed parameters as well as the organ and tissue burdens and doses as functions of time post exposure.

MODEL NAME	: AIRDOS
AUTHORS	: R.E. Moore
ESTABLISHMENT	: Oak Ridge National Lab. (USA)
DATE OF PUBLICATION	: 1975
AIM OF THE MODEL	: to assess the dose to man and population due to routine releases in the atmosphere
CONTAMINATION SOURCE	: continuous releases to the atmosphere from BWRs
NUCLIDES CONSIDERED	: 36 radionuclides (Pu and Am are included)
RADIOISOTOPE PATHWAYS	: inhalation; air exposure; ingestion of contaminated foods; submersion in contaminated water
DATA GIVEN IN THE REPORT	: quantity of rare gases released from a BWR
FORMULAS	: air concentration; dry and wet resuspension; radionuclide concentrations along the food-chain and man's organs
MODELING AND MATHEMATICAL APPROACH	: compartmental model, composed of three computer codes: AIRMOD (atmospheric), INREM (dose to man) and TERMOD (food concentrations). (FORTRAN IV)

Descripttion of the Model

AIRDOS a FORTRAN IV computer code, was written to estimate population and individual doses resulting from the continuous simultaneous atmospheric release of as many as 36 radionuclides from a nuclear facility. Five pathways to man are considered: (1) inhalation of air containing radionuclide gases or particulates, (2) immersion in contaminated air, (3) exposure to surfaces contaminated by radioactive fallout, (4) ingestion of food produced on contaminated ground surfaces, (5) immersion in contaminated water Dose and dose commitments are estimated for each pathway and the following eleven reference organs: whole body, GI tract, bone, thyroid, lungs, muscle, kidneys, liver, spleen, testes, and ovaries. The environmental model in AIRDOS consists of a 20 X 20 square grid with the nuclear facility located at the center. The size of each grid is specified in the input data. Human population, numbers of beef and dairy cattle, and idenfication as to whether an area is used for production of vegetable crops or is a water area are specified for each of the 400 grids. Population doses are summarized in output tables in every possible manner. The highest individual dose received in the area and its location are printed in the output.

MODEL 3	REFERENCE N^{o} 10
MODEL NAME	: AISITE II
AUTHORS	: R.A. Blaine, E.L. Bramblett
ESTABLISHMENT	: NAA, Canoga Park, California (USA)
DATE OF PUBLICATION	: 1964
AIM OF THE MODEL	: parametric investigation of reactor siting and calculation of doses to man's organs
CONTAMINATION SOURCE	: accidental and continuous releases in the atposphere due to reactor operation
NUCLIDES CONSIDERED	: fission products and plutonium
RADIOISOTOPE PATHWAYS	: inhalation and air submersion
DATA GIVEN IN THE REPORT	: Pasquill's meteorological data, mass of man's organs; ray absorption in air
FORMULAS	: fission products inventory; atmospheric release; inhalation dose from radioactive air plume
MODELING AND MATHEMATICAL APPROACH	: mathematical atmospheric and radiological model (FORTRAN II)

Description of the Model

AISITE II is a reactor siting code written to provide a tool for parametric investigation of reactor siting. The code automatically varies any one of 46 parameters such as reactor power, building leak rate, iodine cleanup rate, halogen filter efficiency, etc. Dose versus distance curves are obtained for inhalation, direct building, and direct cloud doses. The printed edit consists of the dose versus distance data, fractional contribution by isotope group to the inhalation dose, and critical distances for both a 2-hr and a 30-day release. Graphical displays can be obtained for critical distances as a function of the variable parameter and dose versus distance for any organ or the critical organ, for each value of the parameter. Other features of the code include built-in libraries of isotope decay constants, average gamma energies, yields, absorption coefficients in air, mass of organs, and others. Programming is modular so that models are easily replaced when necessary.

MODEL 4	REFERENCE N° 11
MODEL NAME	: Evaluation of the Radioactive Waste Disposal into the Deep Ocean
AUTHORS	: I. Aoyama, M. Yamamoto et al.
ESTABLISHMENT	: Kyoto Univers. (Japan)
DATE OF PUBLICATION	: 1977
AIM OF THE MODEL	: to estimate individual and collective doses
CONTAMINATION SOURCE	: leaching of radioactive waste solidified into cement
NUCLIDES CONSIDERED	: Co - 60 and Cs - 137
RADIOISOTOPE PATHWAYS	: ingestion of sea foods
DATA GIVEN IN THE REPORT	: concentration factors; sea diffusion coefficients; diet of populations
FORMULAS	: leaching of cement; radionuclide concentration in marine surface; vertical diffusion from deep sea water
MODELING AND MATHEMATICAL APPROACH	: the mathematical model and sensitivity analysis are rather sophisticated

Description of the Model

This paper presents a hazard assessment for deep sea disposal of low level radioactive solid wastes which originate from nuclear power reactors in Japan. The model takes account of leaching characteristics of radionuclides from wastes solidified with cement. Maximum and average concentrations of radionuclides in an upper mixed layer of the sea are estimated and maxixmum doses for individual and population doses are calculated. In order to evaluate an uncertainty of parameters in the model, a sensitivity analysis is performed. Generally, the most sensitive parameter is the depth of the sea where the solidified wastes would be deposited. The concentration of radionuclides in the surface water is not sensitively affected by the vertical diffusion coefficient.

MODEL 5 REFERENCE N° 12

MODEL NAME	: Mathematical Models for Dispersion of Radionuclides in Aquatic Systems
AUTHORS	: E. Armstrong, E. Gloyna
ESTABLISHMENT	: Env. Health Eng. Lab., Texas Univ. (USA)
DATE OF PUBLICATION	: 1968
AIM OF THE MODEL	: to predict the radioactivity transport in surface waters
CONTAMINATION SOURCE	: hypotetic, continuous and accidental releases from a generic nuclear plant
NUCLIDES CONSIDERED	: Sr - 85 and Cr - 51
RADIOISOTOPE PATHWAYS	: water, sediments and aquatic vegetals
DATA GIVEN IN THE REPORT	: trophic level concentrations
FORMULAS	: water dispersion equations; radioactivity uptake at the trophic levels; sorption of activity in sediments
MODELING AND MATHEMATICAL APPROACH	: mathematical and dynamic model that uses a sophisticated mathematical approach; written in FORTRAN language

Description of the Model

A general equation is presented which describes radionuclide transport in terms of hydraulic dispersion and convection and by detention systems which sorb and release. A model to descrive sorption by various substrates using the concentration gradient between the equilibrium activity in the substrate and the actual activity is also presented. Linear and non-linear equations are discussed concerning accuracy of prediction and effect on ease of obtaining a solution.

MODEL 6 | **REFERENCE N° 13**

MODEL NAME	:	AQUAMOD
AUTHORS	:	S. Booth
ESTABLISHMENT	:	Oak Ridge Nat. Lab (USA)
DATE OF PUBLICATION	:	1975
AIM OF THE MODEL	:	to assess the distribution of fission products between water and sediments
CONTAMINATION SOURCE	:	contamination of liquid effluents
NUCLIDES CONSIDERED	:	fission products
RADIOISOTOPE PATHWAYS	:	surface water
DATA GIVEN IN THE REPORT	:	distribution coefficients in the sediments
FORMULAS	:	fission product concentrations in water and sediments
MODELING AND MATHEMATICAL APPROACH	:	dynamic and compartmental model (FORTRAN IV)

Description of the Model

Equilibrium radionuclide concentrations in waters receiving radioactive effluents and in bottom sediments associated with the receiving waters were calculated so that potential doses to man and biota and radionuclide buildup in the environment could be determined realistically. These calculations were performed to test the accuracy of simpler models, where receiving water concentrations were determined by neglecting the influence of bottom sediments. The simplified calculations were incorporated into environmental impact statements for nuclear power stations prepared by Oak Ridge National Laboratory for the U.S. Nuclear Regulatory Commision. A four-compartment systems analysis model was developed to predict dynamic radionuclide transfer. The dependent variables of the model are the receiving water, interstitial water, and bottom sediment particles that undergo only sorption reactions with the interstitial water. Preliminary results indicate that the usual effect of a neglect of sediment interactions is an overestimate of the total potential dose to man from the radionuclides. The reason is that a neglect of sediment interactions overestimates receiving water concentrations which, in turn, overestimates potential doses from important pathways (drinking water or eating fish) directly related to the receiving water concentration.

MODEL 7	REFERENCE N° 14
MODEL NAME	: Pathways for the Transfer of Radionuclides from Nuclear Power Reactors through the Environment to Man
AUTHORS	: L. Blanchard, E. Kahn
ESTABLISHMENT	' U.S. Envir. Protect. Agency, Cincinnati, (USA)
DATE OF PUBLICATION	: 1971
AIM OF THE MODEL	: to estimate the doses to man's organs near BWRs and PWRs
CONTAMINATION SOURCE	: continuous releases to atmosphere and surface waters
NUCLIDES CONSIDERED	: fission products and noble gases
RADIOISOTOPE PATHWAYS	: ingestion of contaminated foods; inhalation; external contamination
DATA GIVEN IN THE REPORT	: annual releases from PWRs and BWRs; trophic level concentrations
FORMULAS	: deposition of vegetals
MODELING AND MATHEMATICAL APPROACH	: equilibrium compartmental model based on specific environmental data

Description of the Model

Detailed studies are described on site and in the vicinity of a boiling water reactor (BWR) and a pressurized water reactor (PWR). Concentrations of specific radionuclides are determined in the gaseous and aqueous effluents and in the environment for the following pathways:

1) atmospheric discharge — Deposition on grass — milk — man
2) atmospheric discharge — deposition on leafy vegetables — man
3) atmospheric discharge — deposition on grass — cattle — beef — man
4) atmospheric discharge — inhalation exposure
5) atmospheric discharge — whole body external exposure
6) aqueous discharge — river — fish — man
7) aqueous discharge — river — water supply — man —

The critical pathway at the BWR is determined to be external radiation to the whole body from gaseous fission products in the plume. The second most significant pathway is that leading to the consumption of milk. At the PWR, consuption of fish is determined to be the critical vector. The highest population exposure is several mrem per year at the BWR, and considerably less at the PWR.

