NUCLEAR SAFETY

In addition to the investigations reported on more fully below, various topics were studied on behalf of and in collaboration with the Israel Nuclear Hazards Evaluation Committee (INHEC). These are mentioned briefly here.

Nuclear safety and hazards evaluation studies connected with the proposed dual purpose nuclear reactor for sea water desalination and electricity production were continued, including:

a) Specification of the nuclear safety requirements concerning siting and construction of nuclear reactors in Israel.

b) Site selection studies for the proposed dual purpose nuclear reactor.

c) Compilation of the INHEC requirements concerning the prior survey of environmental data (meteorological, hydro-geological, seismological, oceanographic, demographic, etc.) at a site considered for a nuclear reactor.

A study of the weighting factors of nuclear radiation doses (external and internal) according to the number of people affected by these doses, was initiated. The first phase of this study consisted in the computation of the environmental hazards resulting from a hypothetical accident occurring in a nuclear reactor located at different sites in Israel, and selection of the typical consequences to be analysed.

A set of isopleths indicating the radiation doses in the vicinity of the IRR-1 reactor following a major accident, was prepared for different release conditions (height of release, atmospheric conditions etc.). These isopleths are intended to serve as a "canned" computation for rapid evaluation of the consequences to the environment in case of an emergency.

A guide was issued for the submission of periodical reports to the compliance committee, concerning the safety of a nuclear reactor or chemo-nuclear installation. The pertinent data to be included in these reports were set out.

Background studies were started for the preparation of safety regulations for nuclear installations, and for the drawing up of standards and criteria related to licensing, safe operation, etc. The following items are in preparation:

a) Licensing and compliance regulations for nuclear installations.
b) Criteria for radioactive waste disposal.
c) Standards for establishing a radioactivity monitoring network in the vicinity of nuclear installations.
d) Standards for testing safety systems in nuclear installations.
e) Standards for the environmental surveys required for licensing a nuclear installation.
f) Standards for the emergency network required in a nuclear installation.

<u>Radiation Doses from a Radioactive Cloud and from Deposition of Fission Products, as a Function of Distance from Release Point, for Various Atmospheric Conditions</u>: J. Tadmor and H. Galron

In the evaluation of the hazards to the environment resulting from an accident in a nuclear reactor, diffusion of the fission products released from the reactor during inversion conditions and their deposition by rain are generally taken as representative of the most hazardous conditions[1-3]. However, it was shown in a previous report[4,5] that for small distances from the release point and for inversion conditions, the radiation doses from dry deposition are greater than those from rainout deposition, the situation being reversed at larger distances.

In the present work the radiation doses from a radioactive cloud and from dry and rainout deposition of fission products were investigated as a function of distance from release point for different atmospheric conditions. The computations were made for a point source (1 curie) released instantaneously at zero height. The dry deposition velocity was taken as 10^{-2} m/sec for the halogens and 10^{-3} m/sec for other fission products(6). The fraction deposited from the cloud by rain was considered to be 10^{-4} for the halogens and 2×10^{-4} for the other fission products(7). Sutton's diffusion equation and Chamberlain's correction for deposition(8) were used. Both lapse and inversion conditions were investigated, for different wind velocities (1, 2, 3 m/sec for inversion conditions and 5 and 10 m/sec for lapse conditions). The atmospheric diffusion parameters were identical to those assumed in a previous report(9).

The Total Integrated Concentration (TIC) in the radioactive cloud, as a function of distance from release point under various atmospheric conditions, is shown in Fig. 38 for the iodines and in Fig. 39 for the other fission products released. It is seen that in the latter case the TIC is higher during inversion conditions than during lapse conditions over the whole range of distances investigated. The situation is different for the iodines. These have a relatively high velocity of deposition (10^{-2} m/sec), and during inversion conditions, when deposition is higher, they are depleted from the radioactive cloud. Thus, beyond a certain distance from the release point, the TIC during lapse conditions is greater than during inversion conditions.

