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A Comparison of the COMRADEX-IV and AIRDOS-EPA Methodologies for Estimating the Radiation Dose to Man from Radionuclide Releases to the Atmosphere

Charles W. Miller
F. Owen Hoffman
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HEALTH AND SAFETY RESEARCH DIVISION
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SI UNITS

As per the official policy of Oak Ridge National Laboratory, this report has been prepared using the International System of Units (SI). The relationship between the new SI units and other units used for quantities found in this report are shown in the table below.

Quantity	New SI unit and symbol	Basic SI dimensions	Old unit and symbol	Conversion
Exposure		coulomb per kilogram, $C\ kg^{-1}$	roentgen (R)	$1\ C\ kg^{-1} = 3.9\ 10^3\ R$
Absorbed dose	gray (Gy)	joules per kilogram, $J\ kg^{-1}$	rad (rad)	1 Gy = 100 rad
Dose equivalent	sievert (Sv)	joules per kilogram, $J\ kg^{-1}$	rem (rem)	1 Sv = 100 rem
Activity	becquerel (Bq)	per second, s^{-1}	curie (Ci)	$1\ Bq = 2.7 \times 10^{-11}\ Ci$

ABSTRACT

This report presents a comparison between two computerized methodologies for estimating the radiation dose to man from radionuclide releases to the atmosphere. The COMRADEX-IV code was designed to provide a means of assessing potential radiological consequences from postulated power reactor accidents. The AIRDOS-EPA code was developed primarily to assess routine radionuclide releases from nuclear facilities. Although a number of different calculations are performed by these codes, three calculations are in common – atmospheric dispersion, estimation of internal dose from inhalation, and estimation of external dose from immersion in air containing gamma emitting radionuclides. The models used in these calculations were examined and found, in general, to be the same. Most differences in the doses calculated by the two codes are due to differences in values chosen for input parameters and not due to model differences. A sample problem is presented for illustration.

1. INTRODUCTION

A project is currently under way at Oak Ridge National Laboratory (ORNL) to evaluate transport and dosimetry models used for the assessment of health impacts associated with environmental releases of radionuclides (Kanak and Miller, 1980). The purpose of this project is to determine the uncertainty associated with the use of these models (Little and Miller, 1979) and to recommend, where possible, those models and parameters best suited for predicting individual and population exposures resulting from routine and accidental breeder reactor radioactive discharges (Miller et al., 1980b).

During the course of this project a number of computer codes have been identified which have been used in the assessment of radionuclide releases to the environment (Hoffman et al., 1977). Many of these codes include methodologies for estimating the dose to man from radionuclides released to the atmosphere since this is a major mode of releases for most nuclear facilities (Hoffman and Kaye, 1976). The purpose of this report is to compare the methodologies in two sets of these codes: the COMRADEX family of codes, which were designed primarily to assess accidental releases, and the AIRDOS codes, which were designed primarily to assess routine releases. COMRADEX was chosen because it is often used in radiological assessments associated with the breeder reactor program. AIRDOS, which was developed and is widely used both in the Technology Assessments Section of the Health and Safety Research Division at ORNL and elsewhere, was chosen because it, too, has been used in the breeder reactor program.

While comparisons of assessment models provide useful insights, a code comparison such as this does not directly address the basic problem of model uncertainty. The validity of a model can best be quantified by comparing results calculated by the model with measurements of the same quantity under field conditions. However, there is currently a general lack of validation data for environmental transport and dosimetry models (Hoffman et al., 1978). Therefore, until such validation data become more readily available, code comparisons such as this one will at least provide information about the relative predictive capabilities of these assessment methodologies.

2. THE PURPOSE OF EACH CODE

COMRADEX (Willis, Spangler, and Rhoades, 1970) was developed originally to provide a means of assessing potential radiological consequences from postulated power reactor accidents. It is designed to account for the effects of COntainment and Meterology on the environmental RADiation EXposure. Recent applications of COMRADEX include preparation of accident assessments for the Clinch River Breeder Reactor (CRBR) project (Piper et al., 1978). The code has been changed a number of times since its inception (Specht et al., 1975; Otter and Conners, 1975). The latest documented version is referred to as COMRADEX-IV (Otter and Chung, 1977). The code can also be used to assess routine radionuclide releases, but that has not been its primary use to date.

AIRDOS (Moore, 1975; 1977), on the other hand, was developed primarily to assess routine radionuclide releases, although it has been used for assessing accidental releases (Miller et al., 1980a). It provides estimates of individual and population doses to man resulting from atmospheric releases of radionuclides from point and area sources. AIRDOS has been used in the preparation of numerous environmental impact analyses and statements written at ORNL (USERDA, 1975a; USERDA, 1977), including the environmental statement for the liquid metal fast breeder reactor program (USERDA, 1975b). The latest documented version of this code is AIRDOS-EPA (Moore et al., 1979).