MODEL 8	REFERENCE N° 15
MODEL NAME	: BIORAD
AUTHORS	: V. Kaye
ESTABLISHMENT	: Oak Ridge Nat. Lab. (USA)
DATE OF PUBLICATION	: 1973
AIM OF THE MODEL	: doses to aquatic and terrestrial animals
CONTAMINATION SOURCE	: generic releases of contaminated aqueous effluents
NUCLIDES CONSIDERED	: fission products, Pu, Am and Cm
RADIOISOTOPE PATHWAYS	: ingestion; food chains
DATA GIVEN IN THE REPORT	: concentration factors
FORMULAS	: dose calculation
MODELING AND MATHEMATICAL APPROACH	: equilibrium compartmental mode, written in BASIC language

Description of the Model

BIORAD is a conversational code written in BASIC and designed for use through remote terminal access to the DEC System 10. The user inputs a concentration of the selected radionuclide in water or in sediment ($\mu Ci/cm^3$), and BIORAD estimates internal and external radiation dose to aquatic plants, invertebrates, fish, and terrestrial animals dependent on aquatic food supplies. The BIORAD data base is contained in a set of on-line files in the computer's disk storage. The program permits the addition of new nuclides an changes of parameter values by the user.

MODEL 9	REFERENCE N° 16
MODEL NAME	: Model du transfert à l'homme des radioisotopes
AUTHORS	: R. Bittel, M. Merlini, C. Myttenaere et al.
ESTABLISHMENT	: EURATOM - CEA - CEN
DATE OF PUBLICATION	: 1971
AIM OF THE MODEL	: dose evaluation to man
CONTAMINATION SOURCE	: routine discharge of liquid effluents from nuclear plants
NUCLIDES CONSIDERED	: Co, Zn, Ru
RADIOISOTOPE PATHWAYS	: aquatic and terrestrial food chains
DATA GIVEN IN THE REPORT	: transfer coefficients in the food chain; the effect of artificial chelating agents is considered
FORMULAS	: dose by ingestion
MODELING AND MATHEMATICAL APPROACH	: equilibrium compartmental model

Description of the Model

On the basis of certain assumptions, the dose delivered to man by the ingestion of food contaminated by radioactive pollution of water can be evaluated in any situation. This paper describes the use of a type of standard calculation for aquatic food chains in order to establish the consequences for man of the contamination of continental waters by radioruthenium and metallic activation products, in particular, radioisotopes of cobalt and zinc. A study of concrete examples based on the results of food surveys and of experiments performed mainly at Ispra and Mol indicates the doses reaching man in different cases and permits estimation of the incidence of variations of some of their parameters.

MODEL 10	REFERENCE N° 17
MODEL NAME	: Model previsionnel et chaine alimentaire dans les eaux
AUTHORS	: R. Bittel
ESTABLISHMENT	: CEA, Fontenay-aux-Roses (France)
DATE OF PUBLICATION	: 1971
AIM OF THE MODEL	: evaluation of doses to population
CONTAMINATION SOURCE	: releases of contaminated effluents into sea water
NUCLIDES CONSIDERED	:
RADIOISOTOPE PATHWAYS	: food chains
DATA GIVEN IN THE REPORT	:
FORMULAS	: dose to man; radioactivity distribution in the sea
MODELING AND MATHEMATICAL APPROACH	: compartmental equilibrium model

Description of the Model

The object of this paper is to examine to what extend a model proposed for the evaluation, in any situation of the dose delivered to man following the ingestion of food contaminated by polluted water can be used for the establishment of discharge formulae. This model is expressed by a simple relation between the «ingestible dose», the quantitites of each food ingested by the populations concerned, the transfer factors from the water to the foods for the various radionuclides, and the levels of pollution of the water. If these levels can be expressed as a function of the quantities of radionuclides discharged during a given period, the above relation constitutes a discharge formula which takes account explicitly of the eating habits of the populations concerned and the transfer factors of the pollution from the environment to the foods consumed by man. The conditions of practical application of these concepts an their extension to the case of chemical pollution are briefly discussed.

MODEL 11	REFERENCE N° 18
MODEL NAME	: Mathematical Model in the Marine Environment
AUTHORS	: S. Bloom, G. Raines
ESTABLISHMENT	: Batt. Mem. Inst., Columbus, Ohio (USA)
DATE OF PUBLICATION	: 1969
AIM OF THE MODEL	: evaluation of internal doses to man due to food ingestion
CONTAMINATION SOURCE	: underground nuclear explosions, which contaminate ground waters and air
NUCLIDES CONSIDERED	:
RADIOISOTOPE PATHWAYS	: transport by ground water and sea water; ingestion
DATA GIVEN IN THE REPORT	:
FORMULAS	: water dispersion in the sea; sea concentration; internal dose to man
MODELING AND MATHEMATICAL APPROACH	: mathematical dynamic model

Description of the Model

In the unlikely event of a venting accident during the underground testing of nuclear devices near a marine environment, the marine environment may be contaminated by fallout. Even without a venting accident, the explosion may create fissures that would allow a small amount of radioactivity to contaminate the groundwater. The groundwater, in turn, may contaminate the marine environment through direct groundwater flow into the ocean or through groundwater flow into streams and from streams into the ocean. Fallout usually produces an initially high level of contamination, which disperses rapidly, while groundwater usually produces a relatively low level of contamination, which persit for a longer period of time. Expressions for describing the physical transport of materials in the ocean are available in the form of partial differential equations that have (1) time and distance as independent variables, (2) concentration of the material in the water as the dependent variable, (3) current velocities and turbulent diffusivities as parameters, and (4) the rates of material addition to the ocean, land features, and bottom features as boundary and initial conditions.

MODEL 12	REFERENCE N° 19
MODEL NAME	: Atmospheric Dispersion Model and Building Diluition and Radioactive Decay
AUTHORS	: I. Charack
ESTABLISHMENT	: Argonne Nat. Lab. (USA)
DATE OF PUBLICATION	: 1967
AIM OF THE MODEL	: atmospheric dispersion evaluation of fission products
CONTAMINATION SOURCE	: accidental releases from nuclear plants
NUCLIDES CONSIDERED	: fission products
RADIOISOTOPE PATHWAYS	: atmospheric transport
DATA GIVEN IN THE REPORT	:
FORMULAS	: down-wind concentration; ground deposition
MODELING AND MATHEMATICAL APPROACH	: mathematical model written in FORTRAN

Description of the Model

Sutton's diffusion equation, which is commonly used for the computation of atmospheric dispersion of fission products, is modified to account for the effect of dilution of the fission products due to mixing of the contaminated air inside the reactor building with clean air prior to exhaust. The effect of radioactive decay is also considered. The resulting integral equation is solved for a specific example using a Romberg integration to a washout calculation is described.

MODEL 13	REFERENCE N° 20
MODEL NAME	: Modello matematico per la valutazione di inquinamenti radioattivi
AUTHORS	: A. Cigna, F. Breuer et al.
ESTABLISHMENT	: CNEN (Italy)
DATE OF PUBLICATION	: 1971
AIM OF THE MODEL	: evaluation of radioactivity levels in foods and comparison with max. permissible doses to population
CONTAMINATION SOURCE	: liquid wastes released into surface waters
NUCLIDES CONSIDERED	: fission products and plutonium
RADIOISOTOPE PATHWAYS	: water transport; drinking water; food crops
DATA GIVEN IN THE REPORT	: distribution coefficients; irrigation rate; animal diet; Ca in cow diet; Ca in milk; biological transfer coefficients
FORMULAS	: trophic level concentrations; sediment concentrations
MODELING AND MATHEMATICAL APPROACH	: equilibrium compartmental model

Description of the Model

Application of a mathematical model fo determining at community scale the discharge standards for radioactive effluent. In a previous publication by the same authors a mathematical model was developed for defining a formula for the discharge of liquid radioactive effluent into surface waters. In this paper the general procedure is applied to various possible concrete cases, including that of a water used for drinking purposes, that of a water course and used for irrigation, that of a lake used for fishing and for water supplies, that of a river along the course of which there are several discharges of radioactive waste. The possibility of applying the method to the problems associated with radioactive contamination of the air is also considered.

MODEL 14 | REFERENCE N° 21

MODEL NAME	:	COMRADEX
AUTHORS	:	C. Willis, A. Spangler, A. Rhoades
ESTABLISHMENT	:	Oak Ridge Nat. Lab. (USA)
DATE OF PUBLICATION	:	1970
AIM OF THE MODEL	:	to calculate doses to man, due to accident occurring in a nuclear reactor
CONTAMINATION SOURCE	:	release from a nuclear reactor
NUCLIDES CONSIDERED	:	fission products
RADIOISOTOPE PATHWAYS	:	from atmospheric release, through inhalation and direct exposition
DATA GIVEN IN THE REPORT	:	
FORMULAS	:	air concentration; dose to man's internal organs
MODELING AND MATHEMATICAL APPROACH	:	sophisticated mathematical model, written in FORTRAN

Description of the Model

The Comradex code was developed to calculate radiation doses from accidents postulated for advanced reactors with sophisticated engineered safeguards. The use of a direct numerical technique, designed especially for quasilinear differential equations to solve the leakage and decay chains, permits the inclusion of several special features. These include the capability for considering up to four levels of containment, each with an indipendent time-varying leak rate. Provision is also included for filtration, particle coagulation and fallout, and special cleanup systems. A full fission product inventory (plus special isotopes) is used with input release fractions. The meteorology mode is that of Pasquill and Gifford. Internal doses are determined with the ICRP model. The cloud gamma dose is obtained by integrating over the anisotropic Gaussian cloud.

MODEL 15 REFERENCE N° 22

MODEL NAME	: CONDOS
AUTHORS	: F. O'Donnel et al.
ESTABLISHMENT	: Oak Ridge Nat. Lab. (USA)
DATE OF PUBLICATION	: 1976
AIM OF THE MODEL	: evaluation of dose to man
CONTAMINATION SOURCE	: a variety of products of general use containing radioactive materials
NUCLIDES CONSIDERED	: isotopes of Th, Ra, Po, Pb, Bi, U, Tl and H-3, C-14, Co-60, Ni-63, Kr-85, Tc-99, Cs-137, Pm-147, Np-237, Am-241
RADIOISOTOPE PATHWAYS	: from air, ingestion, inhalation, contact with contaminated surfaces
DATA GIVEN IN THE REPORT	:
FORMULAS	: dose equations for different pathways
MODELING AND MATHEMATICAL APPROACH	: radiological compartmental model

Description of the Model

As an aid in assessing the potential radiological impacts of consumer products which contain radionuclides, a model of the life span of a consumer product has been developed, together with a computer code (CONDOS) which calculates radiation doses to man which result from exposure to the product during one or more of the stages in the product's life. The model treats five stages (distribution, transport, use, disposal, and emergencies) in the life of a product and provides a framework for description of the exposure events. These descriptions identify homogeneous groups of exposed persons and thus facilitate the selection of individuals who represent the exposed population groups. Both internal and external components of the dose are calculated.