The point of intersection between the TIC of the iodines for inversion and lapse conditions varies with the wind velocity, reflecting the influence of this factor on the dilution of the cloud; higher wind

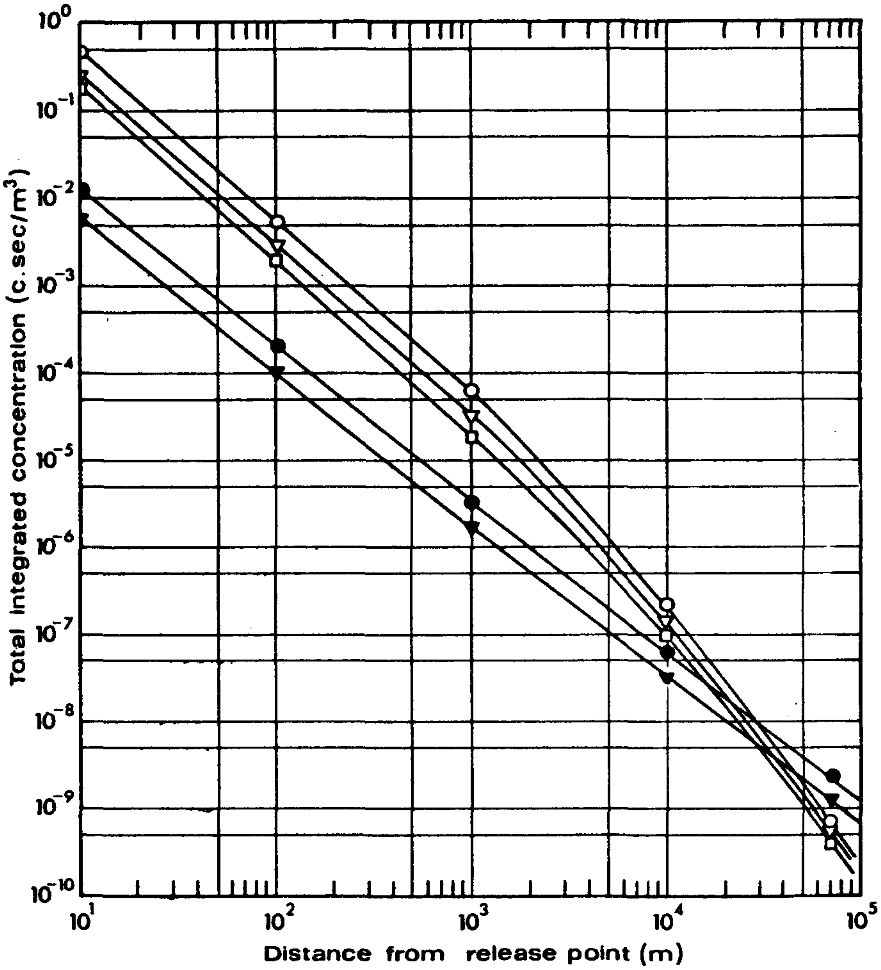

Fig. 38

Total integrated concentration (TIC) of the iodines in the radioactive cloud, as a function of distance from release point, for various atmospheric conditions and wind velocities (u)

○ inversion, u = 1 m/sec
▽ inversion, u = 2 m/sec
□ inversion, u = 3 m/sec
● lapse, u = 5 m/sec
▼ lapse, u = 10 m/sec