3. ESTIMATES MADE BY THE CODES

3.1 Common Calculations

The basic characteristics of COMRADEX-IV and AIRDOS-EPA are summarized in Table 1. It can be seen that these codes make a number of calculations in common. Both calculate atmospheric dispersion following release of the material to the atmosphere from point sources. Both codes calculate an internal dose due to inhalation of the dispersed radionuclides. COMRADEX-IV routinely has provision for calculating an inhalation dose for the total body and up to eight organs, with an option provided for adding up to three additional organs if desired. The organs routinely considered are bone, muscle, thyroid, liver, kidneys, spleen, lungs, and gastrointestinal (GI) tract. AIRDOS-EPA estimates doses for total body, red marrow, lungs, endosteal cells, stomach wall, lower large intestine wall, thyroid, kidneys, testes, and ovaries. Both codes calculate an external air immersion dose due to gamma-ray-emitting radionuclides. Both the internal and external doses can be calculated at up to 20 distances downwind from the point of release.

3.2 Unique Calculations

3.2.1 Reactor inventory and containment

In addition to their common elements, some calculational aspects of each code are unique (Table 1). COMRADEX-IV calculates the effects of up to four levels of containment on the release of the reactor inventory of radionuclides following the postulated accident. The initial radionuclide inventory plus the leakage and cleanup (filtering, particulate "plate-out") rates must be supplied as input to the code. The leakage from the final level of containment represents the source term for the atmospheric dispersion calculations. Either an initial point source or volume source may be assumed. AIRDOS-EPA, however, does not consider the internal functioning of the reactor or its containment facilities. These factors must be included in the preparation of the source term provided as input to AIRDOS-EPA.

Table 1. A summary of the characteristics of the COMRADEX-IV and AIRDOS-EPA computer codes

Characteristic	AIRDOS-EPA	COMRADEX-IV
Point sources	X	X
Area sources	X	
Effects of reactor containment		X
Environmental transport		
Atmospheric	X	X
Wet deposition	X	
Dry deposition	X	X
Terrestrial foods	X	
External dosimetry		
Reactor building		X
Finite plume		X
Air immersion, gamma	X	X
Air immersion, beta		X
Ground exposure	X	
Water immersion	X	
Internal dosimetry		
Inhalation	X	X
Ingestion	X	

3.2.2 Number of radionuclides addressed

COMRADEX-IV can accommodate up to 500 entries in its list of radionuclides released. However, the same radionuclide may appear more than once in this list. This is because the same radionuclide is considered a separate entry in the list of radionuclides released each time it appears in a decay chain. Each entry in the list of radionuclides released is assigned a level of activity (Bq), and the number of times a given radionuclide appears in this list is determined by the number of decay chains in which it is found. AIRDOS-EPA can handle as many as 36 radionuclides for each release point in any given computer run. The buildup of radioactive daughters as a function of time and distance from the release must be introduced in AIRDOS-EPA by way of an estimated buildup factor.

3.2.3 Number of release points

COMRADEX-IV considers a single release point, such as a stack or vent, for each computer run. AIRDOS-EPA can handle up to six point sources or six area release points in a single computer run.

3.2.4 Temporal characteristics of the release

In COMRADEX-IV the total release can be divided into five time periods to allow for changes in the dispersion meteorology and the breathing characteristics of the receptor. (The latter is discussed further in Sect. 4.3.) Different meteorological parameters for dispersion of the release can be chosen for up to four of these time periods. Note, however, that the meteorological parameters in effect for a given time period only affect the dispersion of material which is released during that same time period. Multiple runs of AIRDOS-EPA are needed to duplicate this calculational feature.

3.2.5 Type of release

In COMRADEX-IV the environmental release is assumed to be an instantaneous point release (puff). AIRDOS-EPA also considers releases from point sources. However, at the option of the user the source can be a finite area from which radionuclides are assumed to be released uniformly. Dispersion calculations are made for a given downwind receptor after transforming the original area source into an annular segment with the equivalent area.

3.2.6 Exposure pathways

The two codes also calculate doses resulting from different additional downwind exposure pathways. COMRADEX-IV calculates the direct gamma dose from the reactor building and the external air immersion beta dose due to the cloud of radioactivity moving downwind. On the other hand, AIRDOS-EPA calculates (1) the external gamma dose from radionuclides deposited on ground surfaces, (2) the internal dose from ingestion of contaminated foods, and (3) the external dose from immersion in contaminated water.

3.2.7 Output

As documented, the various doses calculated by COMRADEX-IV are printed out as a function of downwind distance and release time. These doses are totals resulting from all radionuclides present in the initial inventory. Doses due to individual radionuclides are not provided. The doses from AIRDOS-EPA, however, are printed out as a function of downwind distance for each radionuclide considered. Such radionuclide-specific output is very useful when analyzing the release to determine the relative effect of each radionuclide present on the total dose and when performing diagnostic tests on the dose calculation routines. General Electric has modified its version of COMRADEX to provide such radionuclide-specific dose output (Hayes, 1977).