MODEL 16 | REFERENCE N° 23

MODEL NAME	: Evaluation of the Potential Radiological Impact of Gaseous Effluents on Local Environments
AUTHORS	: E. Cowser, M. Reeves, P. Fowler et al.
ESTABLISHMENT	: Oak Ridge Nat. Lab. (USA)
DATE OF PUBLICATION	: 1971
AIM OF THE MODEL	: evaluation of the dose to populations from radioactive gaseous effluents
CONTAMINATION SOURCE	: routine atmospheric releases from nuclear reactors
NUCLIDES CONSIDERED	: Kr, Xe, Rb, Cs
RADIOISOTOPE PATHWAYS	: by air exposition and inhalation; skin deposition
DATA GIVEN IN THE REPORT	: deposition rate; air concentration; water solubility of the radionuclides
FORMULAS	: air dispersion
MODELING AND MATHEMATICAL APPROACH	: see INREM and EXREM computer codes

Description of the Model

This paper emphasizes the methods used and the models developed to permit estimates of dose equivalents to members of a potentially exposed population group from gaseous effluents from nuclear facilities. A computer code is used for the calculation of average annual downwind air concentrations and ground surface deposition rates for routine stack releases and displays results as contour plots. Parametric study is possible since the code permits variation of meteorological variables and stack height, release rate, dry deposition velocity, washout coefficient, and a decaying chain of radionuclides emitted from the stack. Release of radioactive noble gas reported for a boiling water reactor is used to illustrate program application and the impact of parent-daughter decay chains and washout and fallout on dose estimation.

MODEL 17	REFERENCE N° 24
MODEL NAME	: CUEX methodology
AUTHORS	: S. Keye, S. Booth et al.
ESTABLISHMENT	: Oak Ridge Nat. Lab. (USA)
DATE OF PUBLICATION	: 1971
AIM OF THE MODEL	: estimate of dose to man and population due to releases in the atmosphere
CONTAMINATION SOURCE	: continuous and accidental releases from an hypothetic nuclear plant
NUCLIDES CONSIDERED	:
RADIOISOTOPE PATHWAYS	: from inhalation; water submersion; ingestion; air exposure; ground exposure
DATA GIVEN IN THE REPORT	: see TERMOD and AIRMOD computer codes
FORMULAS	: CUEX index
MODELING AND MATHEMATICAL APPROACH	: the report illustrates a methodology and utilizes AIRMOD and TERMOD computer codes

Description of the Model

The Comulative Exposure Index (CUEX) has been developed to facilitate efficient realistic assessment of environmental releases of radioactivity. The aim of CUEX is to assess the release on the basis of time-integrated radionuclide concentrations measured in suitable environmental sampling media. Typical measurements would be concentrations of radioactivity in air or water or on the land surface. The measured concentrations are assessed against basic radiation safety standards recommended for members of the public by recognized authorities. Because the recommended standards ae expressed in units of dose (rem), the CUEX index, of necessity, embodies environmental models and dose models to convert the measured environmental radionuclide concentrations into estimates of radiation dose to man. The final estimate of dose and dose commitment used in calculation of CUEX includes contributions for each radionuclide and exposure mode of significance, and is compared to the appropriate radiation dose limit to complete the assessment. As proposed in this paper, CUEX is a more appropriate index to apply to exposure of the public than are the MPC's. A schematic is presented for applying CUEX to nuclear plant siting using environmental systems analysis techniques to model the movement of radionuclides.

MODEL 18	REFERENCE N° 25
MODEL NAME	: CURIE-DOSE-THUNDERHEAD
AUTHORS	: P. Kenfield et al.
ESTABLISHMENT	: Atomics International (USA)
DATE OF PUBLICATION	: 1965
AIM OF THE MODEL	: calculation of the doses to man's organs
CONTAMINATION SOURCE	: accidental atmospheric release from nuclear power reactors
NUCLIDES CONSIDERED	: fission products
RADIOISOTOPE PATHWAYS	: from inhalation and air exposition
DATE GIVEN IN THE REPORT	: dose to critical organs
FORMULAS	: fission products in the spent fuel as a function of burn-up; dose by inhalation
MODELING AND MATHEMATICAL APPROACH	: mathematical model written in FORTRAN

Description of the Model

The CURIE-DOSE-THUNDERHEAD program is a combination of three basic computer programs employed in succession. The first, CURIE, calculates the fission product buildup and decay as a function of reactor operating time, operating power, and decay time. The second, DOSE, uses the fission product inventory obtained from CURIE to calculate the dose to 14 internal body organs due to inhalation of fission products released to the atmosphere. The third, THUNDERHEAD, also uses fission product activity data from CURIE to calculate the external cloud gamma exposure from the released fission products.

MODEL 19	REFERENCE N° 26
MODEL NAME	: DOSE-B
AUTHORS	: W. Ellison, B. Dunham
ESTABLISHMENT	: Knolls Atom. Power Lab., New York (USA)
DATE OF PUBLICATION	: 1967
AIM OF THE MODEL	: evaluation of the external dose to whole body and dose to thyroid inhalation
CONTAMINATION SOURCE	: accidental and continuous release from a generic nuclear plant
NUCLIDES CONSIDERED	: fission products with emphasis to jodine
RADIOISOTOPE PATHWAYS	: inhalation and external exposure
DATA GIVEN IN THE REPORT	:
FORMULAS	:
MODELING AND MATHEMATICAL APPROACH	: mathematical model

Description of the Model

The Dose-B Program has been written to facilitate the calculation of distance factors for nuclear reactor sites as described in the USAEC Document «Calculation of Distance Factors for Power and Test Reactor Sites», TID-14844. The calculations are essentially as described in this document except that the dose code allows for arbitrary operating power histories and variable containment leak rates. The program calculates the thyroid and direct gamma doses received by an individual standing at a distance D from the point of fission product release for a time TAU subsequent to the time of release and based upon a given reactor operating history.

MODEL 20 | REFERENCE N° 27

MODEL NAME	:	Modeling the Behaviour of Radionuclides in some Natural Systems
AUTHORS	:	L. Eberhardt, F. Nakatani
ESTABLISHMENT	:	Batt. Nort. West Lab. (USA)
DATE OF PUBLICATION	:	1967
AIM OF THE MODEL	:	ecological evaluation of the radionuclides in a natural food chain and dose to man
CONTAMINATION SOURCE	:	not defined
NUCLIDES CONSIDERED	:	
RADIOISOTOPE PATHWAYS	:	food chains
DATA GIVEN IN THE REPORT	:	
FORMULAS	:	compartmental radioactive intake; bio-concentration and trophic loss
MODELING AND MATHEMATICAL APPROACH	:	dynamic ecological model taking into account the environmental variability

Description of the Model

Some quantitative aspects of the uptake, retention and food-chain cycling of radionuclides are assessed through simple models. The influence of some relevant populational and physiological factors is briefly condisdered.

MODEL 21	REFERENCE N° 28
MODEL NAME	: EXREM III
AUTHORS	: K. Trubey, S. Kaye
ESTABLISHMENT	: Oak Ridge Nat. Lab. (USA)
DATE OF PUBLICATION	: 1973
AIM OF THE MODEL	: evaluation of the individual dose and dose to man's organs due to external irradiation
CONTAMINATION SOURCE	: accidental and routine releases from power reactors
NUCLIDES CONSIDERED	: fission products and actinides
RADIOISOTOPE PATHWAYS	: air exposure; water exposure; ground exposure; shoreline exposure
DATA GIVEN IN THE REPORT	: radioactive decay data
FORMULAS	: dose calculations
MODELING AND MATHEMATICAL APPROACH	: mathematical and compartmental model written in FORTRAN

Description of the Model

EXREM III is a computer code to estimate the dose rate and the total dose from beta, positron, electron, x-ray, and gamma radiation resulting from submersion in contaminated water, immersion in contaminated air, and exposure to a contaminated surface. There can be more than one environmental release, and esposure can begin at any time after the first relase. EXREM III considers contributions from environmental releases and from nuclide decay chains. For a particular problem the user may choose to calculate either the dose rates at any selected time, or the total dose integrated over any selected time period, or both for any of the three modes of exposure. A separated solution array is printed for each mode of exposure. Nuclear data for over 200 radionuclides comprise the basic data base for this code. EXREM III has been used in preparing radiation dose estimates for environmental impact statements for nuclear power plants and other nuclear facilities.

MODEL 22	REFERENCE N° 29
MODEL NAME	: FOOD
AUTHORS	: A. Baker, R. Hones, J. Soldat
ESTABLISHMENT	: Batt. Nort. West Lab. (USA)
DATE OF PUBLICATION	: : 1976
AIM OF THE MODEL	: internal dose calculation due to ingestion of contaminated foods
CONTAMINATION SOURCE	: continuous releases to biosphere from generic nuclear plants
NUCLIDES CONSIDERED	: fission products and actinides (nobles gases are not considered)
RADIOISOTOPE PATHWAYS	: wet deposition; dry deposition; food chains; ingestion
DATA GIVEN IN THE REPORT	: animal diet; transfer coefficients; removal rates from vegetals
FORMULAS	: deposition rate on crops; vegetal and animal concentrations; dose to man
MODELING AND MATHEMATICAL APPROACH	: mathematical model, written in BASIC language

Description of the Model

An interactive code, FOOD, has been written in BASIC for the UNIVAC 1108 to facilitate calculation of internal radiation doses to man from radionuclides in food products. In the dose model, vegetation may be contaminated by either air or irrigation water containing radionuclides. The model considers two mechanisms for radionuclide contamination of vegetation: 1) direct deposition on leaves and 2) uptake from soil through the root system. The user may select up to 14 food categories with corresponding consumption rates, growing periods and either irrigation rates or atmospheric deposition rates. These food include various kinds of produce, grains and animal products. At present, dose may be calculated for the skin, total body and five internal organs from 109 radionuclides. The output also includes estimated radionuclide concentrations in soil, plants and animal products.