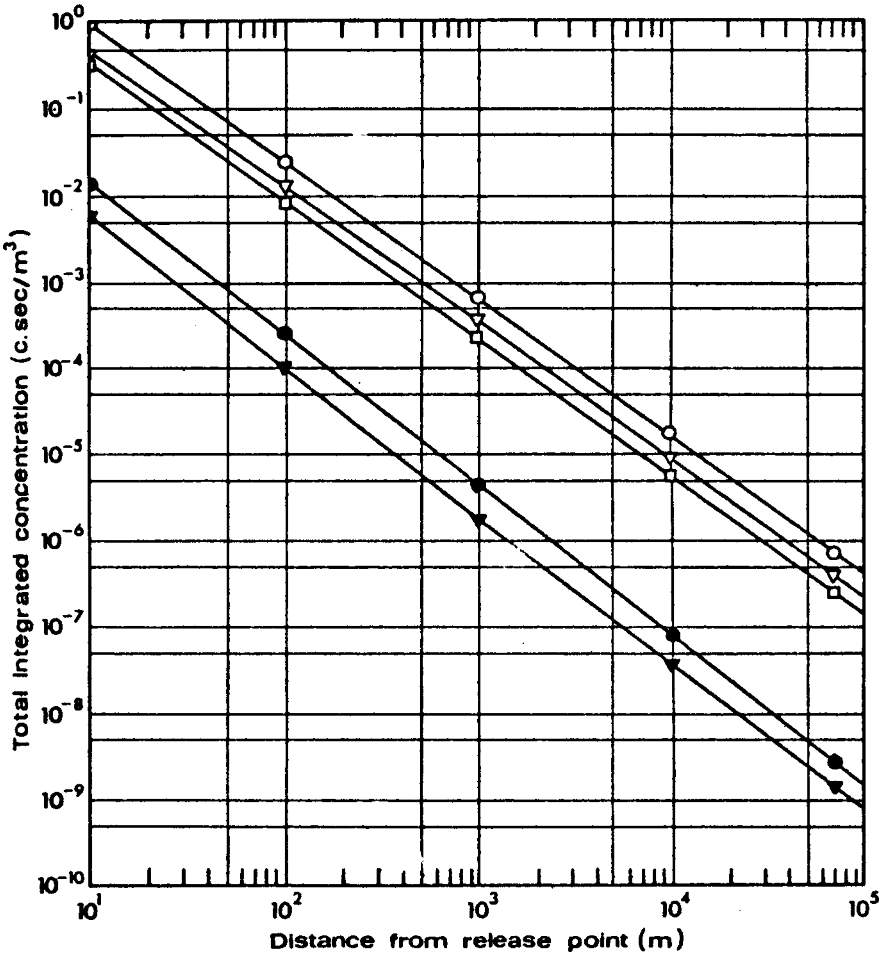

Fig. 39

Total integrated concentration (TIC) of fission products, excluding iodines, in the radioactive cloud, as a function of distance from release point, for various atmospheric conditions and wind velocities (u)

○ inversion, u = 1 m/sec
▽ inversion, u = 2 m/sec
□ inversion, u = 3 m/sec
● lapse , u = 5 m/sec
▼ lapse, u = 10 m/sec