4. COMPARISON OF COMMON CALCULATIONS

It is not the purpose of this report to examine all of the models in both of these codes. It was noted above, however, that both codes make three calculations in common – atmospheric dispersion, estimation of inhalation dose, and estimation of external gamma dose from air immersion. The methods used by the codes in these common areas will be compared in the remainder of this section.

4.1 Modeled Atmospheric Dispersion

4.1.1 Gaussian plume model

Both COMRADEX-IV and AIRDOS-EPA incorporate the generalized Gaussian plume model for calculating atmospheric dispersion (Gifford, 1968):

$$\frac{\chi}{Q} = \frac{1}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} , \quad (1)$$

where

χ = concentration in air (Bq/m^3) at x meters downwind, y meters cross-wind, and z meters above ground,

Q = emission rate (Bq/s),

$\bar{u}$ = mean wind speed (m/s),

σ_y, σ_z = horizontal and vertical dispersion coefficient (m), respectively,

H = effective height of the release (m).

The term within the braces includes a modification of the basic Gaussian formula to include the reflection of the plume from the ground assuming perfect reflection and no deposition. This modification is based on the technique of locating an imaginary image source symmetrically, with respect to the ground plane, to the actual source. In COMRADEX-IV the downwind location (x, y, z) of each receptor is specified as input. In AIRDOS-EPA only the x position is specified, with y and z being set equal to zero. The result is that the centerline ground-level concentration is calculated using Eq. (1). However, such calculations represent the highest predicted concentrations from any given release condition.

Both codes include an option to allow the concentration to be averaged over a 22.5° sector. For ground-level concentrations this sector-average is calculated as follows (Moore et al., 1979):

$$\frac{\chi}{Q} = \frac{1}{0.16\ \pi x \sigma_z \bar{u}} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] . \qquad (2)$$

COMRADEX-IV, however, allows this option to be used only for release times subsequent to the initial time period.

The dispersion parameters, σ_y and σ_z, are empirically determined parameters which vary as a function of the downwind distance and atmospheric stability. A number of different sets of values for these parameters have been proposed as a result of different atmospheric dispersion experiments (Gifford, 1976). However, both COMRADEX-IV and AIRDOS-EPA use values which have been proposed by Briggs (1973). These values are based on a number of different experiments and are designed to be applicable for downwind distances, x, in the range 100 m < x < 10,000 m. It is of interest to note that the most often used values are those based on the work of Pasquill as modified by Gifford. These values, however, have been derived from diffusion measurements out to a distance of only 800 m (Gifford, 1976).

4.1.2 Plume depletion

4.1.2.1 Gravitational settling. Equations (1) and (2) assume that the plume is made up of gases and particulates that are too small in size to be appreciably affected by gravity during travel. There are cases, however, where larger, more dense particles may be released. Both COMRADEX-IV and AIRDOS-EPA apply a correction to Eqs. (1) and (2) to account for gravitational settling, but the methods they use are slightly different.

AIRDOS-EPA treats gravitational settling by "tilting" the plume downward by subtracting $v_g x/\bar{u}$ from H in the dispersion equations, where v_g is the gravitational fall (or settling) velocity (Van der Hoven, 1968). COMRADEX-IV uses the same "tilting" term, $v_g x/\bar{u}$, but adds it to z instead of subtracting it from H. This amounts to transposing the vertical coordinate and has the effect of reducing the contribution of the image term discussed above. Pasquill (1974) has also suggested that the image term be reduced since the material is being deposited, although he does this differently than is done in COMRADEX-IV.

When Eq. (1) is corrected according to the COMRADEX-IV method it becomes:

$$\frac{\chi}{Q} = \frac{1}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \left\{ \exp\left[-\frac{1}{2}\left(\frac{z + \{v_g x/\bar{u}\} - H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z + \{v_g x/\bar{u}\} + H}{\sigma_z}\right)^2\right] \right\} . \quad (3)$$

When the AIRDOS-EPA method is applied Eq. (1) becomes:

$$\frac{\chi}{Q} = \frac{1}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \left\{ \exp\left[-\frac{1}{2}\ \frac{z + \{v_g x/\bar{u}\} - H}{\sigma_z}^{\ 2}\right] + \exp\left[-\frac{1}{2}\left(\frac{z - \{v_g x/\bar{u}\} + H}{\sigma_z}\right)^2\right] \right\} . \quad (4)$$