MODEL 23	REFERENCE N° 30
MODEL NAME	: Methodologie d'évaluation des doses à la population résultant de rejets radioactifs dans l'atmosphère
AUTHORS	: A. Garnier
ESTABLISHMENT	: CEA, Fontenau-aux-Roses (France)
DATE OF PUBLICATION	: 1976
AIM OF THE MODEL	: evaluation of the dose to population
CONTAMINATION SOURCE	: accidental atmospheric release from a nuclear power reactor
NUCLIDES CONSIDERED	: I - 131, rare gases
RADIOISOTOPE PATHWAYS	: milk and vegetables ingestion; air inhalation; external exposure
DATA GIVEN IN THE REPORT	: biological half-lives; dose conversion factors; radiological parameters; quantity of rare gases released from BWR
FORMULAS	: atmospheric dispersion; ground deposition; milk and vegetal contamination; dose to the thyroid
MODELING AND MATHEMATICAL APPROACH	: radiobiological model

Description of the Model

This model permits to assess the doses to population, as a consequence of an accidental release of rare gases and I-131 from a nuclear power reactor; climatic and demographic average French conditions are considered. Inhalation, external irradiation and contaminated food ingestion are treated as potential pathways to man; the dilution with products from uncontaminated regions is taken into account.

MODEL 24	REFERENCE N° 31

MODEL NAME	: Atmospheric Dispersion
AUTHORS	: F. Gifford
ESTABLISHMENT	: Oak Ridge Oper. Office (USA)
DATE OF PUBLICATION	: 1969
AIM OF THE MODEL	: evaluation of the atmospheric dispersion
CONTAMINATION SOURCE	: general nuclear plants
NUCLIDES CONSIDERED	:
RADIOISOTOPE PATHWAYS	:
DATA GIVEN IN THE REPORT	: dispersion and diffusion coefficients; air concentrations; ground deposition
FORMULAS	: air dispersion; air diffusion
MODELING AND MATHEMATICAL APPROACH	: atmospheric model

Description of the Model

The differences among various atmospheric models arising from different choices of the considered parameters are discussed. This model introduces further parameters not generally taken into account, for a more detailed analysis of atmospheric dispersion of radioactive effluents from nuclear plants.

MODEL 25	REFERENCE N° 32
MODEL NAME	: HERMES
AUTHORS	: F. Fletcher, L. Dotson
ESTABLISHMENT	: Hanford Eng. Develop. Lab. (USA)
DATE OF PUBLICATION	: 1971
AIM OF THE MODEL	: dose to individuals and population
CONTAMINATION SOURCE	: effluents released towards the biosphere from nuclear reactors
NUCLIDES CONSIDERED	: fission products
RADIOISOTOPE PATHWAYS	: all the environmental transport pathways
DATE GIVEN IN THE REPORT	: animal and human diets; transfer coefficients; rate of the deposition on vegetals; effective half-lives
FORMULAS	: concentration in food crops; water transport and sediment diffusions; air and water dispersion; dose calculations
MODELING AND MATHEMATICAL APPROACH	: compartmental model at the equilibrium, written in FORTRAN IV

Description of the Model

The HERMES (Hanford Engineering Regional Model for Environmental Study) model is designed to calculate radionuclide release and radiation dose occurring within a study area. The initial development of the HERMES model was based on a study of the region comprising the Upper Mississippi and Lower Mississippi River basins. The model has been developed to assess the radioactive releases from a nuclear power reactor, and the related doses to population living in the region. It is very extensive since nearly all the possible pathways of radioelements in the biosphere are considered, and many formulas and numerical data are given. As a result, doses to internal organs, to individuals and to population are calculated, both from external and internal irradiation sources. In order to provide comprehensive estimates of population dose, the HERMES model as initially developed is large and complex. It will be further refined to reduce its complexity based on the results of sensitivity studies performed during the study of the Upper Mississippi region. Refinement are expected to include the elimination of radionuclides and dose pathways that are shown to be insignificant in their contribution to dose.

MODEL 26	REFERENCE N° 33
MODEL NAME	: INDOS
AUTHORS	: G. Killough, S. Rohwer
ESTABLISHMENT	: Batt. Nort. West Lab. (USA)
DATE OF PUBLICATION	: 1974
AIM OF THE MODEL	: to evaluate the dose to man's organs and to aquatic organisms
CONTAMINATION SOURCE	: continuous and accidental releases from nuclear plants
NUCLIDES CONSIDERED	: fission products and actinides
RADIOISOTOPE PATHWAYS	: water pathways; inhalation; ingestion
DATA GIVEN IN THE REPORT	: physiological transfer coefficients; concentration factors in marine organs
FORMULAS	: concentration in organs and dose calculation
MODELING AND MATHEMATICAL APPROACH	: compartmental and radiological model written in FORTRAN IV

Description of the Model

The INDOS code computes the dose to internal organs resulting from the uptake of radionuclides by that organ. It consits of three subprograms INDOS I, II and III. This model permits to consider a continuous intake at a constant rate or a succession of single intakes at specified times. The internal doses to aquatic organisms living near a nuclear facility are also calculated, as consequence of contaminated effluent releases.

MODEL 27	REFERENCE N° 34
MODEL NAME	: INREM
AUTHORS	: G. Killough, S. Rohwer, D. Turner
ESTABLISHMENT	: Oak Ridge Nat. Lab. (USA)
DATE OF PUBLICATION	: 1975
AIM OF THE MODEL	: evaluation of the dose to individuals, to man's organs and population
CONTAMINATION SOURCE	: routine and accidental releases from a generic nuclear plant
NUCLIDES CONSIDERED	: 200 radionuclides among fission products and actinides
RADIOISOTOPE PATHWAYS	: inhalation; ingestion
DATA GIVEN IN THE REPORT	: mass of organs; biological half-lives
FORMULAS	: organ concentrations; dose estimation
MODELING AND MATHEMATICAL APPROACH	: mathematical and radiological model based on the ICRP models, written in FORTRAN

Description of the Model

INREM is a Fortran IV computer code which estimates the dose to various human body organs following inhalation or ingestion, or both, of one or more radionuclides. Individuals from a population for which such dose estimates are to be computed may be described by parameters which are either age independent or age dependent. The dose models implemented in INREM are based on those described in Publication 2 of the ICRP. First written in 1968, INREM has subsequently undergone a number of modifications, and an updated report has recently been issued. The revised code is available from the Radiation Shielding Information Center, Oak Ridge Natinal Laboratory, P.O. Box X, Oak Ridge, Tennessee 37830.

MODEL 28	REFERENCE N° 35
MODEL NAME	: ISOLA II
AUTHORS	: W. Hubschmann, D. Nagel
ESTABLISHMENT	: Kernforschungszentrum, Karlsruhe (Germany)
DATE OF PUBLICATION	: 1975
AIM OF THE MODEL	: α and β dose calculation to the population living in the proximity of a nuclear center
CONTAMINATION SOURCE	: continuous atmospheric releases
NUCLIDES CONSIDERED	: 15 radionuclides among α and β emitters
RADIOISOTOPE PATHWAYS	: air exposure
DATE GIVEN IN THE REPORT	:
FORMULAS	: atmospheric dispersion
MODELING AND MATHEMATICAL APPROACH	: mathematical and radiological model written in FORTRAN IV

Description of the Model

ISOLA II is a FORTRAN IV code for the calculation of the long -term α- and β-dose distribution in the vicinity of nuclear installations. It is used to calculate the annual radiation doses caused by α and β active off-gases in the environment of the Karslruhe Nuclear Research Center. In the revised version the double Gaussian distribution model is strictly observed. As a consequence, the contribution of activity from neighbour sectors is taken into account. Up to 15 emitters may be coped with simultaneously. The emission rates are considered to be constant during the given time interval. Optionally either the isodoses chart of a specified area or a list of doses calculated at up to 2000 locations in the environment may be set up.

MODEL 29 **REFERENCE N° 36**

MODEL NAME	: Migration of Plutonium in natural soils
AUTHORS	: H. Jakubick
ESTABLISHMENT	: ABRA, Karlsruhe (Germany)
DATE OF PUBLICATION	: 1976
AIM OF THE MODEL	: deposition and vertical migration into soil of fall-out plutonium
CONTAMINATION SOURCE	: fall-out
NUCLIDES CONSIDERED	: Pu-239, Pu-240
RADIOISOTOPE PATHWAYS	: water
DATA GIVEN IN THE REPORT	: vertical migration velocity and depth of penetration as a function of time
FORMULAS	: soil concentration and migration
MODELING AND MATHEMATICAL APPROACH	: top soil box model

Description of the Model

The paper deals with the deposition and migration of fall-out plutonium, which is considered here as analogous to an industrial PuO_2 contamination of soil. By correlating the few Pu measurements available in Germany with the fall-out data coming from Ispra, the probable history of Pu concentration in the air is derived. To find out the transport mechanism of Pu in soil, the data of Pu distribution in soil seems to obey an exponential law with a characteristic turnover time of 5-6 years in a 5 cm thick partially saturated soil layer. Using the previously derived input function and the estimated turnover time, the probable Pu concentration in the top soil in Germany was computed. Furthermore, the case of instantaneous soil contamination is considered. It is shown that a model using a sequence of boxes leads to a Poisson-type equation which predicts for PuO_2 migration velocity of 0.8 cm/a. Finally, the relative migration velocities of PuO_2 and $Pu(NO_3)_4$ are compared, indicating that the migration of PuO_2 is about 100 times faster than that of plutonium when applied to soil in the $Pu(NO_3)_4$ form.

MODEL 30	REFERENCE N° 37
MODEL NAME	: Compartmental Model in a Tropical Environment
AUTHORS	: S. Kaye, S. Ball
ESTABLISHMENT	: Oak Ridge Nat. Lab. (USA)
DATA OF PUBLICATION	: 1967
AIM OF THE MODEL	: evaluation of the dose to man due to underground nuclear explosions
CONTAMINATION SOURCE	: underground nuclear explosions
NUCLIDES CONSIDERED	: fission products
RADIOISOTOPE PATHWAYS	: ground water transport; inhalation; food crops ingestion
DATA GIVEN IN THE REPORT	: biomasses; transfer coefficients
FORMULAS	: compartmental equations; sensitivity analysis
MODELING AND MATHEMATICAL APPROACH	: ecological model

Description of the Model

The feasibility study for construction of a sea-level canal in Central America with nuclear devices required prediction of the movement of radionuclides in a tropical environment and estimation for the possible radiation doses to indigenous man. Large complex environments can be schematically simplified if represented by coupled compartment diagrams which contain critical pathways leading to man. A preliminary diagram was constructed which has enough flexibility for future modification and necessary expansions after on-site data become available. Such preliminary diagrams are useful because they can be used for computer sensitivity analyses using frequency response techniques when linear differential equations with constant coefficients are specified in the model. The SFR-3 digital computer code was used to determine the sensitivity of the various environmental transfer coefficients of a banana plantation to the concentration of radioactivity in the bananas which would be eaten by man. This code also provides an estimate of the integrated concentration of radioactivity in bananas resulting from a fallout pulse input to the system and the magnitude and time of the peak concentration, all of which are directly related to the internal dose received by man.