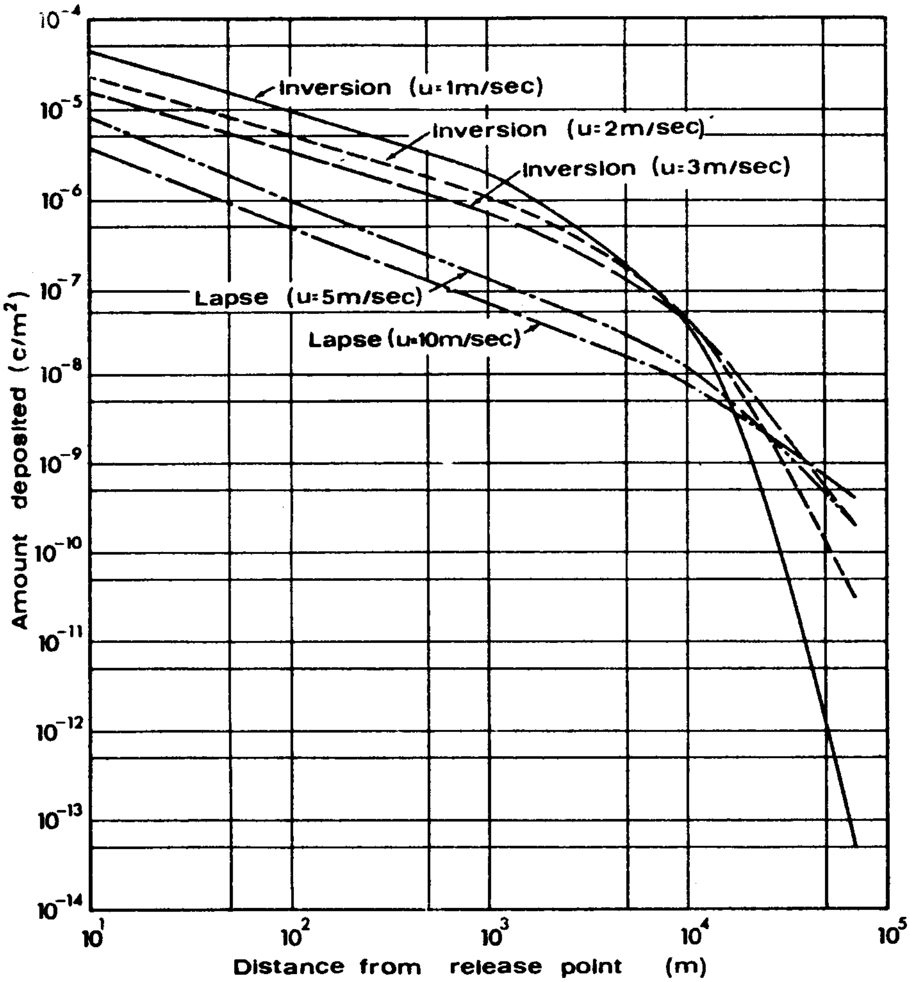

Fig. 40

Rainout deposition of fission products, excluding iodines, from the radioactive cloud, as a function of distance from release point, for various atmospheric conditions and wind velocities

velocities during inversion conditions and lower wind velocities during lapse conditions cause the intersection point to move closer to the point of release. For the conditions studied the intersection point was 15 to 45 km from the release point.

A similar picture is obtained for the iodines deposited on the ground during dry atmospheric conditions. For rainout conditions both the iodines and the other fission products, show this behaviour due to the relatively high fraction of all fission products deposited by rainout (see Fig. 40).

An intersection point between dry and rainout deposition as a function of distance, as found previously[4,5] for inversion conditions, was found in the present work also for lapse conditions.

The existence of the intersection points discussed above indicates that in the hazards evaluation of nuclear installations, all atmospheric conditions have to be considered, since for certain distances from the release point, at which highly populated centers may exist, consideration of inversion and rainout conditions only may lead to underestimation of the hazards.

References:

1. Final Hazards Summary Report for Big Rock Point Plant; Big Rock Nuclear Plant Consumers Power Company (Nov.14, 1961) Vol.I, Section 13
2. USAEC Report, ACNP-60573 (1962)
3. USAEC Report, ACNP-62574 (1962)
4. TADMOR, J. and GILAAD, Y., Israel AEC Semi-Annual Report, January-June 1964, IA-984, p.131
5. TADMOR, J. and GILAAD, Y., Israel AEC Semi-Annual Report, July-December 1964, IA-1021, p.134
6. USAEC Report, WASH-740, p.50
7. EISENBUD, M., Environmental Radioactivity, McGraw-Hill Book Company Inc. (1963), p.91
8. CHAMBERLAIN, A. C., UKAEA Report AERE HP/R 1261 (1953)
9. TADMOR, J., Israel AEC Report, IA-689, p.132

<u>QJHAZ - A Code for Environmental Hazards Evaluation</u> : Y. Milmann and J. Tadmor

The first version of this code[1] has now past the debugging phase. The code performs the following calculations:

a) For a given reactor power, irradiation time and cooling time, it calculates the fission products inventory for 27 isotopes which constitute the major environmental hazards[2].

b) Using Sutton's diffusion equation it calculates external and internal doses for instantaneous point and volume sources at various heights. The virtual distance concept[3] is introduced. The external dose is taken as the sum of the dose from the cloud passing overhead at a given distance, and the dose from radio-isotopes deposited on the ground. External doses are computed as a function of distance, time of exposure and meteorological parameters. Internal doses to the thyroid and bones as the critical organs are calculated as a function of distance and meteorological parameters.

c) Isopleth widths as a function of distance are calculated for both types of exposure, from which a quick estimate of damage can be made.