Note that Eqs. (3) and (4) are the same except for the sign of $v_g x/\bar{u}$ in the last term. The effect of this difference on the resulting air concentration will depend on the particular downwind distance, release height, and atmospheric stability conditions being considered. For H = 0, Eqs. (3) and (4) are identical. Shown in Table 2 is a sample calculation comparing the term in braces in Eqs. (3) and (4), the settling term, for a release height of 100 m and atmospheric stability category Pasquill A. These release conditions are often considered in the assessment of accidental radionuclide releases. To maximize the differences between the two different settling terms it was assumed that u = 1 m/sec, z = 0, and V_g = 0.08 m/sec, a settling velocity representative of 80-μm-diam particles (Van der Hoven, 1968). The AIRDOS-EPA code requires that the expression $(H - V_g x/\bar{u}) \geqq 0$ must always be satisfied. This condition was applied when calculating the AIRDOS-EPA values shown in Table 2. It can be seen that the differences in the methods used to treat gravitational settling have relatively little effect on the value of the settling term. Intuitively, it seems quite reasonable that the effect of the reflection term in Eq. (1) should be reduced if this heavy, dense material is rapidly falling to the earth. Thus, one might expect the COMRADEX-IV method to give more reasonable results than the more traditional AIRDOS-EPA approach. However, these results indicate the difference between the methods is small, and until more experimental evidence is obtained, there is no way of determining which approach is actually the more valid procedure to calculate the downwind air concentraton.

4.1.2.2 Dry and wet deposition. Particulates and reactive or soluble gases that are not appreciably affected by gravitational settling can still be removed from the plume as it travels downwind either by other dry deposition processes or scavenging by rain or snow. These other dry deposition processes include the removal of particles and gases by grasses, leaves or other surfaces as a result of impingement, electrostatic interactions, chemical reactions, or dissolution in surface moisture. The surface deposition and accompanying plume depletion resulting from wet and dry deposition processes is considered by AIRDOS-EPA, while COMRADEX-IV considers only the effect of dry deposition processes on plume depletion. Both of these codes account for plume depletion as a result of dry deposition through the use of the so-called source depletion model (Van der Hoven, 1968). In its sector-averaged form with V_g = 0 this is

Table 2. A comparison of the settling terms used in COMRADEX-IV and AIRDOS-EPA[a]

Downwind distance (m)	COMRADEX-IV	AIRDOS-EPA
100	0	0
500	1.22	1.68
1,000	1.67	2.00
5,000	1.84	1.96
10,000	1.84	1.94

[a] $\bar{u}$ = 1 m/sec; z = 0; V_g = 0.08 m/sec; H = 100 m; and Atmospheric stability = Pasquill[g]A (unstable).

$$\frac{\chi_d}{\chi} = \exp \left\{ - \sqrt{\frac{2}{\pi}} \frac{v_d}{\bar{u}} \int_0^x \frac{dx'}{\sigma_z(x') \exp[h^2/2\sigma_z(x')]} \right\}, \quad (5)$$

where

χ = the ground level air concentration (Bq/m^3) at some downwind distance, x(m), without depletion being considered,

χ_d = the ground level air concentration (Bq/m^3) at the same downwind distance with depletion being considered,

v_d = deposition velocity (m/s), the transfer factor from air to the surface being considered.

The value of v_d for gases and small particulates has been found to range between 10^{-6} and 10^{-1} m/s in the atmosphere depending on the material being deposited, the surface on which it is depositing, and atmospheric conditions (Sehmel, 1979). For elevated releases, close to the source, Eq. (5) is not very sensitive to variations in v_d, but for ground-level releases v_d must be chosen with care (Miller, Hoffman, and Shaeffer, 1978). COMRADEX-IV calls for a value of v_d to be input for each release time and each of the three radionuclide classes, typically noble gases, halogens, and solids. In AIRDOS-EPA a single value of v_d may be used for the entire release or it might vary with radionuclide, wind direction, and distance so as to account for changes in material and surface characteristics.

It should be pointed out that Eq. (5) is physically unrealistic in that it removes material from the entire vertical column of the plume simultaneously, while, in fact, removal occurs more rapidly at the bottom of a plume than at higher elevations in the plume. However, some of this unrealism may be partially offset by the value of v_d commonly used in Eq. (5). Values of v_d have been found to vary with height in the atmosphere, but the values commonly used for radiological assessments are referenced to a measurement height of 1 m (Miller, Hoffman, and Shaeffer, 1978). A number of seemingly more realistic approaches to plume depletion have been proposed (Markee, 1967; Overcamp, 1976; Horst, 1977; 1979), but these models also generally utilize values of v_d measured near ground level. There is a great need for experimental data to determine which of these models actually gives the best results.

4.1.3 Plume rise

The effective height of release, H, used in Eqs. (1) and (2) is the physical height of the release location plus the effects of plume rise due to the momentum or buoyancy of the discharged material. In COMRADEX-IV the total effective stack height is an input parameter. In AIRDOS-EPA the physical stack height is an input parameter, but the plume rise may either be input or calculated in the code. Rupp's equation (Rupp et al., 1948) is used to estimate plume rise for momentum dominated plumes while Briggs' (1969) equations are used for hot, buoyant plumes. It has been shown that H is a critical parameter in Eqs. (1) and (2) (Weber, 1976), so the possible occurrence of plume rise must be carefully considered whenever these equations are utilized.