MODEL 31	REFERENCE N^{o} 38
MODEL NAME	: LIDIA
AUTHORS	: D. Dini, L. Pucciarelli
ESTABLISHMENT	: CNEN (Italy)
DATE OF PUBLICATION	: 1978
AIM OF THE MODEL	: calculation of the dose to individuals, population
CONTAMINATION SOURCE	: atmospheric accidental release from a generic nuclear plant
NUCLIDES CONSIDERED	: fission products
RADIOISOTOPE PATHWAYS	: air exposure; inhalation
DATA GIVEN IN THE REPORT	:
FORMULAS	: atmospheric dispersion; plume concentration; dose calculation; ground deposition
MODELING AND MATHEMATICAL APPROACH	: generic mathematical model, written in FORTRAN IV

Description of the Model

The program LIDIA permits to assess the radiological impact in terms of environmental pollution and dose rates to man, due to accidental atmospheric fission products release from nuclear facilities. It can be used both in preliminary siting analysis and in safety assessment.

MODEL 32 **REFERENCE N° 39**

MODEL NAME	: Analog Computer for the Model of the Metabolism of Some Radionuclides
AUTHORS	: A. Likhtarev et al.
ESTABLISHMENT	: RSFSR (USSR)
DATE OF PUBLICATION	: 1974
AIM OF THE MODEL	: physiological study of the behaviour of some radioisotopes in mammals
CONTAMINATION SOURCE	: intravenous injection and ingestion
NUCLIDES CONSIDERED	: Pu (DTPA), I, Sr, Ca
RADIOISOTOPE PATHWAYS	: blood
DATA GIVEN IN THE REPORT	:
FORMULAS	: non linear transfer equations
MODELING AND MATHEMATICAL APPROACH	: compartmental and mathematical model

Description of the Model

It concerns the mathematical modeling of the radionuclide metabolism in the human body and experimental animals. There are a number of situations where the linear kinetic models of radionuclide transport cannot be applied. These include cases where coefficients in differential equation systems are functions of time or contain products of functions. Such systems cannot be integrated analytically, as a rule, even in quadrature solutions. Meanwhile, the solution of such problems is of considerable practical and theoretical value, since this class of models includes the interaction of radionuclides with chelate complexing agents, e.g. DTPA, the protective action of stable iodine and, finally, the models simulating the changes of metabolic «constants» with aging. A continuous solution for non-linear models may be offered and the structure of these solutions can be studied for arbitrary input functions through the application of analog computers (AC) equipped with special devices for non-linear systems of the abovementioned types. This paper deals with these models and some methods of solution and discusses the effectiveness of this computer analysis technique.

MODEL 33	REFERENCE N° 40
MODEL NAME	: Modeling of Radionuclide migration from a low-level Radioactive Waste Burial Site
AUTHORS	: A.H. Lu
ESTABLISHMENT	: Radiol. Sc. Lab., State Dept. of Health, Albany
DATE OF PUBLICATION	: 1978
AIM OF THE MODEL	: to describe the migration of leachate from waste buried in trenches
CONTAMINATION SOURCE	: leaching of radioactive wastes by trench water
NUCLIDES CONSIDERED	: tritium, strontium
RADIOISOTOPE PATHWAYS	: water infiltrating into a porous medium
DATA GIVEN IN THE REPORT	: water velocity; distribution coefficients
FORMULAS	: equations for migration of radioisotopes
MODELING AND MATHEMATICAL APPROACH	: hydrogeological model

Description of the Model

A simplified mathematical model for analysing the migration of leachate and radioactive material contained in radioactive waste burial trenches has been developed. A differential equation describing the distribution and movements of radioisotopes is analytically solved assuming a constant flux of trench water infiltrating into a saturated porous medium which is not an aquifer.

MODEL 34	REFERENCE N° 41
MODEL NAME	: Plutonium Transport and Dose Estimation Model
AUTHORS	: E. Martin, S. Bloom
ESTABLISHMENT	: Batt. Columbus Lab., Ohio (USA)
DATE OF PUBLICATION	: 1975
AIM OF THE MODEL	: Pu dose to man calculation
CONTAMINATION SOURCE	: NTS soil contaminated by nuclear tests
NUCLIDES CONSIDERED	: Pu-239
RADIOISOTOPE PATHWAYS	: resuspension and inhalation; soil and food crops ingestion
DATA GIVEN IN THE REPORT	: inhalation rates; diets; transfer coefficients
FORMULAS	: deposition on vegetals; inhalation; concentration in food crops
MODELING AND MATHEMATICAL APPROACH	: compartmental model developed for Pu-239 in terrestrial environment

Description of the Model

A Standard Man is assumed to live in and obtain most of his food from a Pu-contaminated area at NTS. A Pu-transport model, based on the results of other studies at NTS, provides a basis for estimating the surface soil of the reference area. A dose estimation model, based on parameters recommended in ICRP publications, is used to estimate organ burdens, accumulated doses, and dose commitments as functions of exposure time. The doses due to inhalation and ingestion of Pu-239 for 50 years are calculated for the following organs: thoracic lymph nodes, lung, bone, liver, kidneys, total body, and gastrointestinal tract; inhalation accounts for 100% of the predicted dose to thoracic lymph nodes and lungs and for about 94% of the predicted dose to bone, liver kidneys, and total body.

MODEL 35	REFERENCE N° 42
MODEL NAME	: METEO–1
AUTHORS	: O. Veverka et al.
ESTABLISHMENT	: Skoda Works (Czecho-Slovakia)
DATE OF PUBLICATION	: 1975
AIM OF THE MODEL	: evaluation of the atmospheric dispersion of radioisotopes
CONTAMINATION SOURCE	: accidental and routine releases of radioactive effluents from generic nuclear plants
NUCLIDES CONSIDERED	:
RADIOISOTOPE PATHWAYS	: atmosphere
DATA GIVEN IN THE REPORT	:
FORMULAS	: Pasquill's formulas
MODELING AND MATHEMATICAL APPROACH	: atmospheric model

Description of the Model

This paper gives a description of the programmes METEO-H (reactor crash out flows) and METEO-N (operational outflow statistics). A complete list is given of the used formulae for both cases based on the Pasquill-formulation of the problem. The following phenomena are enclosed:

- Reactor-crash outflow
- Operational outflow statistics
- Normal temperature gradient (decrease with height), inversion (increase with height)
- Lofting
- Fumigation
- High stack
- Short stack
- Leakage from reactor building
- Two terms of decay chains for rare gases, one term for other isotopes
- Fall out and wash out deposition processes
- Statistical fluctuations of the wind direction for the case of reactor crash outflow.

MODEL 36	REFERENCE N° 43
MODEL NAME	: MIRD
AUTHORS	: F. Butler, N. Vanek et al.
ESTABLISHMENT	: Univ. of Florida, Gainesville (USA)
DATE OF PUBLICATION	: 1977
AIM OF THE MODEL	: dose to human organs
CONTAMINATION SOURCE	: Tc-99 labelled pharmaceutical products
NUCLIDES CONSIDERED	: Tc-99 (DHTA)
RADIOISOTOPE PATHWAYS	: blood
DATA GIVEN IN THE REPORT	: physiological transfer coefficients
FORMULAS	: absorbed dose
MODELING AND MATHEMATICAL APPROACH	: mathematical and radiological model (FORTRAN IV)

Description of the Model

Although determinations of radiation absorbed dose estimates for internally administered radiopharmaceuticals have been facilitated through the use of recently published S-factors, extensive data manipulation is still required in many cases. Computer programs for determination of cumulated activity from experimentally measured retention data and computer programs for determination of radiation absorbed dose using the new S-factors are described. These programs, which are available from the Biomedical Computing Technology Information Center of the Oak Ridge National Laboratory, can be used to eliminate the tedious and repetitive calculations required in internal dosimetry.

MODEL 37	REFERENCE N° 44
MODEL NAME	: MUNDO
AUTHORS	: F. Heller, W. Schikarski et al.
ESTABLISHMENT	: Kernforschungszentrum, Karlsruhe (Germany)
DATE OF PUBLICATION	: 1967
AIM OF THE MODEL	: radioactivity doses to man due to nuclear reactor core melting accident
CONTAMINATION SOURCE	: atmospheric release from melted reactor core
NUCLIDES CONSIDERED	: 80 fission products
RADIOISOTOPE PATHWAYS	: inhalation; air exposure; ingestion
DATA GIVEN IN THE REPORT	:
FORMULAS	: atmospheric dispersion; deposition; biological half-lives; dose calculation
MODELING AND MATHEMATICAL APPROACH	: sophisticated mathematical model, written in FORTRAN

Description of the Model

The main consequence of a major reactor accident is radiation in the environs. To establish the extent of irradiation (accident dose rate), the following relationships have to be quantified:

1. Physical relationship between the accident sequence under investigation and release of radioactive materials from the core. 2. Transport phenomena and decontamination, deposition and filtering behaviour of radioactive materials released on the accident in the reactor building. 3. Leakage of radioactive materials in the reactor building through the reactor containment system. 4. Distribution and spread of radioactive material issuing from the reactor building as a function of weather. 5. Application of accident dose rate at a point in the reactor plant environs by external and internal radiation. The MUNDO computer code calculates the dose equivalent received at the point F and time t in rem, as a function of the above parameters and relationships.

The following values in particular can be allowed for: fuel release function, fuel release factors, decontamination factors, filter factors, leak functions, multi-containment, ground release, stack release, weather conditions, external radiation, radiation by incorporation, direct radiation from reactor building.

The MUNDO code computes accident dose contributions from approx. 80 fission products and fuel isotopes.