A second version of the QJHAZ code is being developed. It has the additional feature that it provides for continuous release of fission products to the atmosphere, allowing a stepwise time dependence of the release function (the fraction of radioisotopes released from the containment as a function of time). Two types of accidents are considered: explosion type and fire type.

The basic equations were formulated by Alonso[4]. They are simple material balance equations for the growth and decay of radioisotopes, but the source and sink terms contain information about the type of accident and the nature of the safeguards of the reactor. The "explosion type" accident is represented by a source term of the form

$$S_{j,i}(T) = F_{j,i}\, N_{j,i}(\tau,\ t,\ P_o)\, \delta(T)$$

where the indices j,i denote the i-th isotope in the j-th radioactive decay chain. $S_{j,i}$ (T) is the source term as a function of time, $F_{j,i}$ is the fraction of the particular radioisotope released from the core, $N_{j,i}$ is the number of atoms produced in the core as a function of irradiation time τ, cooling time t and power P_o, and $\delta(T)$ is the Dirac impulse function.

The "fire type" accident is represented by a source term of the form

$$S_{j,i}(T) = \begin{cases} KF_{j,i}\, N_{j,i}(\tau, t+T, P_o) & 0 < T \leq K^{-1} \\ 0 & T > K^{-1} \end{cases}$$

that is, the source term is assumed to be proportional to the number of atoms existing at time T for the period $0 < T \leq K^{-1}$, and zero for $T > K^{-1}$, so that K^{-1} is the time needed to extinguish the fire.

The sink term includes expressions for double and single containment, and for engineered safeguards such as emergency sprays, forced plating out, retention systems and delay systems.

The solutions of the equations turn out to be cumbersome. As an example, we reproduce here the solution for one of the simple cases, namely a fire type accident, with single containment, a delay system, and only two radioisotopes in every radioactive decay chain. Let $A_i(T)$ denote the activity of the parent isotope in chain i, and $B_i(T)$ that of the daughter isotope. ϕ is the sink term, τ' the delay time of the retention system, V the ventilation constant and D the decontamination factor.

$$A_i(T) = \begin{cases} VDA_i(0)\exp(-\lambda_{A_i}\tau')\,\dfrac{1-\exp(KF_{A_i}-\phi_{A_i})T}{\phi_{A_i}-KF_{A_i}} & \text{for } 0 < T < K^{-1} \\[2ex] VDA_i(0)\exp(F_{A_i}-\phi_{A_i}\tau')\,\dfrac{\exp(-F_{A_i})-\exp(K^{-1}\phi_{A_i})}{\phi_{A_i}-KF_{A_i}} + \\[2ex] + \dfrac{\exp(K^{-1}\phi_{A_i})-\exp(\phi_{A_i}T)}{\phi_{A_i}} & \text{for } T > K^{-1} \end{cases}$$

$$B_i(T) = \begin{cases} VD\ \exp(-\lambda_{B_i}\tau')\ {}_BB_i(0)\,\dfrac{1-\exp(KF_{B_i}-\phi_{B_i})T}{\phi_{B_i}-KF_{B_i}} + \\[2ex] + {}_AB_i(0)\,\dfrac{1-\exp(KF_{A_i}-\phi_{A_i})K^{-1}}{\phi_{A_i}-KF_{A_i}} & \text{for } 0 < T < K^{-1} \\[2ex] VD\ \exp(-\lambda_{B_i}\tau')\ {}_BB_i(0)\,\dfrac{1-\exp(KF_{B_i}-\phi_{B_i})K^{-1}}{\phi_{B_i}-KF_{B_i}} + \end{cases}$$

$$+ {}_AB_i(0)\,\frac{1-\exp(KF_{A_i}-\phi_{A_i})K^{-1}}{\phi_{A_i}-KF_{A_i}} +$$

$$+ {}_{C}B_i(0)\,\frac{\exp(-K^{-1}\phi_{A_i})-\exp(-\phi_{A_i}T)}{\phi_{A_i}} +$$