4.1.4 Mixing layer

Equation (1) is restricted in application to within the downwind distance, x, where the plume first encounters the top of the mixing layer, often referred to as a "lid" (Weber, 1976). The distance at which this occurs is quite variable, but it is often beyond the point of maximum ground-level concentration. There are circumstances, however, when even this calculation will be affected by the depth of the mixing layer so this concept must be considered anytime Eq. (1) is utilized. In AIRDOS-EPA Eq. (1) is modified when the "lid" becomes a significant influence on the results (Turner, 1969). No such provision is provided in COMRADEX-IV.

4.2 Site-Specific Atmospheric Dispersion

In addition to the use of Eq. (1) for estimating dispersion, COMRADEX-IV has an option which allows site-specific dispersion factors, χ/Q, to be input to the code for use in estimating downwind air concentrations and resulting doses. This, in fact, is what is normally done when COMRADEX-IV is utilized in the CRBR project (Piper et al., 1978). AIRDOS-EPA has an option which allows the user to input directly concentrations in air and rates of deposition on ground surfaces.

4.3 Inhalation Doses

Both COMRADEX-IV and AIRDOS-EPA use basically the same methodology to calculate the inhalation dose, D_{inh}, for a specific organ at any downwind distance of concern:

$$D_{inh} \propto (\chi)(BR)(DCF), \quad (6)$$

where

χ = the air concentration at the point of interest,

BR = human volumetric breathing rate,

DCF = dose conversion factor for the organ of concern.

The proportionality constant used will depend on the units chosen for χ, BR, and DCF.

The value of BR used in COMRADEX-IV depends on the release time being considered, as shown below (USNRC, 1974):

Release time, t (h)	Breathing rate, BR ($m^3 s^{-1}$)
$t < 8$	3.47×10^{-4}
$8 < t < 24$	1.75×10^{-4}
$t > 24$	2.32×10^{-4}

In AIRDOS-EPA the breathing rate is an input parameter, and it is held constant throughout a given run. Multiple runs of AIRDOS-EPA would be needed to duplicate the capabilities of COMRADEX-IV in this area.

The values of DCF used in both COMRADEX-IV and AIRDOS-EPA are input parameters. The values generally used in those codes are dose conversion factors for a 50-year dose commitment resulting from the initial intake of a unit amount of the radionuclide. COMRADEX-IV includes a library of DCF's (Specht, 1975; Conners, Hart, and Otter, 1977) developed by the authors from a number of sources as well as the set of DCF's recommended by the U. S. Nuclear Regulatory Commission (NRC)(Conners, Hart, and Otter, 1977; USNRC, 1976). Both of these sets of values are based almost exclusively upon the methods recommended by the International Commission on Radiological Protection – Committee II (ICRP-II) (ICRP, 1959). It has been suggested in the COMRADEX-IV documentation that the NRC values be used when calculating the dose for just the first year following exposure and the other values be used when calculating a 50-year dose commitment (Otter and Chung, 1977). This recommendation is apparently in error because the NRC values are specifically intended to represent 50-year dose commitments (USNRC, 1976). The DCF's generally used in AIRDOS-EPA are generated by the INREM II computer code (Killough et al., 1978; Dunning et al., 1979; 1980). INREM II utilizes newer dosimetric models and data recommended by the International Commission on Radiological Protection (Morrow et al., 1966; ICRP, 1979) and other recognized authorities. Because the DCF's are input parameters in both codes, any set desired by the user for a particular situation can be utilized.

4.4 External Gamma Dose

Both COMRADEX-IV and AIRDOS-II normally base their external doses, D_{ext}, from immersion in air containing gamma-emitting radionuclides on the semi-infinite cloud model (Healy and Baker, 1968):

$$D_{ext} = 0.25\ (E_\gamma)(\chi)\ , \tag{7}$$

where

E_γ = the average gamma energy released per disintegration,

χ = air concentration at the point of interest.

In COMRADEX-IV the dose in Sv is calculated directly using Eq. (7) and multiplying the product by a "local shield factor." The assumption is made that $\bar{E}_\gamma \sim \Gamma/6$, where Γ is the radionuclide gamma dose rate constant

($C\text{-}m^2/Kg\text{-}Bq\text{-}s$)(Johns and Cunningham, 1971). This factor depends on the number and energy of photons emitted per disintegration. Tabular values of Γ are available for many commonly used radionuclides (USPHS, 1970). Values of Γ for a particular radionuclide are subject to change as the decay scheme of the radionuclide is updated. A tabulated set of Γ values commonly used in COMRADEX-IV, derived from a number of sources, has been provided (Specht, 1975; Conners, Hart, and Otter, 1977). Since the Γ values are input parameters for the code, however, a user may choose other sets of values.

In AIRDOS-EPA, D_{ext} is not calculated directly from Eq. (7). Instead, the air concentration is multiplied by an external dose conversion factor (Sv/year per Bq/cm^3). This factor is an input parameter to the code. The values normally used are calculated using the semi-infinite cloud assumption discussed above (Kocher, 1979). However, other values could be input if so desired.