MODEL 38	REFERENCE N° 45
MODEL NAME	: Transfer of Radioactivity through a Marine Ecosystem
AUTHORS	: N. Murray and A. Avogadro
ESTABLISHMENT	: J.R.C., Euratom (Italy)
DATE OF PUBLICATION	: 1977
AIM OF THE MODEL	: to develop a methodology for the assessment of the distribution of actinide isotopes introduced into a marine ecosystem
CONTAMINATION SOURCE	: polluted river water
NUCLIDES CONSIDERED	: Plutonium and Americium
RADIOISOTOPE PATHWAYS	: aquatic food chains
DATA GIVEN IN THE REPORT	: concentration ratios in marine organisms and in sediments
FORMULAS	: radioactivity dispersion in the sea and absorption into sediments; biological transfer
MODELING AND MATHEMATICAL APPROACH	: compartmental model at the equilibrium

Description of the Model

A methodology for the assessment of the distribution and of the associated hazard of artificial radioactivity in the case of its introduction into surface waters of a coastal marine ecosystem is presented. The identification of the various environmental compartments and the processes occurring within them which are of importance in affecting the behaviour and thus the distribution of actinide elements in aquatic systems are outlined. The theoretical basis for the mathematical treatment of these processes are shortly reviewed. The compartment model system (box model) chosen is applied to an imaginary coastal area. Various types of processes in the environmental compartments are considered separately and then assembled to show their combined interactions. The system is assumed to be at steady state.

MODEL NAME	:	NAEG Plutonium Study Modeling Program; Pu Transport and Dose Estimation Model
AUTHORS	:	E. Martin, S. Bloom et al.
ESTABLISHMENT	:	Nevada App. Ecol. Group (USA)
DATE OF PUBLICATION	:	1974
AIM OF THE MODEL	:	to estimate the fraction of Pu-239 transported to man through food-chain
CONTAMINATION SOURCE	:	Pu - contaminated desertic environment
NUCLIDES CONSIDERED	:	Pu-239
RADIOISOTOPE PATHWAYS	:	from soil via: inhalation; ingestion
DATA GIVEN IN THE REPORT	:	air concentration; physiological and trophic transfer coefficients; primary productivity; diets
FORMULAS	:	compartmental equations; soil resuspension; dilution growth rate factor
MODELING AND MATHEMATICAL APPROACH	:	dynamic compartmental model

Description of the Model

A computer program based on a matrix exponential method is used to solve a system of ordinary differential equations which simulate the behaviour of Pu-239 in desert ecosystems such as those found at and near the Nevada Test Site. The model is used to estimate the rates of Pu-239, transport, via several environmental pathways, to Standard Man, who is assumed to live in a contaminated area. These estimates are then used to calculate radiation doses and dose commitments, as a function of time, to different organs. The model provides a method for evaluating the potential radiological hazard to man due to the presence of Pu-239 in a given area.

MODEL 40	REFERENCE N° 47
MODEL NAME	: The Environmental Impact I-129 Model
AUTHORS	: M. Palms, R. Veluri, W. Boone
ESTABLISHMENT	: Emory Univ. (New Mexico)
DATE OF PUBLICATION	: 1975
AIM OF THE MODEL	: evaluation of I-129 doses to the tyroid
CONTAMINATION SOURCE	: routine iodine release from reprocessing plants
NUCLIDES CONSIDERED	: I-129
RADIOISOTOPE PATHWAYS	: inhalation; ingestion; external exposure
DATA GIVEN IN THE REPORT	: physical parameters for atmospheric dispersion; air concentration; ecological data
FORMULAS	: inhalation rate; external irradiation; concentration in milk and forage
MODELING AND MATHEMATICAL APPROACH	: compartmental model at the equilibrium, the dose to man is calculated by MIRD computer code

Description of the Model

The environmental impact of I-129 released by the Allied-General Nuclear Services - Barnwell Nuclear Fuel Plant (BNFP) - is assessed. On the bases of present knowledge, it is expected that the predicted releases from the plant will not raise the concentration of I-129 to levels that would be hazardous to man or the environment. This article summarizes the analyses associated with the release of I-129 to the environment, including the presently estimated BNFP releases and calculations of resulting dose to man using the state-of-the-art dose models. Thyroid doses are calculated by the specific activity model and the critical pathway model. The degree of conservativeness involved in the specific activity model which makes it unacceptable as a realistic model is discussed and the critical pathway model is briefly assessed. Thyroid doses for adults and infants due to inhalation and ingestion are presented. For an air concentration of 3.6×10^{-5} pCi/m^3 of I-129, resulting from a release at the rate of 1.5×10^{-9} Ci/sec, the infant and the adult thyroid doses due to ingestion via milk are calculated by the critical pathway model to be 0.24 and 0.12 mrem/year, respectively. The adult thyroid dose due to ingestion of leafy vegetable is found to be 0.04 mrem/year. The inhalation and whole-body doses are orders of magnitude smaller.

MODEL 41 **REFERENCE N° 48**

MODEL NAME	:	RADS – ARADS
AUTHORS	:	P. Plato, D. Menker, M. Daner
ESTABLISHMENT	:	Univ. of Miami, Florida (USA)
DATE OF PUBLICATION	:	1967
AIM OF THE MODEL	:	atmospheric transport evaluation
CONTAMINATION SOURCE	:	routine and accidental atmospheric releases from nuclear reactors
NUCLIDES CONSIDERED	:	fission products
RADIOISOTOPE PATHWAYS	:	
DATA GIVEN IN THE REPORT	:	air concentration
FORMULAS	:	
MODELING AND MATHEMATICAL APPROACH	:	mathematical model written in FORTRAN IV

Description of the Model

They are two computer programs written for an IBM 10401/7040 digital computer in FORTRAN IV computer language. The programs are called RADS and ARDS, acronyms for Radiological Atmospheric Dispersion Study and Alternate RADS, respectively. Both programs are designed to investigate the use of various equations formulated to predict the dispersion of radioactive effluents deposited into the atmosphere from a smokestack. The release of the effluents may be of either an instantaneous or continuous nature. Predictions of atmospheric concentrations are made for approximately 600 points throughout an observation area surrounding the smoke source, allowing contour lines of equal concentrations to be drawn. The RADS program was designed for one particular effluent release. The program predicts the path of the smoke from the source to one of the boundaries of the observation area. Predictions are then made concerning the dispersion of the smoke. The ARDS program uses average meteorological conditions to predict the air concentrations resulting from long-term releases of a smokestack effluent. The output data for both programs contain a scaled map of the observation area showing the location of the predicted concentrations in order to simplify the drawing of the contour lines. While the authenticity of the prediction equations is not certain, a definite relationship between relative air concentrations with respect to the location of the source was established. The programs permit fast, accurate, and voluminous solutions to the complex equations, and provide a tool with which to examine the prediction equations themselves.

MODEL 42	REFERENCE N° 49
MODEL NAME	: RADOS
AUTHORS	: R.E. Cooper
ESTABLISHMENT	: Savannah River Lab. (USA)
DATE OF PUBLICATION	: 1967
AIM OF THE MODEL	: external dose evaluations
CONTAMINATION SOURCE	: accidental atmospheric releases from nuclear plants
NUCLIDES CONSIDERED	: fission gases
RADIOISOTOPE PATHWAYS	: atmospheric transport; air exposure
DATA GIVEN IN THE REPORT	:
FORMULAS	: dose calculations
MODELING AND MATHEMATICAL APPROACH	: mathematical model written in FORTRAN IV

Description of the Model

RADOS is a computer code that represents the finite spatial distribution of airborne source material as an infinite number of line source. The code provides a means of rapidly calculating whole body gamma dose from a finite cloud of radioactive material. The simplifying assumptions used to minimize computation time are:

1. The material release is instantaneous and results in a radioactive cloud of unit thickness in the X or downwind direction.
2. There is no change in the size and shape of the cloud during passage over the effective range of the receptor.
3. The gamma buildup factors can be expressed analytically with sufficient accuracy.

These assumptions limit the applicability of RADOS as follows: the material release should occur over a relatively short time; the receptor distance should be more than 600 meters downwind from the release point; and the gamma energies should be in the specified range.

MODEL 43 **REFERENCE N° 50**

MODEL NAME	:	RAMM
AUTHORS	:	R.B. Lyon
ESTABLISHMENT	:	Whiteshell Nucl. Res. Est. (Canada)
DATE OF PUBLICATION	:	1976
AIM OF THE MODEL	:	dose to man evaluation due to radioactive pollution of environment
CONTAMINATION SOURCE	:	general environmental pollution
NUCLIDES CONSIDERED	:	Cs-137
RADIOISOTOPE PATHWAYS	:	food chains
DATA GIVEN IN THE REPORT	:	transfer coefficients fresh water to fish
FORMULAS	:	general formulas
MODELING AND MATHEMATICAL APPROACH	:	dynamic time-dependent model

Description of the Model

A generalized system of computer programs, designated RAMM (Radioactive Materials Management) system, has been developed to assist in the analysis of the movement of radionuclides through the environment to man. A nodal approach is used whereby the system to be analysed is split up into parts small enough that the distribution of nuclides within the node may be taken to be homogeneous. Pathways are defined between nodes, and appropriate transfer coefficients are input or generated. Nodes are general «containers of nuclides» and may be volumes, such as a volume of water or a body organ, or surfaces such as a square metre of land surface. Nodes may be defined as belonging to streams within which movement may be transportation as well as by diffusion. Output includes the time dependent contents of the nodes and dose rates, integrated doses and dose commitments of selected nodes.

MODEL 44 | REFERENCE N° 51

MODEL NAME	: A Computer Code for Analyzing Routine Atmospheric Release of Short-lived Radioactive Nuclides
AUTHORS	: M. Reeves, G. Fowler et al.
ESTABLISHMENT	: Oak Ridge Nat. Lab., Tenn. (USA)
DATE OF PUBLICATION	: 1972
AIM OF THE MODEL	: evaluation of the air concentration and soil deposition of radioisotopes
CONTAMINATION SOURCE	: routine atmospheric releases from nuclear plants
NUCLIDES CONSIDERED	: short-lived radioisotopes
RADIOISOTOPE PATHWAYS	: atmosphere; dry deposition; air exposure; inhalation
DATA GIVEN IN THE REPORT	: deposition rate; washout coefficients
FORMULAS	: air concentration; soil concentration
MODELING AND MATHEMATICAL APPROACH	: atmospheric model

Description of the Model

A computer code is presented which calculates average annual ground level air concentrations, deposition rates, and ground concentrations for a decaying chain of radioactive nuclides. Members of this chain are assumed to have been emitted from a stack under routine nonaccidental operating conditions. Averages are performed relative to atmospheric stabilities, wind speeds, and wind directions.