$$+ {}_{D}B_i(0)\,\frac{\exp(-K^{-1}\phi_{B_i})-\exp(-\phi_{B_i}T)}{\phi_{B_i}} \qquad \text{for } T > K^{-1}$$

where

$${}_{A}B_i(0) = \frac{\lambda_{A_i}\;A_i(0)}{\phi_{B_i}-KF_{B_i}-(\phi_{A_i}-KF_{A_i})}$$

$${}_{B}B_i(0) = B_i(0)-{}_{A}B_i(0)$$

$${}_{C}B_i(0) = \exp(F_{A_i})\,\frac{\lambda_{A_i}\;A_i(0)}{\phi_{B_i}-\phi_{A_i}}$$

$${}_{D}B_i(0) = {}_{B}B_i(0)\exp(F_{B_i}) + {}_{A}B_i(0)\exp(F_{A_i}-K^{-1}\phi_{A_i}+K^{-1}\phi_{B_i})$$

$$- {}_{C}B_i(0)\exp(K^{-1}\phi_{B_i}-K^{-1}\phi_{A_i})$$

Similar results have been obtained for a variety of other cases and the equations are included in the program.

Other features included in the code are Chamberlain's correction term for deposition when the height of release is greater than zero[5], and calculation of the direct radiation from the reactor building (considering build-up and attenuation factors).

References:

1. MILMANN, Y. and TADMOR, J., Israel AEC Semi-Annual Report July-Dec. 1964, IA-1021, p.132
2. GALRON, H. and TADMOR, J., Proceedings of the Second National Health Physics Meeting, Nahal Soreq, 6 May 1964, p.17
3. HOLLAND, J. Z., USAEC Report ORO-99
4. ALONSO, A., "NUBE" - A Digital Code to Evaluate the Hazards of Different Types of Reactor Accidents
5. CHAMBERLAIN, A. C., UKAEA Report AERE HP/R 1261

Relative Hazards of Fission Products in the Environmental Hazards Evaluation of Nuclear Reactors : H. Galron and J. Tadmor

In continuation of the study reported previously[1-3], the relative hazards of the fission products which may be released in an accident at a nuclear reactor were evaluated for rain conditions.

The infinite time radiation dose caused by contamination of the ground was considered. This varies with distance. At relatively short distances from the release point (a few km), the sequence of importance of the fission products arranged according to magnitude of radiation dose is

$$Ru^{103},\ Cs^{137} - Ba^{137},\ Ru^{106} - Rh^{106},\ I^{131},\ Zr^{95}\ \text{etc.} \qquad (1)$$

This sequence is determined by the fission yield, gamma energy, percentage of release from molten fuel, and radioactive decay of the various fission products. At distances of a few tens of kilometers, the sequence is different, the radioactive iodines being the main contributors to the radiation dose. This change is caused by the fact that during rainout conditions the depletion of the iodines from the travelling cloud is relatively lower as compared with the other fission products.

It is interesting to note that the sequence of importance of the fission products deposited during dry weather conditions (for which the halogens have the highest velocity of deposition), is similar to (1) over the whole range of distances studied, up to 70 km.

If we consider the radiation doses from contaminated ground as a function of time since deposition, the sequence of importance of the fission products varies, owing to the differences in the radioactive decay of the products. Figure 41 illustrates this for the case of deposition at a distance of 7 km, during rainout conditions.