One problem associated with the use of Eq. (7) is that it applies only to locations where the airborne plume has essentially reached ground level. It can underestimate the dose for elevated plumes close to the release point where the ground-level air concentration may be very low but where irradiation may be received from the elevated plume. A case in point might be an elevated release dominated by noble gases. As a result of this problem, COMRADEX-IV contains an option which may be used for modeled dispersion to calculate an external gamma dose from the plume passing overhead. To do this, a dose source is accumulated at the downwind point of interest, and then it is distributed over an anisotropic Gaussian disc. The extent of this disc depends on the extent of the Gaussian plume passing overhead, as determined by the parameters in Eq. (1). The computer time for this calculation is quite long, so it is not used unless the radionuclides in the plume and the release conditions are such as to require it. This method is not employed when site-specific χ/Q's are used because the cloud dispersion parameters, σ_y and σ_z, needed to perform the calculation are usually not available. The documentation of AIRDOS-EPA provides recognition of the problem of the overhead plume, but no provision is made in the code to account for this effect.

5. SAMPLE PROBLEM

5.1 Methods

To complete the comparison of these codes it was decided to make some sample calculations using the methods in these codes. Four different radionuclides that might be released in a breeder reactor accident were considered:

Radionuclide	Total release, Bq
^{85m}Kr	1.7×10^{20}
^{131}I	7.8×10^{20}
^{134}Cs	1.1×10^{19}
^{238}Pu	1.0×10^{19}

An accident situation was considered because that is the situation for which COMRADEX-IV is most often used in the breeder reactor program (Piper et al., 1978).

The General Electric Company ran their version of COMRADEX-IV using the following χ/Q values as input for all four radionuclides (Hayes, 1977):

Location	Downwind distance, m	χ/Q, sec·m^{-3}
1	6.758×10^{2}	1.86×10^{-3}
2	1.609×10^{3}	8.10×10^{-4}
3	3.219×10^{3}	7.2×10^{-4}
4	4.023×10^{3}	5.05×10^{-4}

For site-specific atmospheric dispersion, General Electric's version of COMRADEX-IV should not be significantly different from COMRADEX-IV as discussed above. An instantaneous release directly to the environment was assumed for all four radionuclides. The gamma dose rate constants used in COMRADEX-IV to calculate external photon doses due to immersion in air are shown in Table 3. The inhalation DCF's used in the COMRADEX-IV calculation are given in Table 4.

Table 3. Data used to calculate external photon dose due to immersion in air

Radionuclide	COMRADEX-IV gamma dose rate constant,[a] $C\text{-}m^2/kg\text{-}Bq\text{-}s$	AIRDOS-EPA total-body dose conversion factor,[b] $Sv\text{-}cm^3/Bq\text{-}yr$
^{85m}Kr	1.6E-19[c]	2.4E-01
^{131}I	4.3E-19	5.7E-01
^{134}Cs	1.7E-18	2.3
^{238}Pu	0	8.5E-05

[a] Specht, 1975.

[b] Kocher, 1979.

[c] $1.6E\text{-}19 = 1.6 \times 10^{-19}$.

Table 4. Inhalation dose conversion factors used in the General Electric version of COMRADEX-IV and AIRDOS-EPA(1) sample runs

Radionuclide	Organ	Dose conversion factor, Sv/Bq	Reference
^{131}I	Total body	6.9E-10[a]	Conners, Hart, and Otter, 1977
	Bone	8.5E-10	
	Thyroid	4.0E-07	
^{134}Cs	Total body	2.5E-08	Conners, Hart, and Otter, 1977
	Bone	1.3E-08	
	Lungs	3.3E-09	
^{238}Pu	Total body	3.8E-05	Specht, 1975
	Bone	1.5E-03	
	Liver	2.2E-04	
	Kidneys	1.6E-04	
	Lungs	5.1E-05	
	Intestine	9.7E-09	

[a] 6.9E-10 = 6.9×10^{-10}.

As noted above, AIRDOS-EPA accepts as input values of χ, not values of χ/Q. As a result, in this study the total release for each radionuclide was first converted into an annual average release rate, Bq/y, and the given χ/Q values were then used to determine the input air concentration at each of the four downwind distances. These concentrations are shown in Table 5. The values given for ^{85m}Kr (half-life = 4.5 h) include a correction for decay during transport using a wind speed of 1 m/s.

The external photon DCF's used by AIRDOS-EPA are also given in Table 3. Two different sets of internal DCF's were used as input to AIRDOS-EPA. The code was first run using the same inhalation DCF's used by COMRADEX-IV and shown in Table 4. These results are subsequently labeled AIRDOS-EPA(1). A second computer run, AIRDOS-EPA(2), used as input the inhalation DCF's presented in Table 6. A breathing rate of 3.5×10^{4} m^3/s was assumed in both the AIRDOS-EPA(1) and AIRDOS-EPA(2) computer runs.

5.2 Results

5.2.1 External dose calculations

The resulting total-body external doses calculated for this sample problem by both computer codes are shown in Table 7. All doses calculated with AIRDOS-EPA are lower than the corresponding doses calculated by COMRADEX-IV. We note that while COMRADEX-IV did not calculate an external dose from ^{238}Pu, the ^{238}Pu external dose in this example is negligible compared to those estimated for the other three radionuclides considered.