MODEL 45 **REFERENCE N° 52**

MODEL NAME	: RISC
AUTHORS	: H. Anno, J. De Bois et al.
ESTABLISHMENT	: Aerojet (USA)
DATE OF PUBLICATION	: 1963
AIM OF THE MODEL	: evaluation of the dose to human organs
CONTAMINATION SOURCE	: generic accidental atmospheric release from whatever radioactivity source
NUCLIDES CONSIDERED	: 50 radionuclides among fission products and α-emitters
RADIOISOTOPE PATHWAYS	: inhalation
DATA GIVEN IN THE REPORT	:
FORMULAS	:
MODELING AND MATHEMATICAL APPROACH	: atmospheric and radiological model

Description of the Model

The radiological consequences from the inhalation of the released airborne radioactive material may be predicted by using the RISC (Radiological Inhalation Safety Code) machine program described here. RISC is a digital machine program used to compute internal exposure to seven body organs or tissues (thyroid, bone, muscle, lungs, gastro-intestinal tract, soft body tissues, and testes), incurred over the first year following short-duration inhalation. Doses to these body organs are based on computations of up to 50 radionuclide sources. These computations include both radioactive and atmospheric source, strength determination, and the dose contributions from any of the 50 radionuclides to any or all of the above mentioned body organs.

MODEL 46 **REFERENCE N° 53**

MODEL NAME	:	RISØ Model
AUTHORS	:	P. Hedemann J. et al.
ESTABLISHMENT	:	Risø Nat. Lab. (Denmark)
DATE OF PUBLICATION	:	1977
AIM OF THE MODEL	:	calculation of the dose to individuals and population due to a core melting accident
CONTAMINATION SOURCE	:	atmospheric release from melted reactor core
NUCLIDES CONSIDERED	:	25 radionuclides (actinides are considered)
RADIOISOTOPE PATHWAYS	:	inhalation; air exposure
DATA GIVEN IN THE REPORT	:	Pasquill's data; deposition velocity; photon energy groups
FORMULAS	:	air plume concentration; inhalation dose; deposition rate
MODELING AND MATHEMATICAL APPROACH	:	meteorological and radiological model utilizing a sophisticated mathematical approach

Description of the Model

Individual and population doses on Danish territory are calculated from hypothetical, severe core-melt accidents at the Swedish nuclear plant at Barsebäck. The release fractions for these accidents are taken from WASH-1400. Based on parametric studies, doses are calculated for very unfavourable, but not incredible weather conditions. The probability of such conditions in combination with wind direction towards Danish territory is estimated. Doses to bone marrow, lungs GI-tract and thyroid are calculated using dose models developed at Riso. These doses are found to be consistent with doses calculated with the models used in WASH-1400.

MODEL 47	REFERENCE N° 54
MODEL NAME	: Forage Model
AUTHORS	: J. Smith, A. Callegos
ESTABLISHMENT	: Los Al. Sc. Lab. (USA)
DATE OF PUBLICATION	: 1974
AIM OF THE MODEL	: to describe the transfer of fall-out plutonium from soil to vegetables
CONTAMINATION SOURCE	: fall-out
NUCLIDES CONSIDERED	: Pu
RADIOISOTOPE PATHWAYS	: deposition from air; transfer to vegetables; resuspension
DATA GIVEN IN THE REPORT	: solar energy; weathering coeff.; water requirement for biomass; resuspension rate; transfer coeff.
FORMULAS	: solar radiation; biomass production; humus convertion; turnover
MODELING AND MATHEMATICAL APPROACH	: ecological model

Description of the Model

This module may be simply described as a forage generator which has provision for plutonium and other transuranic uptake and for surface contamination from fallout deposition of TRU-bearing particles. The major outputs of this model are estimates of herbage densities (g/m^2 dry weight), and the plutonium activity in the herbage throughout the year. Presently, the module considers native warm and cool season grasses, all of which are perennials, as the major forage plants. However, provision can be made to simulate the growth of annual grasses and herbs if necessary.

MODEL 48	REFERENCE N° 55
MODEL NAME	: Environmental pathways and radiation doses from nuclear facilities
AUTHORS	: J.K. Soldat
ESTABLISHMENT	: Batt. Nort. West Lab. (USA)
DATE OF PUBLICATION	: 1971
AIM OF THE MODEL	: evaluation of the dose to man and population
CONTAMINATION SOURCE	: continuous release and deposition on soil from nuclear reactors
NUCLIDES CONSIDERED	: fission products
RADIOISOTOPE PATHWAYS	: inhalation; terrestrial food chain; aquatic food chain; air exposure
DATA GIVEN IN THE REPORT	: radioactivity retention in the respiratory tract
FORMULAS	: food chains formulas; dose factors (inhalation, submersion, ingestion)
MODELING AND MATHEMATICAL APPROACH	: compartmental model

Description of the Model

A computer model was developed which calculates total annual radiation doses and 50-year dose commitments to several categories of persons at population centres and combines these calculated doses into integrated (man-rem) annual and 50-year doses for large populations. The doses model was designed as one portion of an overall computer program developed to delineate the nuclear facilities expected in the year 2000, the radionuclides released to air and water, their diffusion, dispersion, and reconcentration in the environment, and the resulting radiation doses to people. Equations for calculating dose factors were derived from those given by the ICRP. Effective decay energies for various radionuclides were calculated from the ICRP model, which assumes that all the radionuclide is in the centre of a spherical organ with an appropriate effective radius. Where data were lacking, metabolic parameters for the Standard Man were used for other ages as well. The model includes a sub-routine which calculates radionuclide concentrations in a wide variery of foods at time of harvest from concentrations in air, irrigation water, and soil. The later concentrations are output from previous portions of the overall computer program.

MODEL 49	REFERENCE N° 56
MODEL NAME	: Models and Computer Codes ...
AUTHORS	: M. Soldat, A. Robinson et al.
ESTABLISHMENT	: Batt. Nort. West Lab. (USA)
DATE OF PUBLICATION	: 1974
AIM OF THE MODEL	: calculation of the dose to individuals, population and other organisms
CONTAMINATION SOURCE	: gaseous and liquid effluent releases from a nuclear reactor
NUCLIDES CONSIDERED	: fission products and actinides
RADIOISOTOPE PATHWAYS	: water exposure; air exposure; inhalation; food ingestion
DATA GIVEN IN THE REPORT	: concentration ratios; diets
FORMULAS	: dose to man and to aquatic organisms
MODELING AND MATHEMATICAL APPROACH	: equilibrium compartmental model (BASIC language)

Description of the Model

The model calculates radiation doses to the total body and selected organs of individuals and population groups, and to organisms other than man. It includes all air and liquid exposure pathways through to be significant and for which a reasonable amount of supporting data is available. Internal doses to man are based on a 1-year radionuclide intake, assuming us prior accumulation in the body. The radionuclide content of ingested food is assumed to be at equilibrium with the environment. This paper discusses the models in detail and describes the programs ARRRG, CRITR and GRONK Although the programs were originally intended specifically for nuclear reactors, they are applicable to any nuclear facility which releases radioactive effluents to air or water.

MODEL 50 | **REFERENCE N° 57**

MODEL NAME	:	Radiological Model
AUTHORS	:	S. Snyder, R. Ford, S. Watson
ESTABLISHMENT	:	Oak Ridge Nat. Lab. (USA)
DATE OF PUBLICATION	:	1975
AIM OF THE MODEL	:	to describe the transfer of inhaled radioactivity to different organs
CONTAMINATION SOURCE	:	atmospheric pollution
NUCLIDES CONSIDERED	:	as much as 160 radioisotopes
RADIOISOTOPE PATHWAYS	:	inhalation
DATA GIVEN IN THE REPORT	:	
FORMULAS	:	physiological transport and accumulation in the organs
MODELING AND MATHEMATICAL APPROACH	:	radiological compartmental model

Description of the Model

This model describes the transfer of inhaled radioactive isotopes from lungs to other organs of the human body; it is a dynamic model, which is applicable to as much as 160 nuclides, and is very flexible in that it is possible to give as an input a blood concentration. The output consists of the dose to various organs

MODEL 51	REFERENCE N° 58
MODEL NAME	: TERMOD
AUTHORS	: R.S. Booth, U. Kaye et al.
ESTABLISHMENT	: Oak Ridge Nat. Lab. (USA)
DATE OF PUBLICATION	: 1971
AIM OF THE MODEL	: to calculate the radionuclide intake to man from fall-out contaminated food crops
CONTAMINATION SOURCE	: fall-out
NUCLIDES CONSIDERED	: Sr-90, I-131, Cs-137, P-32, W-185, Hg-203 and Tl-204
RADIOISOTOPE PATHWAYS	: from soil and air to vegetals and to beef cattle; to man through food-chains
DATA GIVEN IN THE REPORT	: transfer coefficients; primary productivity; radionuclide turnover; growth rates of vegetals; biomasses
FORMULAS	: transfer equations to trophic levels; intake to man from food ingestion
MODELING AND MATHEMATICAL APPROACH	: dynamic compartmental model utilizing linear differential equations; turnover and growth rate are taken into consideration, dose to man is calculated by INREM code (written in FORTRAN IV)

Description of the Model

TERMOD is a generalized coupled-compartment code intended for preedictions of radionuclide intakes by man through consumption of milk, beef, and plant parts contamined directly by deposited radionuclides as well as by uptake from the soil. A standard data base for 75 radionuclides is included in the code. The code is sufficiently versatile for application to all radionuclides released to a variety of terrestrial environments, because the interactive nature of the code allows site- and nuclide-specific parameters to be specified from a remote terminal. The code has been used in numerous estimates of transfer of radioactive materials through the terrestrial environment, including those required for environmental impact statements for nuclear facilities. The TERMOD code is written in BASIC language for use in a conversational mode at a remote terminal and is designed to be run on the DEP PDP-10 computer system.