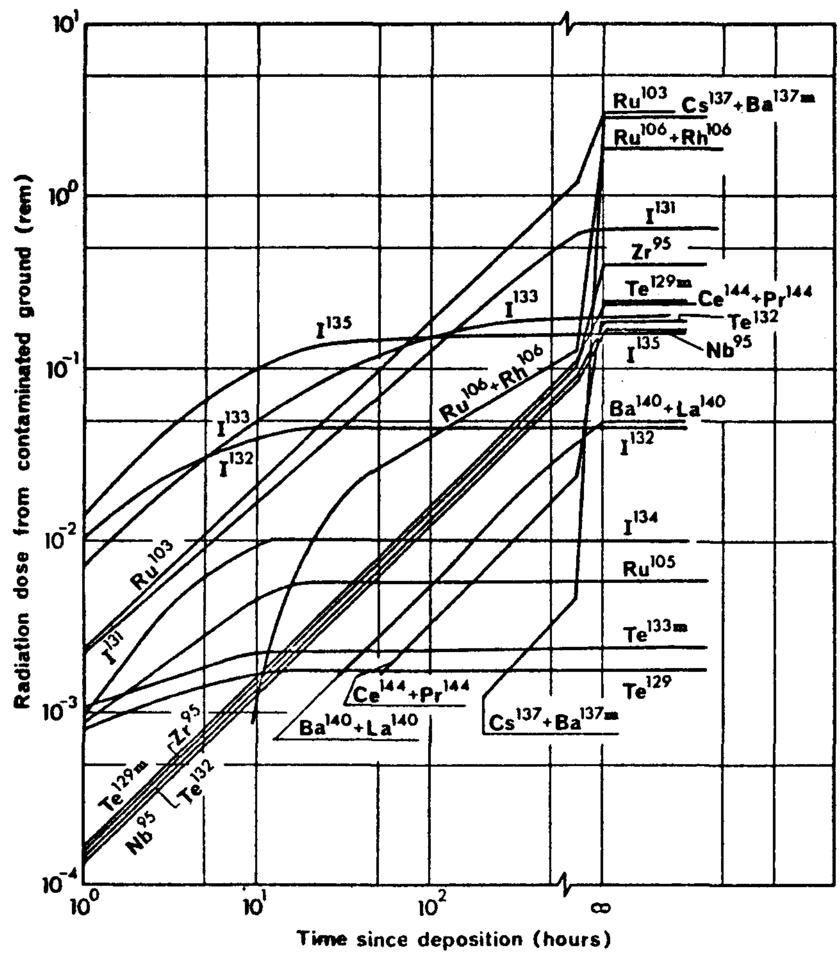

Fig. 41

Radiation doses from fission products deposited during rainout conditions, as a function of time since deposition

References:

1. GALRON, H. and TADMOR, J., Israel AEC Semi-Annual Report Jan.-June 1964 IA-984, p.128
2. GALRON, H. and TADMOR, J., Israel AEC Semi-Annual Report July-Dec.1964 IA-1021, p.135
3. GALRON, H. and TADMOR, J., Proceedings of the Second National Health Physics Meeting, Nahal Soreq, 6 May 1964, p.17

Turbulent Diffusion from an Instantaneous Plane Source : Y. Milmann and J. Tadmor

In a previous work[1] the concentration of diffusing matter in a turbulent medium was computed numerically using Joseph's expression extended to the case of a plane source, with initial conditions governed by Sutton's diffusion formula[1]. In contiauation of this work, a more general solution of the problem has been developed.

The basic equation governing diffusion is

$$\frac{\partial c}{\partial t} = \mathrm{div}\ (D\ \mathrm{grad}\ c)$$

where c is the concentration of diffusing matter, t is the time variable and D the diffusion coefficient. In a turbulent medium D is not constant. On the basis of experimental investigations, it is best given by the relation

$$D = K_{\sigma}^{\ n} \qquad (1)$$

where σ is the standard deviation of the physical dimensions of the diffusing spot, K is a proportionality constant and n is an exponent determined experimentally.

Since the standard deviation is a rather difficult quantity to deal with in diffusion phenomena, we tried to find a relation with more convenient variables. The usual approach[2] is to regard D as a function of the coordinates, $D = D(x(t), y(t), z(t))$, and proceed to solve the diffusion equation by an iterative procedure. The approach which we used was to find an equation with t as the (only) explicit variable

$$D = D(t) \tag{2}$$

The advantage of this lies in the fact that the divergence operates only on the spatial coordinates, so that the basic equation can be written

$$\frac{\partial c}{\partial t} = D(t)\, \nabla^2 c \tag{3}$$

The particular problem on which this method was tried was that of an instantaneous plane source which is introduced into an infinite medium with axial symmetry. The diffusion equation is

$$\frac{\partial c}{\partial t} = D(t)\, \frac{\partial^2 c}{\partial r^2} + \frac{1}{r}\frac{\partial c}{\partial r} \tag{4}$$