The DCF used in the AIRDOS-EPA computations is the organ dose-rate factor for total body. Kocher (1979) also supplies photon dose-rate factors for tissue equivalent material at the body surface of an exposed individual. The organ dose-rate factors are based on these surface dose-rate factors and on estimates of absorbed dose rates in the body organs developed by Poston and Snyder (1974). An examination of the COMRADEX-IV documentation (Otter and Chung, 1977) indicates that the COMRADEX procedure for calculating external dose due to immersion in

Table 5. Air concentrations (Bq/m^3) used as input for AIRDOS-EPA sample runs

Radionuclide	Downwind location			
	1	2	3	4
^{85m}Kr	9.5E+09[a]	4.0E+09	3.3E+09	2.2E+09
^{131}I	4.6E+10	2.0E+10	1.8E+10	1.2E+10
^{134}Cs	6.5E+08	2.8E+08	2.5E+08	1.8E+08
^{238}Pu	5.9E+08	2.6E+08	2.3E+08	1.6E+08

[a]9.5E+09 = 9.5 x 10^9.

Table 6. Inhalation dose conversion factors used in AIRDOS-EPA(2) sample run

Radionuclide	Organ	Dose conversion factor, Sv/Bq[a]	Reference
^{131}I (Class D)[b]	Total body	1.7E-10[c]	Killough et al., 1978
	Endosteal cells[d]	6.0E-11	
	Thyroid	3.1E-07	
^{134}Cs (Class D)	Total body	1.2E-08	Killough et al., 1978
	Endosteal cells	1.6E-08	
	Lungs	9.1E-09	
^{238}Pu (Class Y)	Total body	1.6E-05	Dunning et al., 1980
	Endosteal cells	8.8E-04	
	Liver	1.9E-04	
	Kidneys	2.4E-05	
	Lungs	1.6E-04	
	Intestine	3.2E-08	

[a]These dose conversion factors based on inhalation of particles 1 μm in diameter and assume a quality factor of 20 for alpha particles.

[b]ICRP Task Group Lung Model respiratory clearance classification (Morrow et al., 1966).

[c]1.7E-10 = 1.7×10^{-10}.

[d]Endosteal cells comprise a radiosensitive tissue in bone.

Table 7. Results of the external dose calculations in the sample problem

Radionuclide	Location	Dose, Sv	
		COMRADEX-IV	AIRDOS-EPA
^{85m}Kr	1	3.0E+03[a]	2.3E+03
	2	1.2E+03	9.7E+02
	3	1.0E+03	8.1E+02
	4	7.0E+02	5.5E+02
^{131}I	1	3.9E+04	2.6E+04
	2	1.7E+04	1.1E+04
	3	1.5E+04	1.0E+04
	4	1.0E+04	7.1E+03
^{134}Cs	1	2.2E+03	1.5E+03
	2	9.7E+02	6.5E+02
	3	8.6E+02	5.8E+02
	4	6.0E+02	4.1E+02
^{238}Pu	1	-[b]	5.0E-02
	2	-[b]	2.2E-02
	3	-[b]	1.9E-02
	4	-[b]	1.4E-02

[a] 3.0E+03 = 3.0 x 10^3.

[b] Indicates that no dose was calculated for this combination of conditions.

air is more likely to result in body surface dose rate than an average organ dose rate. This observation is supported by the fact that the use of Kocher's (1979) body surface dose-rate factors in AIRDOS-EPA results in the calculation of external doses for the radionuclides in the sample problem that are essentially identical to those calculated by COMRADEX-IV. However, the organ dose-rate factors are considered to be more appropriate to use for assessment purposes than the body surface dose-rate factors (Kocher, 1980). Thus the body surface dose-rate factors are not tabulated in this report.

5.2.2 Internal dose calculations

Given in Table 8 are the predicted inhalation dose commitments calculated by both computer codes for the sample problem. As expected, the COMRADEX-IV and AIRDOS-EPA(1) dose estimates are in excellent agreement since the same DCF's were used in both cases. The use of revised DCF's in the AIRDOS-EPA(2) runs, however, results in lower predictions of dose than those calculated with the former DCF estimates except for ^{134}Cs doses to lungs and endosteal cells and ^{238}Pu doses to kidneys, lungs, and intestine.

The differences observed between these two sets of dose conversion factor estimates may be attributed to several factors. The more recent estimates (Killough et al., 1978; Dunning et al., 1980) are derived from contemporary internal dosimetry models and parameters, similar to those suggested by the ICRP (ICRP, 1979). The COMRADEX-IV estimates (Conners, Hart, and Otter, 1977; Specht, 1975), however, are based upon computational models and data from much earlier ICRP recommendations (ICRP, 1959).