MODEL 52 **REFERENCE N° 59**

MODEL NAME	: Model for Predicting the Redistribution of Particulate contaminants from Soil Surfaces
AUTHORS	: R. Travis
ESTABLISHMENT	: Los. Alam. Sc. Lab. (USA)
DATE OF PUBLICATION	: 1975
AIM OF THE MODEL	: evaluation of soil resuspension and deposition
CONTAMINATION SOURCE	: PuO_2 – contaminated soil
NUCLIDES CONSIDERED	: Pu-238
RADIOISOTOPE PATHWAYS	: wind
DATA GIVEN IN THE REPORT	: resuspension factors; erosion depth and erosion coefficients
FORMULAS	: air concentration; soil erosion; atmospheric dispersion and soil deposition
MODELING AND MATHEMATICAL APPROACH	: atmospheric model (FORTRAN)

Description of the Model

This computerized model was developed to describe the redistribution of wind eroding soil-contaminant mixtures. Potentially mobile particulate contaminants can be assumed to be indistinguishable from the wind eroding soil in which they are distributed. Material is transported through the vertical and top surfaces of a control volume by a modified Bagnold-Chepil horizontal flux formulation and modified Gillette vertical flux formulation, respectively. The vertical emissions, considered as puffs from area sources, create at regular time intervals a contaminant cloud which is proportional to the suspendable ground concentration. These puffs diffuse downwind under time-dependent wind velocity and atmospheric stability conditions, maintaining during the time interval a three-dimensional Gaussian distribution of concentration with cloud volume. Material from each puff is deposited in downwind cells, leading to the possibility of many different flights from these new sources.

MODEL 53	REFERENCE N° 60
MODEL NAME	: VADOSCA
AUTHORS	: L. Bramati, T. Mazzullo et al.
ESTABLISHMENT	: ENEL, Roma (Italy)
DATE OF PUBLICATION	: 1973
AIM OF THE MODEL	: evaluation of the dose to population due to nuclear reactors
CONTAMINATION SOURCE	: continuous gaseous and liquid effluents released into the biosphere
NUCLIDES CONSIDERED	: fission and activation products (Pu-239 is considered)
RADIOISOTOPE PATHWAYS	: inhalation; external irradiation; water and contaminated-foods ingestion; accidental soil ingestion
DATA GIVEN IN THE REPORT	: biological concentration ratios; concentration of stable elements in vegetals and animals; diets
FORMULAS	: air concentrations; trophic transfer; dose to man calculation
MODELING AND MATHEMATICAL APPROACH	: equilibrium compartmental model consisting of two parts (liquid and gaseous discharges), written in FORTRAN

Description of the Model

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 all the compartments of the critical paths outlines in the ICRP Publication No. 7, and the valuation of the annual doses for five critical organs (whole body, G.I. tract, thyroid, bones, lungs) 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 valuations required to define the amount of radioactivity that can be released and the associated exposures.

MODEL 54	REFERENCE N° 61
MODEL NAME	: Distribution Model for Radioactive and other Persistent Pollutants in the Environment and in the Food Chain
AUTHORS	: G. Zuccaro Labellarte
ESTABLISHMENT	: CNEN (Italy)
DATE OF PUBLICATION	:
AIM OF THE MODEL	: food-chain contamination from hypothetic nuclear plants
CONTAMINATION SOURCE	: continuous releases to air and to surface waters
NUCLIDES CONSIDERED	:
RADIOISOTOPE PATHWAYS	: food chains
DATA GIVEN IN THE REPORT	:
FORMULAS	: atmospheric dispersion; fresh and sea water dispersion; transfer equations
MODELING AND MATHEMATICAL APPROACH	: compartmental model time-dependent written in FORTRAN

Description of the Model

The paper describes a computerized model for radioactive and persistent pollutants in the environment and in the human food chain. The study of the distribution of radioactive pollutants released from nuclear plants led to this model, which allows of the calculation of seasonal or annual averages of pollutant concentrations due to stationary or quasistationary sources. The model input includes a detailed list of each pollutant released in air, in freshwater and in seawater, the frequency of occurrence of various meteorological conditions during the period of time under consideration and physical features of the receiving water bodies. The oputput of the model gives, for each pollutant being considered. a) its concentration function in each link of the food chain, b) its source-to-man transfer function for a given population and c) its critical pathways. The analogies and differences in the behaviour between radioactive and persistent pollutants are discussed. The model is written in FORTRAN.

MODEL 55	REFERENCE N° 62
MODEL NAME	: A model for the Evaluation of the Deep Ocean Disposal of Radioactive Waste
AUTHORS	: G. Webb, F. Morley
ESTABLISHMENT	: NRPB, Harwell (England)
DATE OF PUBLICATION	: 1973
AIM OF THE MODEL	: evaluation of the dose to population from radioactive wastes disposed of in deep sea
CONTAMINATION SOURCE	: continuous leaching of the wastes
NUCLIDES CONSIDERED	: Mn, Zu, Ru, Ce, Fe, Co, H-3, Sr, Cs, Ra, Pu
RADIOISOTOPE PATHWAYS	: aquatic food chain
DATA GIVEN IN THE REPORT	: concentration factors
FORMULAS	: diffusion equations; concentration at the considered trophic levels; interzone dilution
MODELING AND MATHEMATICAL APPROACH	: compartmental model for risk assessment

Description of the Model

The report reviews the nature of packaged solid radioactive waste disposed of in the deep Atlantic and the scientific and technical considerations involved in assessing the movement of radionuclides following disposal. A model is established and used to estimate the relationship between continuous rates of disposal and the radiation doses ultimately received by those persons likely to be exposed to the greatest extent. The model takes account of oceanographic factors and the transfer of radionuclides through marine ecosystems; there are many inherent safety factors. Separate consideration is given to alpha and beta-gamma active waste; tritiated wastes are treated as a special case. The rates of disposal corresponding to the Dose Limits set by International Commission on Radiological Protection are calculated to illustrate the concept of «limiting environmental capacity».

MODEL 56	REFERENCE N° 63
MODEL NAME	: WEERIE
AUTHORS	: H. Clarke
ESTABLISHMENT	: Berkeley Nucl. Lab. (England)
DATE OF PUBLICATION	: 1973
AIM OF THE MODEL	: to evaluate doses to man from radioactive effluents
CONTAMINATION SOURCE	: continuous and accidental atmospheric releases from nuclear reactors
NUCLIDES CONSIDERED	: fission products
RADIOISOTOPE PATHWAYS	: inhalation; air exposure
DATA GIVEN IN THE REPORT	: fraction of fission products released to atmosphere
FORMULAS	: release to cooling circuits; atmospheric release and transport; dose calculation
MODELING AND MATHEMATICAL APPROACH	: dynamic mathematical model (FORTRAN IV)

Description of the Model

A mathematical model has been devised for guidance in the safety and siting aspects of nuclear installations under operational or accident conditions. The model begins with the full fission generated for any reactor type and irradiation history. The amount of fuel involved in the incident may vary as a function of time and either a time decaying or constant fission product inventory may be used to specify the release. The activity leaks from the circuit with allowances for time-dependent plate-out, resuspension and filtration of each elemental species By preserving the full nuclide decay schemes, nuclides leaking into the atmosphere depend not only upon their own release behaviour but also on that of their precursors. The effluent in the atmosphere is dispersed from an effective stack height and allowance is made for building entrainment Standard meteorological dispersion models are used and the effects of radioactive buildup and decay, ground and inversion reflections and ground deposition are taken into account WEERIE then evaluates the inhalation and the cloud β doses, while integration over the volume of the plume leads to estimates of the cloud γ exposures. WEERIE is written in FORTRAN IV (H) and executes on the IBM 370/165 computer requiring 250 kbytes of fast core storage.

MODEL 57 REFERENCE N° 64

MODEL NAME	: WRED
AUTHORS	: E. Cooper
ESTABLISHMENT	: Savannah River Lab. (USA)
DATE OF PUBLICATION	: 1968
AIM OF THE MODEL	: assessment of γ-dose rates to whole body and to the tyroid
CONTAMINATION SOURCE	: accidental atmospheric release from nuclear reactors
NUCLIDES CONSIDERED	: different isotopes among which iodine isotopes
RADIOISOTOPE PATHWAYS	: air exposure
DATA GIVEN IN THE REPORT	:
FORMULAS	: atmospheric dispersion
MODELING AND MATHEMATICAL APPROACH	: mathematical model utilizing the AIRDOS code

Description of the Model

WRED is a reactor siting code designed to estimate probability distributions of whole body gamma and thyroid doses using measured meteorological parameters as input data. Distrubution analyses are performed as a function of downwind distance, activity release height, and wind direction This statistical approach for gamma dose estimates employing thousands of sets of meteorology data is made economically feasible by using two-dimensional tables of space distribution-attenuation integrals and interpolation techniques. Measured meteorological parameters are converted to atmospheric dispersion parameters according to techniques developed at Brookhaven National Laboratory. Code options allow minimum data input (wind speed, direction, temperature) or full input including measured standard deviations of the horizontal and vertical wind directions.

MODEL 58	REFERENCE N^{o} 65
MODEL NAME	: Long-term Risk Assessment of Radioactive Waste Disposal in Geological Formation
AUTHORS	: F. Girardi, G. Bertozzi and M.D'Alessandro
ESTABLISHMENT	: Commission of the European Communities, J.R.C., Ispra
DATE OF PUBLICATION	: 1978
AIM OF THE MODEL	: to assess the dose rate to man due to leaching of actinide elements from wastes disposed of into geological formations
CONTAMINATION SOURCE	: High-level and TRU-wastes
NUCLIDES CONSIDERED	: transuranium elements and their decay products
RADIOISOTOPE PATHWAYS	: ingestion and inhalation
DATA GIVEN IN THE REPORT	: transfer coefficients of actinides in the environment, human diet, radioelement inventory in wastes, leaching rates
FORMULAS	: glass leaching, concentration of isotopes in various food chain compartments
MODELING AND MATHEMATICAL APPROACH	: compartment model at equilibrium

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EUR 6179 — Modelling of artificial radioactivity migration in environment: a survey

G. Bignoli and G. Bertozzi

Joint Research Centre, Ispra Establishment

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The aim of this report is to present a compilation and description of models to assess the environmental behaviour and effects of accidental and routine releases of artificial radioactivity from nuclear power facilities.

About 60 models are described and a card is given for each one, to indicate in summarized form its features and data content. This collection is intended to help in developing specific personal models by assembling different parts chosen among the most suitable ones of different models of various degrees of sophistication.

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