The initial condition is

$$c(r,0) = c_o \exp\left(-\frac{r^2}{\sigma_o^2}\right) \tag{5}$$

and conservation of matter gives:

$$\int_o^\infty \int_o^{2\pi} c(r,t)\, r\, dr\, d\phi = M \tag{6}$$

where M is the total amount of diffusing matter introduced into the medium at time $t = 0$. Let us introduce another time variable, t^*, defined by

$$t^* = \int_o^t D(t)\, dt \tag{7}$$

The equation will now be

$$\frac{\partial c}{\partial t^*} = \frac{\partial^2 c}{\partial r^2} + \frac{1}{r}\frac{\partial c}{\partial r} \tag{8}$$

which can be solved easily:

$$c(r,t^*) = c_o \frac{r_o^2}{\sigma_o^2+4t^*} \exp\left(-\frac{r^2}{\sigma_o^2+4t^*}\right) \qquad (9)$$

The square of the standard deviation is

$$\sigma^2 = \frac{\iint c(r,t^*) r^3 \, dr \, d\phi}{\iint c(r,t^*) \, r \, dr \, d\phi} = \sigma_o^2 + 4t^* \qquad (10)$$

so that we can write the following integral equation for D(t):

$$D(t) = K(r_o^2 + 4\int_o^t D(t)\, dt)^{n/2} \qquad (11)$$

The solution of this equation is

$$D(t) = \left[2(2-n)\, K^{2/n} t + D_o^{2/n-1}\right]^{n/(2-n)} \qquad (12)$$

where $D_o = D(0)$.

Let us now derive the expression for $\sigma = \sigma(t)$:

$$\int_o^t D(t)\, dt = \frac{1}{2\left(\frac{n}{2-n}+1\right)\left(2-n\right) K^{2/n}} \left[\left\{2(2-n)K^{2/n}t + D_o^{2/n-1}\right\}^{n/(2-n)+1}\right]_o^t$$

$$\sigma^2 = \sigma_o^2 + 4\int_o^t D(t)\, dt = \sigma_o^2 + \left[\left\{2(2-n)\, Kt + \left(\frac{D_o}{K}\right)^{2/n-1}\right\}^{2/(2-n)} \right]_o^t$$

from which

$$\sigma^2(t) = \left[2(2-n)\, Kt + \sigma_o^{2-n}\right]^{2/(2-n)} \qquad (13)$$

An expression very similar to eq.13 was derived in Ref.2 by an entirely different method - making an assumption about the form of D and separating the variables. The expression (in our notation) is

$$\sigma^2(t) = \left[(2-n)\ K(t-t_o) \right]^{2/(2-n)} \tag{14}$$

The slight difference may stem from different initial conditions assumed in these methods.

In continuation of the present work, the diffusion coefficient and standard deviation as a function of time will be found for various initial distributions, and conclusions will be drawn regarding the Lagrangian auto-correlation function and spectrum of turbulence.

References:

1. MILMANN, Y. and TADMOR, J., Israel AEC Semi-Annual Report, July-December 1964, IA-1021, p.127
2. Radioactive Waste Disposal into the Sea. International Atomic Energy Agency - Safety Series No.5 (Vienna 1961)

Maxima of Sutton's Equation Corrected for Deposition : Y. Milmann and J. Tadmor

Sutton's equations for the ground level concentration of a diffusing cloud and for the distance of maximum concentration[1] do not take into account depletion of the cloud by deposition. Chamberlain introduced a correction for Sutton's equation in order to take into account this depletion[2].

A study is being carried out to find:

a) the distance from the release point which maximizes Chamberlain's equation for a particular height of release.
b) the height of release which produces the maximum concentration at a given distance from the release point.

This problem is of importance in the design of the height of stack release in a nuclear installation, mainly when release of particles of high velocity of deposition is involved. It turns out that for a given distance from the source, an increase in the height of release, within certain limits, may cause an increase in the ground concentration at this distance.

References:

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