Significant refinements incorporated in the more recent estimates include more detailed representations of activity transfer and retention in the various regions of the lungs and within different tissues of bone; also, irradiation of an organ by activity in other organs (crossfire) is computed explicitly. Perhaps most significantly, metabolic models describing the uptake and retention of various radionuclides in organs of man have been refined as more data become available.

Table 8. Results of inhalation dose calculations in the sample problem

Radionuclide	Organ	Location	Dose, Sv		
			COMRADEX-IV	AIRDOSE-EPA(1)[a]	AIRDOS-EPA(2)[b]
^{131}I	Total body	1	3.5E+05[c]	3.5E+05	8.3E+04
		2	1.5E+05	1.5E+05	3.6E+04
		3	1.3E+05	1.3E+05	3.2E+04
		4	9.4E+04	9.4E+04	2.3E+04
	Bone[d]	1	4.3E+05	4.3E+05	3.0E+04
		2	1.9E+05	1.9E+05	1.3E+04
		3	1.6E+05	1.7E+05	1.2E+04
		4	1.2E+05	1.2E+05	8.1E+03
	Thyroid	1	2.0E+08	2.0E+08	1.5E+08
		2	8.8E+07	8.8E+07	6.7E+07
		3	7.8E+07	7.8E+07	5.9E+07
		4	5.5E+07	5.5E+07	4.2E+07
^{134}Cs	Total body	1	1.8E+05	1.8E+05	8.8E+04
		2	7.6E+04	7.7E+04	3.8E+04
		3	6.8E+04	6.8E+04	3.4E+04
		4	4.8E+04	4.8E+04	2.4E+04
	Bone[d]	1	9.0E+04	9.0E+04	1.1E+05
		2	3.9E+04	3.9E+04	5.0E+04
		3	3.5E+04	3.5E+04	4.4E+04
		4	2.4E+04	2.5E+04	3.1E+04
	Lungs	1	2.3E+04	2.4E+04	6.5E+04
		2	1.0E+04	1.0E+04	2.8E+04
		3	9.1E+03	9.1E+03	2.5E+04
		4	6.4E+03	6.4E+03	1.8E+04
^{238}Pu	Total body	1	2.4E+08	2.4E+08	1.0E+08
		2	1.1E+08	1.1E+08	4.5E+07
		3	9.5E+07	9.4E+07	4.0E+07
		4	6.6E+07	6.6E+07	2.8E+07

Table 8. (continued)

Radionuclide	Organ	Location	Dose, Sv		
			COMRADEX-IV	AIRDOSE-EPA(1)[a]	AIRDOS-EPA(2)[b]
	Bone[d]	1	9.9E+09	9.9E+09	5.7E+09
		2	4.3E+09	4.3E+09	2.5E+09
		3	3.8E+09	3.8E+09	2.2E+09
		4	2.7E+09	2.7E+09	1.5E+09
	Liver	1	1.4E+09	1.5E+09	1.2E+09
		2	6.2E+08	6.2E+08	5.3E+08
		3	5.5E+08	5.6E+08	4.7E+08
		4	3.9E+08	3.8E+08	3.3E+08
	Kidneys	1	1.1E+09	1.1E+09	1.6E+08
		2	4.6E+08	4.7E+08	6.8E+07
		3	4.1E+08	4.1E+08	6.1E+07
		4	2.9E+08	2.9E+08	4.2E+07
	Lungs	1	3.3E+08	3.3E+08	1.1E+09
		2	1.4E+08	1.4E+08	4.6E+08
		3	1.3E+08	1.3E+08	4.1E+08
		4	9.0E+07	9.0E+07	2.9E+08
	Intestine	1	6.3E+04	6.3E+04	2.1E+05
		2	2.7E+04	2.7E+04	9.1E+04
		3	2.4E+04	2.4E+04	8.1E+04
		4	1.7E+04	1.7E+04	5.6E+04

[a]DCF's the same as those used in COMRADEX-IV sample run.

[b]DCF's from Killough et al. (1978) and Dunning et al. (1980).

[c]3.5E+05 = 3.5 x 10^5.

[d]Bone replaced by endosteal cells for AIRDOS-EPA(2) runs.

6. CONCLUSIONS

The methodologies contained in the COMRADEX-IV and AIRDOS-EPA computer codes have been examined. The two codes were basically designed for different purposes, and they do not always perform the same calculations. However, for those areas that are common to the two codes, the same basic models are employed. Differences in the results calculated by the two codes are generally traceable to differences in the input parameters used in the codes. From this analysis it seems inappropriate to say that one of these codes is better than the other. Which of these codes to use in a given situation will depend on the needs of the individual user.

One important consideration that has not been addressed in this report is the validity of these codes. These two codes may result in the same dose estimates, but unless these estimates are compared with measurements in the field it is not possible to know how well these estimates coincide with reality. While it may be infeasible to measure the final dose to man under field conditions, the various transport models used in this calculation should be individually tested against field data. Until more data are obtained for this purpose, it will be difficult to specify quantitatively the uncertainty associated with the doses calculated by codes such as COMRADEX-IV and AIRDOS-EPA.

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